Job-Worker Balance & Polycentric Transit-Oriented Development: Toward Indices and Spatio-temporal Trends

Dedicated to my wife, Trista, to my children, and

In remembrance of Dr. Andrew R. Sanderford

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Abstract

The spatial distribution of resources in cities has a significant direct influence on how well both firms and households can access the unique suite of resources each requires, and hence is a key to opportunities in the city. Those resources include not just raw materials, non-durable goods, housing, food, and water, but they include the infrastructure needed to reach and access them. Not least is the need for firms to access a regional labor market and workers to access locations of employment.

A lack of sufficient access to employment is a key driver of urban poverty and remains so in times of pandemics like COVID-19. The number of critical employment sectors needing workers on-site, even during a pandemic, is high. Many of these essential jobs, while requiring some form of social distancing, still must operate in face-to-face circumstances. Further, many of these essential sectors comprise low-income occupations, and thus, a more vulnerable segment of the workforce that cannot afford to lose vital employment during large-scale quarantines, which themselves are unprecedented prior to the COVID-19 outbreak. Although research in this area is still in the early stages, studies related to the effects of spatial density and land use mix suggest that higher levels of these land development characteristics can aid in the management of pandemics. Further, the complexity of the relationship goes beyond a simple correlation between density and infection levels.

Advocates of transit-oriented development (TOD) assert that the approach is an effective way to improve employment access while lowering the cost of transportation. Further, theory regarding Polycentric development posits that it can enhance job-worker balance by providing more central places where access to local and regional linkages is highest.

This dissertation will consider the relative effectiveness of TOD development at addressing the historic and wicked equity challenge of spatial mismatch, or some urban residents' isolation from relevant employment centers. Further, it will address dynamics in firms' access to their needed workforce. Quantitative spatial and temporal analysis using new methods and theories that add to the robustness of the research will be applied to transit systems across the United States.

Chapter 1: Introduction

The spatial distribution of resources in cities has a significant direct influence on how well both firms and households can access the unique suite of resources each requires, and hence is a key to opportunities in the city. Those resources include not just raw materials, non-durable goods, housing, food, and water, but they include the infrastructure needed to reach and access them. Not least is the need for firms to access a regional labor market and workers to access locations of employment.

Some scholars have praised the city as the most sustainable place on the planet, the most efficient in energy and infrastructure, and the very powerhouse of today's economy through the positive externalities and synergies of agglomeration and concentration in space (Glaeser 2011). Moreover, Glaeser argued, the presence of the poor in the city was a sign that the city presented opportunity to the poor, much greater in many cases than the rural areas they fled. The squatter slums on the periphery of many global cities provide superior opportunities. Yet, Mallach argued, the postindustrial American city now enjoying some degree of revitalization is no longer providing this opportunity environment to its poor.

> The problem is not that today's American cities have poor people living in them. The problem is that the cities have largely stopped being places of opportunity where poor people come to change their lives, and that today's poor and their children remain poor, locked out of the opportunities the cities offer. The most pressing question facing the cities is whether that can change, and whether, as they continue to revive, they can once again become the places of hope and opportunity they once were (Mallach 2018a).

The degree to which the city has ceased to be the best location to find opportunity no doubt varies signficantly from city to city, but Mallach's apprehension is worthy of note, and aligns with similar critiques, such as Galster and Killen (G. C. Galster and Killen 1995): "Horatio Algers lies dead in the streets of the inner city." Florida (Florida 2017a) also expressed concern for the trend in which investment in the urban centers have benefitted very small, spatially concentrated enclaves while most of the rest of the city has continued to suffer from disinvestment. Similar theories include Silverman's "peripheral dual city" (Ribant et al. 2020; Silverman 2018).

A lack of sufficient access to employment is a key driver of urban poverty. As physical distances between land uses have increased during the last century—due to the ever-increasing automobile reliance—accessibility, including employment access, has taken an overall downward turn as evinced by the increasing amount of daily vehicle miles traveled (VMT) per household (Moore, Thorsnes, and Appleyard 2007).

Also of concern is the number of low-access workers reliant upon jobs that are disrupted by public health crises. The number of critical employment sectors needing workers on-site, even during a pandemic such as coronavirus (COVID-19), is high. Many of these essential jobs, while requiring some form of social distancing, still must operate in face-to-face circumstances. These jobs are often held by more vulnerable low-income households. Although research in this area is still in the early stages, studies related to the effects of spatial density and land use mix suggest that higher levels of these land development characteristics can aid in the management of pandemics. Further, the complexity of the relationship goes beyond a simple correlation between density and infection levels (Hamidi, Ewing, and Sabouri 2020; Mouratidis 2022).

Advocates of transit-oriented development (TOD) assert that the approach is an effective way to improve employment access while lowering the cost of transportation. This dissertation will consider the relative effectiveness of TOD development at addressing the historic and wicked equity challenge of spatial mismatch, or some urban residents' isolation from relevant employment centers. Further, it will address dynamics in firms' access to their needed workforce. A quantitative analysis using new methods and theories that add to the robustness of the research will be applied to transit systems across the United States.

Spatial Mismatch & Job-Worker Balance (JWB)

The Spatial Mismatch Hypothesis (SMH) has been studied for decades since Kain's (Kain 1968) elucidation of the topic. It is a lack of co-location of jobs & worker residences. Its basic premise is that spatial separation between worker residences and job locations decreases employment accessibility. This leads to longer commutes and even some decrease in employment rates. Further, it leads to distinct employment rates and wages by race or ethnicity in each region (Ihlanfeldt and Sjoquist 1998; G. Galster and Cutsinger 2007). It is caused partly by the concentration of jobs and housing in separate, often single-use zones in various scales across the urban region. It has been heightened by the dispersal of job locations across the sprawling suburbs. Drilling down into the issue, one finds that residences can be close to many jobs without having access to relevant employment opportunities. Wages and housing costs must coincide sufficiently within a neighborhood or commute shed to reduce the need to leave the neighborhood and commute elsewhere (termed "internal capture"). Thus, a neighborhood must have an "income match," or some degree of comity between area residents' wage levels and neighborhood jobs' wage levels. A region must provide the resident labor force with proximity to, mix within, and centrality of employment locations to overcome the effects of spatial mismatch (G. Galster and Cutsinger 2007)

The causes of spatial mismatch are many, from development and zoning policy to demographic changes (Robert Cervero 1989):

- Fiscal & exclusionary zoning
- Growth moratoria
- Worker earnings / housing cost mismatch
- Two wage-earner households
- Jobs turnover

Job-worker balance (JWB) is measured as a relative balance of the ratio between the number of worker residences and the relevant jobs within a neighborhood or commutershed. Advocates cite multiple benefits of bringing job and residential locations close together: agglomeration economies, lower transportation costs, lower emissions, less traffic congestion, shorter commutes, and fewer vehicle miles traveled (VMT). Agglomeration economies thrive on proximity between land uses, particularly those that synergize in their functions, enhancing each site's *situs* and *linkages*, (Graaskamp 1981; Pivo 2013; Andrews 1971), or spatial interconnections, that set of network connections each parcel of land needs to fully function; and accessibility, which can be defined as "the ease with which people can reach services, activities, and other important destinations" (Smith, Gihring, and Bibliography 2017). Accessibility is defined as a tension between its constituents: proximity and mobility. Proximity between land uses may obstruct high mobility between them, and vice-versa (Proffitt et al. 2019). Graaskamp (Graaskamp 1981) explained,

> Location is often identified as the critical factor in a site, but it is seldom understood that location value is related to the functional needs of the activity and not the site…each relationship between a household [or firm] and another point requires movement of persons, goods, or messages. This is termed a *linkage*, and the time, stress, and dollar costs involved are referred to as the costs *of friction.* Each establishment seeks a location defined as a set of *linkages* that will minimize these costs" (Graaskamp 1981).

Assessing the well-being of a household or firm should include a reckoning between needed and realized linkages, and their relative costs of friction. Factoring the cost of transportation into overall affordability of housing further highlights the importance of proximity and interconnection between housing and employment locations. The need for *situs* makes a home as much about its neighborhood and broader regional accessibility as the parcel and structure alone.

Urban economics provides a lens through which to understand the spatial mismatch problem and how JWB may address it. Therefore, to understand the implications of spatial mismatch between where workers live and the location of the jobs for which they qualify requires a review of urban economics, the spatial patterns of the urban region and the economic processes that cause them. These patterns affect employment accessibility, as many commuters in congested urban centers across the country would attest. Areas with higher employment accessibility, and areas with greater balance between jobs and housing generate shorter work trips than other areas (Stoker and Ewing 2014a). The spatial allocation of land uses determines their pattern of spatial distribution. Through their constraints upon allocation, cities' land use policies have a significant impact upon transportation networks and the land uses that are accessible to communities across the region. This is particularly true of the accessibility needed by firms and households.

Urban economists and regional scientists have long used neo-classical urban economic theory to model regional spatial processes and patterns in terms of the tradeoffs households and firms must make between the costs of land and the costs of access to the CBD, which is the central place in the regional economy. This process of maximizing utility requires finding an optimal location in the region, one that minimizes costs and maximizes benefits through optimizing situs and linkages, among other things. Those who desire the greatest access to central places compete for it through the bid rent process, with the land going to the highest bidder. This dynamic process has an impact upon how cities arrange land uses in and near central places. It also affects the constraints within which various land uses must function. This approach also requires application of the assumptions that agents siting firms or households are making rational and unbiased choices, that those choices are based upon realistic and well-defined beliefs and expectations, and that actors are using all necessary information to do so. They also must act mostly in enlightened self-interest.

These assumptions have been useful for modeling but are idealistic. Bounded rationality theory argues that actors make choices from a partial and incomplete set of information, and do not always act rationally in decision making. Instead, they "satisfice" in their decisions, or choose an option that is satisfactory—good enough—if not the best choice possible. Satisficing results in suboptimal (i.e., "human") choices (Thaler 2016; D. C. Read, Sanderford, and Skuzinski 2019). Actors' choices are further limited by a set of spatial constraints, which are different for each demographic subgroup, household or individual. These come from sources of authority who grant or deny access, from the need to couple with other people or tools in the same location, and from each actor's capacity to use certain tools, fill certain roles, or use certain spaces (Hagerstrand 1970).

The influential Alonso-Mills-Muth model (AMM), a neo-classical model that built upon the important precursor models from von Thünen (Thünen and Wartenberg 1966), Burgess and Park (R. E. Park et al. 1925), and Hoyt (Hoyt 1939) was formulated by Alonso (Alonso 1964), Mills (Mills 1972), and Muth (Muth 1969). The AMM theorized that all employment was located in a Central Business District at the center of the urban region. Housing was generally outside the CBD in concentric rings or quarters. Firms and households competed for land through the bid rent process, which equilibrized supply and demand for land based upon each firm or household's optimal situation for land area, proximity to the CBD, and non-housing goods within a budgetary constraint. Because of the diminishing land area as one approaches the CBD, the AMM model included a series of tradeoffs made by each household or firm between land and proximity to the CBD. Those whose elasticity of demand for space was higher than their elasticity of demand for proximity lived closer to the CBD, thus paying more for access with offsets from reduced transportation costs and less land area. Those who required space more than accessibility opted to pay more for transportation to live outside the CBD and thus pay less per unit of land area. These spaces were historically reserved for those who could pay the cost of the latest transportation technology.

These assumptions held reasonably true empirically during the early stage of the industrial city in the United States; but, as the streetcar became operational in the late 19th century, many opted to live farther from the center than ever before, in the "streetcar suburbs" a few miles outside of the CBD. This occurred when certain households were able to take advantage of the reduced friction of distance afforded them by the streetcar technology. Then the automobile drove urban patterns of development, causing a massive expansion of the land area available for settlement to those who could commute by automobile back to the CBD. The metropolitan region thus underwent major structural changes, as large proportions of the population—those with the means to do so—fled to the suburbs. Firms that needed access to the labor force and the consumer market in the suburbs (along with the greater availability of land) followed them out of the CBD. In many US regions, minority populations were excluded from the suburbs, which forced them to stay in urban neighborhoods that now provided relatively less access to opportunities than prior to the suburban explosion. Spatial mismatch is the result of these dynamics of automobile adoption and suburbanization with minority exclusion.[1] This has also in many places included the exclusion of low-income households. The zoning code has perpetuated many of these spatial patterns, locking in single-use zones and having a serious impact on the value of developed land. In the years since compact and walkable urban places have taken root across the country, and contrary to NIMBY sentiment, research has demonstrated that zones designed to promote multimodal travel, such as walkability, which contain a mixture of uses and building types, do not face danger of property value loss through updating the building types and mixture on the land. Rather, upgrading a neighborhood to be more walkable and mixed-use provides great property value returns, and has been used by some municipalities as a solution to declining property values (Guo, Peeta, and Somenahalli 2017; Dunham-Jones and Williamson 2011). Therefore, property owners have only to gain from a greater JWB facilitated by a broader range of housing types and transportation modal options, and greater land use diversity.

Urban form: Accessibility as Proximity-Mobility Tension

The spatial mismatch issue demonstrates that urban form is an essential aspect of accessibility, or the relative ease and ability to reach desired places. Urban form, or the built environment, consists of landscapes that have been altered by human activity and development. Accessibility, to reiterate, is a key to urban opportunities. Cities are defined as a lack of space between land uses (Glaeser and Kahn 2004). Cities throughout human history have served as places of greater agglomeration of, and therefore access to, all sorts of human needs social, spiritual, economic, governmental, defensive, and cultural. Agglomeration economies drove the clustering of industrial activity throughout the 19th century. Automobiles drastically changed the effects of agglomeration, not least in the minds of populations, governments, businesses, planners, and developers. By the end of the 20th century sprawl, or low-density, single-use and spatially dispersed development, was so ubiquitous as to be omnipresent, and the dispersal of jobs and housing likewise to be found everywhere. Few US cities have not been thus molded by the automobile. Edge Cities, which are little isolated auto-dependent pockets of activity, and Edgeless Cities, which are dispersed auto-dependent activities across the expanding region, have popped up all over the metropolitan areas of the US, replacing the dominance of the Central Business District (CBD) with the dominance of the automobile and seas of blacktop. “Suburbia, edge cities and sprawl are all the natural, inexorable, result of the technological dominance of the automobile.” (Glaeser and Kahn 2004).

[1] While the suburbs have been open to minorities for decades, residential segregation and concentrated poverty remain widespread, and the challenges caused by segregation remain a real problem.

The popularity of small towns and small dispersed places is demonstrated by their ever-growing ubiquity. This trend, however, is mainly due to the dominance of the automobile over other modes of travel. Sprawl with single-use zoning makes spatial mismatch a worse challenge by imposing low-density space with fewer constituent land uses. The low number of land uses decreases the ability to provide linkages between a range of land uses. Moreover, not everyone wants to live in sprawl and the resulting low levels of accessibility. Many survey respondents have voiced a desire for more compact, accessible urban places with opportunities to reach many kinds of land uses quickly on foot. The demand for these places is highly unmet by the market supply (Arthur C Nelson 2013; Rodriguez and Leinberger 2023). Therefore, the automobile and its supportive urban form have influenced the choices of firms and households by constraining their set of choices, imposing a deadweight loss through economic inefficiency.

The real problems of sprawl stem from the related costs. These include the isolation of those who struggle to afford the transportation technology that makes dispersed living possible. The isolation of land uses in various disconnected pockets across regions also increases reliance upon the automobile and upon increasingly congested and under-maintained streets. It also includes the fiscal impacts of the need for constantly expanding public transportation networks, government buildings, and facilities for water, wastewater, and electricity. All of this while existing infrastructure is under-utilized, and maintenance goes under-funded.

The urban planning literature has identified the most salient characteristics of accessibility as those that influence travel behavior. Travel demand is a "derived demand" caused by the demand for access to various places. The dimensions of the built environment that most influence travel are often termed the D's of compact urban form, and they are considered influential in creating Location Efficient places, in which the built environment facilitates accessibility (R. Cervero and Kockelman 1997; Ewing and Cervero 2010). They consist of:

- Density of land use activities – land area or population-weighted
- Diversity of land use activities – entropy or dissimilarity score
- Design of the built environment – e.g., intersection density and block size
- Destination accessibility – gravity or cumulative opportunities
- Distance to transit stations – Euclidean or network-based
- Demand management – e.g., parking
- Demographics – key model controls

Land use density is conceptualized as the number of buildings or parcels in each land area, or within a given level of population. Land use diversity is conceptualized as the level of mixture of land uses within a given neighborhood. Single-use zoning contrasts with high-diversity mixed-use zoning in terms of the variety of commercial, office, retail, industrial, and residential land uses available within a given area of land. Design of the built environment includes such attributes as street network design—gridded or curvilinear, street intersection density, number of 4-way intersections, speed limits, and block size. It also includes pedestrian and cyclist environments. These include the presence of trees, bike lanes, overhead lights, public art, and safety provisions for street crossing. Parking lot locations also influence mode choice.

Characteristics that increase the feeling of well-being and safety, comfort and enjoyment were likewise influential (Hamidi et al. 2020). Destination accessibility is related to density, diversity and mobility. Analyzed with gravity-type models, the degree of attraction between origin and destination ends of any trip is determined by the number of attractors (their "mass") on each end of the trip and constrained by the travel costs to get from origin to destination. Marginal increases in land use densities induce marginal increases in non-auto travel. Higher densities with a higher variety of land uses in each neighborhood further increase non-auto travel and shorten auto trips and their frequency. For example, research has shown that placing convenience and retail stores in and near residential areas can induce walking trips and trip chaining (making multi-stop trips), and thus reduce vehicle miles traveled (VMT) (R. Cervero and Kockelman 1997). Distance to transit stations has been shown to influence travel behavior, increasing reliance upon non-auto modes of travel for all kinds of trips. Demand management, such as limiting the number of parking spots or charging for their use, induces people to consider non-auto travel modes. Demographics are known to be influential in a household's travel behavior, and therefore provide crucial model controls that help isolate other causes of behavior. Further, planners and developers can target specific needs of different groups of people based upon their demographic characteristics.

Centering or nuclearity has entered the literature as another important urban form dimension. Ewing and Hamidi (Ewing, Reid, and Hamidi 2014) built upon Galster et al. (G. Galster et al. 2001), Galster and Cutsinger (G. Galster and Cutsinger 2007) and others to define centering as a combination of key characteristics of the Central Business District (CBD) or other activity centers in a region. These characteristics included containing disproportionately large percentages of 1) regional employment, and 2) regional population. Other studies evaluated these percentages as a function of distance to the CBD (Hajrasouliha and Hamidi 2017). Centering is an important factor in supporting the distance to transit dimension.

Ewing and Cervero (Ewing and Cervero 2010) found that the explanatory variables among the 5 D's with the highest elasticities, which denoted the largest influence on the outcome of VMT, are accessibility, distance to CBD, and the design factors of intersection density and street connectivity.

Location-efficient planning and development have the potential to address accessibility and other key sustainability issues. Adkins et al. (Adkins et al. 2017) produced a useful summary of these sustainability elements. They include increases in public health through more physical activity, greater social capital through higher community cohesion and trust; environmental benefits such as cleaner air, safer streets, and less gas consumption; and mitigation of climate impacts from the transportation sector. Increasing LE can provide greater equity outcomes for lower-income households through higher levels of access to a range of needs, particularly employment, for a more affordable travel cost. As of yet, planning practice has some gaps to fill in implementing accessibility-oriented transportation policy as opposed to traditional mobility-oriented congestion mitigation as a central policy directive (Proffitt et al. 2019).

Polycentric Urban Regions – Networked Central Places

Polycentric development across a region can enhance the JWB by providing more central places where access to local and regional linkages is highest. Polycentric Urban Regions (PUR) are regions with multiple centers—or central places—of employment, trade, industry, public life, and culture. Polycentric urban patterns are those which cluster at multiple regional sub-centers in addition to the central business district (CBD). They operate at and across multiple spatial scales, from the metropolitan region to multiple metropolitan regions that enjoy synergetic outcomes of interregional cooperation. PURs require more intensity, mixture and connectivity of human activity, land uses, and transportation modes than provided by the typical suburb. PURs support human cooperation and result in synergetic efficiencies.

They are theorized as a relaxing of Alonso's (Alonso 1964) assumption that regional employment was located solely at the CBD. This classical assumption applies to an early industrial city model that is largely moribund. Kain's (Kain 1968) work acknowledged the nascent trend of the suburbanization of employment, thus breaking Alonso's assumption. This was particularly true of industrial firms and in those sectors employing low-income households. Simultaneously, those households struggled to gain use of the automobile for the commute to the suburbs. This led to isolation in the urban center near public transit and effectively very far from suburban jobs. Thus, minorities added to their constraints the higher price inelasticity of demand for housing than for transportation. Many low-income households determined in their market decisions that getting around the region was relatively less important than finding a place in the region to live. This trade-off led them to residential areas that were less accessible but more affordable to live. Polycentric urban patterns theoretically alleviate this accessibility-affordability dichotomy by making the entire region more accessible through wider distribution of *central places*, which are defined as those places that provide certain central activities and amenities that attract people to create and support agglomerations, or urban centers (Christaller 1941; Mulligan, Partridge, and Carruthers 2012).

Polycentric Urban Regions are of two scales, 1) the original framework of interurban cooperation between two urban regions, thus creating a larger scale of cooperation, and 2) a new intraurban framework consisting of a center and subcenters within a single region (K. Park et al. 2020). The Metropolitan Statistical Area (MSA) is frequently a central framework for regional planning studies and fits the intraurban scale. A framework of larger regions, often consisting of multiple MSAs, is also frequently used in regional studies (Kloosterman and Musterd 2001; E. Meijers 2005; 2008; Arthur C. Nelson and Lang 2011). These fit the interurban scale. Both urban spatial scales have great potential for enhanced agglomeration economies, network synergies, and urban infrastructural and institutional efficiencies. Theorists suggest that in a polycentric urban region, no one city or center of activity dominates. They consist of several distinct cities or centers, larger centers that differ relatively little in size or economic strength. Trends of urbanization manifest themselves differently in a polycentric region than in a monocentric city in physical or spatial forms, political configurations, functional relationships and cultural identity of the various component entities (Kloosterman and Musterd 2001). In most cases the rank-order rule, or Zipf's Law, may contradict this aspect of the theory, as most metropolitan areas, as well as most regions, exhibit a power rule ranking of cities, with small numbers being very large and exerting a disproportionate economic pull, plus large numbers of smaller cities with less economic influence (Batty 2013).

The typical suburban area does not meet the criteria of a central place in a polycentric urban region (PUR). These include agglomeration, network connectivity, cooperation and complementarity with other centers in the region, and exploitation of group externalities—those gained by group cooperation and collaboration (E. Meijers 2005). Agglomeration requires the Ds of location efficient built environments, particularly diversity of land uses and destination accessibility. Job-worker balance (JWB) is a key aspect of such diversity and accessibility.

Network connectivity for multimodal transport requires a built environment that follows a LE framework, e.g., gridded streets, small block sizes, and a relatively high density of street intersections. Network connectivity aids the commuter and the traveler in sidestepping the automobile congestion that results from successful agglomerations by using alternative transport modes, e.g., walking, bicycling or transit. Cooperation requires proximity sufficient to enable communication. Complementarity or specialization allows central places, firms, and workers to work in economic sectors in which they are most competent in a system of group collaboration. Further, the greater the diversity of economic sectors and agents, the better. Transit-Oriented Development theorists claim to provide a framework for LE places that can become a networked system of central places.

Transit-Oriented Development (TOD) & Place Typology

Transit-Oriented Development (TOD) theory aims at the normative goal of accessibility. According to the theory, Transit-Oriented Developments (TODs) include land use policies that intend to leverage new transit network connections into a use of surrounding land that builds upon the Ds of compact urban form. This compact, mixed-use, walkable urban form 1) provides support to the transit system by inducing ridership, 2) reduces automobile dependency and vehicle miles traveled (VMT) through facilitating other modes of active transportation, 3) improves quality of life by increasing regional access to employment and the workforce, 4) increases neighborhood accessibility to a variety of land uses and amenities while integrating the transit network connection into the place. These descriptive attributes are supplemented by the five main performance-based attributes a transit station must possess to be legitimately TOD, which include: "location efficiency, rich mix of [land use] choices, value capture [i.e., capturing a portion of the land value increase resulting from transit proximity and LE land uses], place making, and resolution of the tension between node and place" (Hamidi, Ewing, and Renne 2016; D. Read and Sanderford 2017; Adkins, Sanderford, and Pivo 2017), , (Dittmar and Ohland 2004).

Of most importance to this study is the question of whether today's TODs make it possible to improve accessibility to both the workplace and the workforce. A substantial amount of the economic activity of transit-served counties is shifting towards transit stations, which now capture nearly fifty percent of all US firms within a half-mile of a transit station (Renne et al. 2016a). This increases regional accessibility and economic resiliency (Arthur C. Nelson, Hibberd, and Currans 2020). Yet, many transit stations cannot be considered fully-formed versions of TODs as currently implemented—most are not dense enough to meet the 8 units per acre minimum of housing density required to support transit use—and unsurprisingly do not provide the theorized externalities (Arthur C. Nelson and Hibberd 2019b; Renne et al. 2016a).

Dittmar and Ohland (2004) cited the gap between the TOD theory and the state-of-practice, ascribing the gap to incomplete implementation: insufficient land use mix, including the range of housing and retail options, insufficient access to and frequency of transit, and inappropriate zoning and financing instruments. These problems persist in much of the current transit station areas (Arthur C. Nelson and Hibberd 2019b). In more fully-formed TOD areas, which have attracted sufficient development, the required attributes of a "rich mix of [land use] choices" and "placemaking," which are among the most salient potential sources of equity gains from TOD, are obstructed by the high cost of land that comes from the tight competition for parcels in TODs. As a result many of the land uses required in TOD theory to create a broad range of private and public-use buildings do not "pencil" without significant public intervention, such as affordable housing subsidies or public-private partnerships. However, much of that competition arises from confounding effects not directly related to transit proximity (E. C. Delmelle, Nilsson, and Bryant 2021).

A major obstruction to balancing TOD areas between housing and commercial uses is the severely constrained supply of TOD-area housing. This results in a disequilibrium in the TOD housing market that artificially drives up prices. It can also be obstructed by inappropriate zoning or slow permitting that adds to the cost of development, as well as by NIMBY opposition from people who believe that TOD will negatively affect the character or the property value of their neighborhood (Arthur C. Nelson 2013; Arthur C Nelson and Hibberd 2022b). The literature also differentiates between TOD types: TOD versus TAD, or Transit-Adjacent Development. The latter lacks the land use and transportation network integration and the density required to increase multimodal accessibility, especially walkability, around the transit station. In between these ends of the TOD spectrum are hybrid station areas. These qualify as such when they exhibit at least one but not both of the two general criteria of density and walkability (Brenda Scheer, Reid Ewing and Khan 2017; Kamruzzaman et al. 2015; Renne et al. 2016a). Most transit commuting, moreover, occurs in the city center where density and transit service frequency is high enough to attract ridership (Renne et al. 2017).

Gentrification may follow transit systems if the land uses near the station are not designed with affordability in mind (Chapple and Loukaitou-Sideris 2019; Zuk and Carlton 2015; Dawkins and Moeckel 2016). It is very difficult to place modest homes and small local businesses in many of these locations. This obstructs implementation of the theoretically vital range of housing options and local businesses to maintain a traditional sense of place. The challenge, as stated above, may be in large part due to insufficient supply of housing near transit stations that artificially inflates the price (Arthur C. Nelson and Hibberd 2019b). Yet, when considering transit impacts on neighborhoods, it is important to factor in the reduction of transportation costs for households, which can be substantially reduced through TOD access (Acevedo-Garcia et al. 2016).

Transportation infrastructure and technology function jointly with land use configurations to influence the spatial patterns in which firms do business, and in which households live and work. At the same time that households need workplace access, firms need workforce access. There exists a significant gap in the literature regarding whether and to what extent increased transit access in the United States has led to an increase in workplace and workforce accessibility. For transit access to result in greater employment access requires a related set of land use decisions that bring housing and employment centers closer together. Theoretically, these dynamics in employment accessibility will also influence economic strength and resilience by providing firms greater access to the needed workforce. Firms' requirements for employees depends upon the size and diversity of firms' operations. Outcomes of transit access on households and firms will vary significantly by metropolitan area, employment sector, and transit system mode (e.g., light rail).

Empirical evidence shows that transit stations increase neighborhoods' resiliency to economic shocks (Arthur C. Nelson, Stoker, and Hibberd 2019). Reducing spatial mismatch can further improve the outcomes of TOD and strengthen regional economies by increasing workplace and workforce accessibility. It should, however, be combined with the many other tools available for increasing accessibility in urban regions, (e.g., high-occupancy toll lanes, ride sharing) which together can act as force multipliers (Downs 2004).

Transit Station Typology - Urban Hierarchy, Local Connectivity, or Node-Place Tension

Transit systems can be broken into a typology of stations by the intensity of certain characteristics that support their function and draw people towards them, or alternatively those characteristics that impede people from using them. Three main constructs exist for these typologies, 1) situating the station in the context of the urban hierarchy, 2) characterizing the station's strength as a node in the transportation network and as a place with land uses that draw people in, and 3) measuring the station's degree of interconnectivity with the surrounding neighborhood's transportation networks and land uses (Arthur C. Nelson, Hibberd, and Currans 2020).[2] The urban hierarchy has been described via multiple dimensions. The Ds of the built environment, outlined above, have become ubiquitous in planning literature (Ewing and Cervero 2001; K. Park et al. 2020).

Bertolini (Bertolini 1996) argued that customers drawn to nodes and those drawn to places are not the same people. That is, travelers are rarely drawn to a station for its land uses, and stayers are not drawn to a place because it is a transit station, but rather for the access to land uses. If not designed with an eye for balance between node and place functions, designing stations as nodes may obstruct those stations' utility as places, and vice-versa. On the other hand, a proper balance between node and place makes the station more desirable and more resilient. Making transport nodes destinations in their own right is important; addressing competition and cooperation between nodes of one system as places is also key (Bertolini 1996). Bertolini's node-place paradigm is useful for its attention to network effects, which are highly important to polycentric development, as one of its key goals is to produce synergies between networked places (E. Meijers 2005). However, Bertolini's paradigm is hard to operationalize in an empirical study of station typology without access to data that describe the station's level of ridership and transit network interconnectedness. One key indicator of node strength, quality, and level of service readily available is the transit mode (e.g., streetcar or light rail). An indicator of place

[2] Thanks to Dr. Kristina Currans for these insights on station typology.

strength is the place's typology, in the form of a scale from poor to high land use mix and accessibility.

The degree of connectivity and relevance of a transit station to its immediate neighborhood is coined as the TOD versus TAD typology, in which transit-adjacent development is not dense enough to support transit and is insufficiently interconnected to the local transportation network and land uses to be considered truly a transit-integrative neighborhood, or TOD.

This dissertation will emphasize the local neighborhood context of each transit station, rather than centering the analysis on the station itself. It will therefore type the transit stations via their context in the surrounding neighborhood by tying neighborhood land use and demographic data to transit via the distance to the nearest transit station and the intensity of local centering at the station. It will also develop the node typology of a neighborhood's nearest station based upon that station's transit modes.

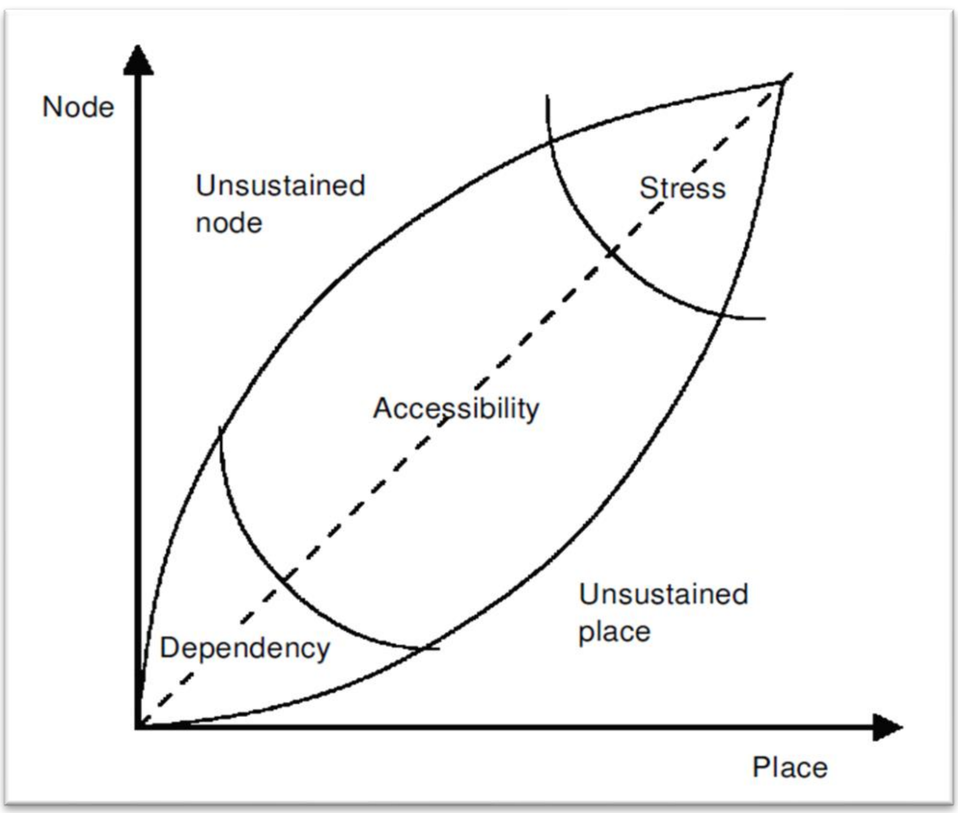

Figure 1. Bertolini's (1999) node-place framework

Bounded rationality and its effect upon TOD

The willingness to pay for a specific bundle of characteristics in residential or commercial real estate depends upon the framework of judgment used by private households or firms, government bodies or community constituencies (Lancaster 1966; Rosen 1974; Ostrom 1998). For workers, perception of the value of proximity to transit and other mixed land uses will determine willingness to pay. Likewise, the perception of the value of living close to one's place of employment will influence willingness to pay. For firms, perception of the strategic value of a location, and the longstanding practices and prevailing decision rules of the firm in budgeting and resource allocation will influence willingness to locate in a TOD. For city governments and private groups and individuals, perceptions of utility, rather than true utility, will drive the decision rule regarding acceptance of TOD and compact development.

Behavioral Theory provides a critique and extension of neoclassical rational choice theory and the utility maximizing model. Behavioralists take issue with some aspects of "economic man," showing that, as explained by the utility satisficing model of Simon (Herbert A Simon 1957), people and organizations (because they are run by people) can be expected to act via a "bounded rationality," that aims at "satisficing," or getting to what may be considered a local maximum or "good enough" state.

Behavioral theory extends also to the organization. The key assumption of behavioral organization theory is that there is a causal canalization of human cognitive capacities into certain features of the organization (to the detriment of other concerns). The aspects of human cognition that cause this canalization of behavior is causally related to such processes in organizations, with managers' path dependencies leading to institutional inertia (Jones 2017a). This Weberian manager-focused decision-making heuristic is based upon people's perceptual capacities. People will, given that full information is not provided them, conduct a search for satisfactory alternatives, and settle on a state that they perceive to be good enough, based upon heuristic balancing of trade-offs between positive and negative aspects of each option (Wong 2002).

Bounded rationality theory seeks to identify the effects of perception on actions taken. A relevant conceptual example is cognitive mapping (also referred to in urban theory literature as "mental mapping" via Lynch (Lynch 1960), with similarities in theory), which relies upon the individual's internal representation of the world. This representation takes on a simplified state, similar to a diagrammatic form, with basic networks of paths and nodes. Public transit systems often take advantage of this understanding of human spatial conceptualization in the chosen form of system maps (Hill 2006). Thus, human cognition incorporates a significant smoothing or simplifying process that reduces the cognitive load imposed by information by identifying perceived priority elements and masking out marginal details. The implementation of organizational goals into action is often stymied by disagreements among decision makers, leading the organization to take simplified shortcuts that fall short of the original goal, but reduce the complexity of the challenge (Jones 2017a).

Behavioralists seek to identify regularities in actual behavior, not optimal behavior. Upon reflection of the use of location theory in business siting, for example, it is clear that optimality is only reached at the cost of the ability to run sophisticated optimization algorithms against large and complex data sets, which have the requisite data about all of the influential factors. Therefore, it is logical to assume that actors without such faculties will not reach the same level of optimality in choosing a home or business site as the location analyst by using simple heuristics.

Nevertheless, the information available is more important than the framework on which choices are made, whether fully rational or boundedly so (Jones 2017a). Bounded rational choices are themselves dependent upon having enough relevant data on which to act. Rational choice of a residential or firm location requires sufficient information about all the attributes of a given property, as well as its local and regional surroundings, and the unique needs of the individual, household, or firm. The satisficing actor may weight each of these attributes differentially, and a diverse set of actors will reach a multitude of subjective decisions guided by whatever level of information is available to them, and their perceptions and preferences.

Simon (H. A. Simon 1956) argued that satisficing decisions are made upon the basis of the characteristics of the organism, but also upon the basis of the structure of the surrounding environment. Therefore, the structural characteristics of the environment will influence a person's adaptive (satisficing) decision making process. The environment thus described as influential comprises the aspects of an organism's environment that have relevance to the organism, or its "life space." This space will vary depending upon the "needs," "drives" or "goals" of the organism, and upon its faculties of perception. An organism will make decisions in an effort to create or improve its *linkages* to the outside world and its provision of needed resources. The capacities, constraints, and limitations found in the "fundamental structural characteristics of the environment" influence the approximating mechanisms employed by satisficing or adaptive actors (H. A. Simon 1956).

Easterlin (Easterlin 1995) has found that households' levels of happiness in terms of satisfaction with their economic well-being is quite subjective in nature and is highly influenced by the material consumption of nearby peers. "Today, as in the past, within a country at a given time those with higher incomes are, on average, happier. However, raising the incomes of all does not increase the happiness of all. This is because the material norms on which judgments of well-being are based increase in the same proportion as the actual income of the society." People's perceptions of their well-being are driven by inductive heuristic comparison, rather than objective quantification. People not acting on historical data about well-being find some alternative source of information on which to establish a baseline of well-being and where they are in relation to it. This form of bounded rationality holds influence upon who decides to locate near transit stations, their place of employment, or their employee base. For example, household choice of place to live may not consider the greater transportation affordability of homes near transit stations.

The available information greatly influences decision making. For example, publicly available indices that rely upon significantly different data sources and methodologies are frequently used to address the same or similar questions. Gabe et al. (Gabe, Robinson, and Sanderford 2018) critically analyzed two aggregate measures of walkability, the WalkScore and the EPA's National Walkability Index, examining them for the implications of the differences between the two frameworks: which led to a deeper understanding of individual phenomena of walkability, which component of the indices were economically relevant to decision makers, whether the variation between the metrics provided potentially misleading information, and the extent to which each of these aggregate indices captured unobservable information useful to the market.

The available options also influence decisions, as the classical supply-side theory, and the filter-down concept wherein actors choose where to live within the constraints of existing development and institutional factors. The demand-side process of making tradeoffs between access and land area through the price effect operates within the context of the supply-side factors but is also subject to the level of information the agent has, and the level of energy the agent is willing to exert in the heuristic search. One conceptual model of the decision-making process is the decision tree, in which consumers step through a series of pairwise comparisons and make a tradeoff at each step between location, dwelling price, and dwelling size, among other characteristics (Wong 2002). In a satisficing scenario, each key characteristic of a dwelling is compared with the rest, one by one, with tradeoffs made according to perceived constraints and preferences. Using this heuristic, moving to a TOD area must stand against many other characteristics in a dwelling's "bundle."

Decisions of individuals and firms are also subject to the *preparation-deliberation tradeoff*. Prepared solutions to problems are less costly to implement than performing problem searches that require new solutions. These pre-packaged solutions fail or are less effective when applied to new problems and problem spaces. Disjointed, incremental, and episodic solutions result when the problem spaces change, and old solutions fail. This is due to the cost of response and solution search. These "punctuated" policies are rare but hold a disproportionate importance in decision making processes (Jones 2017a).

The impact of bounded rationality on urban design is manifold. From satisficing actors who miss many unforeseen opportunities in transportation or the real estate market, to communities obstructing progress over ever-widening political divisions, many optimal solutions are overlooked in favor of a decision made based on "less than our best efforts." The APA Trend Report for 2022 cautions regarding the growth of political divisions:

> "Generally speaking, public trust in the federal government has been declining, while the public remains more trusting of local governments in recent years. Yet many planners are experiencing an increase in interruptions, chaos, and even beratement during public meetings. This indicates that public trust in planning work is weakening in communities with very conservative or very progressive constituents. Local governments and planning organizations should work to maintain local trust and build confidence in their work, such as continuing to highlight accountable implementation of projects and initiatives. Local governments might need to collaborate with federal and state counterparts to minimize the undermining of local goals and visions." – APA Trend Report 2022[3]

[3] American Planning Association Trend Report for 2022. https://www.planning.org/publications/document/9228382/. Accessed 1/14/2023.

This is to say nothing of the manifest need to increase and improve participatory planning, as the APA Trend Report also notes.

Yet, many agents may choose to cooperate, in "better than rational" behavior, as described by Ostrom (Ostrom 1998). Not all actors must be coerced to follow a collective program or policy. They often choose to cooperate or at least to "forge norms to foster such cooperation." (Ostrom 1998).). Some scholars go so far as to claim that because humans' capacity to reason is due to our use of a neural computational device that drives us to act by instinct, that "the rationality of a behavior is irrelevant to its cause or explanation," but that economic theories wrongly build upon the implicit assumption that these devices produce rational decision rules (Cosmides et al. 1994 "Better than rational"). Ostrom (Ostrom 1998) argues that the specialized decision rules people employ are not instinctual but learned through many instances of experiencing interactions with other actors. Groups may lose over time the decision rules regarding cheaters and defectors who break reciprocity norms, for example, and need to be retrained through the school of hard knocks to reinstitute rules of retribution as they work their way through the pain of betrayal in social dilemmas (Ostrom 1998).

The improvement of jobs-worker balance depends entirely on perceptions of those who hold the power over decision making in our communities. These stakeholders comprise a large and complex body of diverse actors, with their own unique decision-rule instincts. This makes the political process in planning and development of more location-efficient urban areas paramount.

Research Plan

This dissertation presents a new way in which to understand John Kain's (Kain 1968) pioneering spatial mismatch hypothesis by applying to it advanced theories, recent data sets, and more sophisticated methodologies than previous studies on the subject. This theory calls on urbanists to address the challenge had among many low-income urban households have of entering or staying in the workforce. This must be accomplished by increasing access to employment. This need also means planners and policymakers have the opportunity to use transit and TODs to reduce spatial mismatch for many people, including households in urban communities that are disproportionately more reliant upon transit than the general population. This includes case populations in disinvested urban (e.g., redlined) neighborhoods. Firms are also in need of an increasingly large regional workforce pool to meet their need for a diverse and sophisticated skill set. Provision of the requisite workforce thus requires a highly diverse land use and transportation regime from which to derive agglomeration economy effects while avoiding the wicked diseconomies of congestion and prohibitively high housing costs for workers across wage levels.

Advocates of TOD present it as a major innovation in pursuit of greater accessibility, but do not sufficiently emphasize the perspective of the firm. As it is expedient for many firms to draw upon the whole of a region for their workforce, and perhaps beyond the region, TOD solutions must deliver regional-scale efficiencies in workforce accessibility. To do this, TODs should rely upon a polycentric urban pattern, with land uses being much more concentrated in regional sub-centers, the transit stations themselves, than the dispersed low-density housing and employment in the archetypal model of the suburbs.

The literature shows that a very small percentage of residential housing exists near transit stations across the country, while about half of all jobs are near these stations (Renne et al. 2016a). This current situation represents significant low-hanging fruit for TOD advocates to increase polycentric development and thus, if the theory is correct, accessibility.

This theory needs more empirical evaluation. Using extensive data sets already compiled from the US Census Decennial Census, American Community Survey 5-year samples and U.S. Census Bureau's Longitudinal Employment-Housing Database (LEHD) job data programs, from CoStar real estate data, and from transit system data in the General Transit Feed Specification (GTFS) static file format, this dissertation will focus on the following inquiries:

Using polycentric urban regions theory to build upon Kain's research, the dissertation will evaluate TOD's effects on regional and local employment accessibility since the year 2002 in two stages. First, it will develop a Job-worker balance Index (JWBI) that can be used to describe the phenomenon in multiple contexts across metropolitan areas of the US. Second, relying upon the JWBI, quasi-experimental spatial regression, geographically-weighted regression, and spatial cluster analyses to update traditional methodologies, the study will gather new evidence on accessibility outcomes of TOD. It will do so by empirically measuring the degree to which TOD has captured growing shares over time of the regional economy in terms of housing and jobs, and whether there is a better job-worker balance in these neighborhoods than in the rest of the region. Further, it will evaluate whether jobs match the skill and wage level of local residents, and whether housing costs match wages from available local jobs. This will provide new evidence regarding whether investing in transit systems provides improvements to accessibility for the firm and the household. Cases of study will include two separate treatment groups: households close to transit generally, and redlined neighborhoods close to transit. The latter is a special case of the historically disinvested neighborhood in need of repair and update to its supportive infrastructure. The control will be neighborhoods outside these treatment areas in counties served by transit systems.

This dissertation aims to break new ground on how effectively TOD policies and design improve employment accessibility to neighborhoods where Fixed-Route Transit (FRT) such as commuter rail (CRT), light rail (LRT), streetcar (SCT), or bus rapid transit (BRT), is introduced. Using new theories, data sets, and methodologies, the research will provide robust evidence regarding transit's effects on employment accessibility for both the workplace and the workforce by producing the Job-worker balance Index (JWBI). The study hypothesizes that the analyses will produce nuance in the grouping of workers and their urban context. Further, it will give new guidance towards transit-driven reductions in spatial mismatch, which will help increase the economic resilience of cities' firms and labor forces. It will also strengthen the transportation field's emphasis on the transportation-land use connection.

Chapter 2: Literature Review

The literature pertinent to this study's research about job-worker balance includes a varied but interconnected range of topics. First, *spatial mismatch* is the lack of spatial proximity between the residences of the labor force—workers and those who are unemployed—and the firms for which they work or are eligible to work. This lack of proximity obstructs employment accessibility. Related to spatial mismatch is *job-worker balance* (JWB), which is the degree to which a neighborhood possesses a balance of employees and their places of work. It implies *income match*, or a balance between resident workers' incomes and the number of jobs available at residents' income levels. Related to JWB is *internal capture*, the degree to which an area captures resident workers' commutes (the commuter shed). The literature has identified multiple methods for its evaluation. Second, *urban form* ranges from compact to sprawling development, from single to multiple land uses, and from single to multiple transportation modes. Urban form has important effects on affordability and accessibility of residents to their workplaces, and vice-versa. Sprawl has continuously increased the distance between land uses and thus decreased accessibility. It has also increased societal reliance upon the technologies of mobility. The related issue of *spatial autocorrelation* is a measure of how similar things are as a function of their distance from one another. Third, *location efficiency theory* prescribes characteristics of places and the ways they interconnect to provide efficiency in urban form through land use, transportation networks, and public infrastructure. Fourth, *polycentric urban regions* are an urban form class for which planners and scholars are increasingly advocating as a location efficient form, consisting of regions that have multiple high-intensity centers of activity that synergize through significant network interconnectivity. These centers can support and increase agglomeration economies of proximity while reducing the usually concomitant diseconomies of congestion and high living costs. Fifth is *transit-oriented development* (TOD) and the related theory of *place typology*. The place typology of transit stations has been usefully theorized as a tension between stations' classification as nodes or as places. TOD is a form of land use oriented towards making stations both important nodes on the regional transportation network and places that attract firms and people. Sixth, the human method for deciding whether to choose to reside in TODs is important to the discussion. The tenets of *efficient market* and *rational choice* theories, which assume a set of rational human agents, are relaxed by *bounded rationality*, which is the basis for human decision making. For example, the availability of information and the cost of accessing and using it influences whether people will choose to live in more location efficient places, such as TODs. In the post-COVID-19 era preliminary research indicates that compact urban form can be beneficial to public health in times of pandemic, and many interventions have been identified to make compact urban spaces safe and supportive to the needs of the community.

Below, we will discuss the conceptualizations and debates around these topics.

Spatial Mismatch

The Spatial Mismatch Hypothesis (SMH) has attracted a lot of research and debate since Kain's (Kain 1968) seminal paper linked the special case of racial housing discrimination to the distribution and level of nonwhite employment in urban areas. He drove his assertion via three hypotheses: 1) racial segregation in housing affected the distribution of black employment, 2) this distribution reduced black job opportunity, and that 3) postwar suburbanization of employment had seriously aggravated the problem. The theory of spatial mismatch has important implications for urban form and worker access to employment.

In hypothesis 1 of the SMH, the dissimilarity index shows high segregation in residential distribution across 207 cities in 1960. Regressing job counts for blacks on distance from ghettos and the proportion of blacks residing in a work zone showed estimated losses due to segregation. In hypothesis 2, racial discrimination in housing markets reduces black employment opportunities. Kain's estimates of black job losses due to segregation are obtained under the assumption of a constant proportion across residence zones. He tested this hypothesis in Detroit and Chicago using 1950s-era data. In hypothesis 3, Kain asserted that postwar suburbanization concentrated black populations in the inner city, whites in the suburbs, and jobs in the suburbs. The result was that suburban jobs could not easily be reached by blacks who used to be a source of cheap labor to industries that had recently suburbanized. Postwar job suburbanization followed the same trends as white suburbanization. Using the dissimilarity index, he demonstrated the ubiquity of starkly segregated inner cities across the United States. High index values for racial segregation were found in US cities, from 60.4 to 98.1 at the CBG level.

Cervero (Robert Cervero 1989), as mentioned above, identified five major forces behind the spatial mismatch between jobs and housing: 1) fiscal and exclusionary zoning, 2) growth moratoria, 3) worker earnings/housing cost mismatches, 4) two wage-earner households, and 5) jobs turnover. The first three underscore the ad-hoc and spatially scattered nature of municipal policy creation, which often divides regions that would otherwise function as whole units just as ecosystems, watersheds, and transportation systems often function (Calthorpe and Fulton 2001). The first, zoning practices, have been cited by multiple studies as major obstructions to the efficient allocation of land to its regional market equilibrium (Benner and Karner 2016a; Downs 2005; Chapple and Loukaitou-Sideris 2019). The last two are greatly influenced by social dynamics, reminding policymakers of the constantly changing structure of regional demographics. The worker earning/housing cost mismatch continues to grow in some areas, as gentrification processes price low and even moderate-income workers out of the neighborhoods where they work.

The SMH was rejected by some scholars because they were seeking the "one major cause" of inner-city minority unemployment, not considering the important likelihood that the cause was multidimensional, or that the spatial dispersal of employment opportunities obstructed access to them. Leonard (1985) and Ellwood (1986) concluded together that racial discrimination, not a spatial mismatch between minority housing and relevant employment, was the cause. Harrison (1972a, 1972b), Masters (1974, 1975) and Jencks and Mayer (1990) all argued that Kain's SMH should be decomposed into two different stories, those of the demand-side and supply-side employment dynamics. The interest of firms in hiring blacks, they argued, was not related to the region's degree of residential segregation. While racial discrimination was the reason for blacks being excluded from living in the suburbs near employment, as well as being excluded on the basis of race from at least some of the suburban jobs they could have reached, the cost of commuting to the suburbs remained another key barrier to be overcome. Put in Kain's words, these critiques "still fail to relate the extent of black residential segregation to the metropolitan distribution of employment opportunities, which is the essence of the spatial mismatch hypothesis" (Kain 1992). Race was the reason why blacks were segregated, but segregation and spatial isolation were main causes of lower employment.

Kain's work influenced the McCone and Kerner Commissions, held by the California and US governments, respectively, in the years after the 1965 Watts riots in Los Angeles. The McCone Commission found that the "most serious immediate problem that faces the [black residents] in our community is employment" and that the spatial distance between black "ghettos" and job centers were influential factors in their unemployment. Kain further argued that in Detroit and Chicago alone, spatial mismatch due to restrictions against black residential choice had cost the black labor force tens of thousands of jobs (Kain 1968; 1992).

His hypotheses were further borne out and given nuance by the work of many subsequent scholars. Massey & Denton (Massey and Denton 1993) provided a nearly exhaustive survey of segregation in U.S. cities from 1900 to the 1980s. Glaeser and Kahn (Glaeser, Edward L. & Kahn 2000) cite three major factors in the decentralization of employment: 1) the residential preferences of workers, 2) human capital level of an industry, and 3) political borders and local government policies. Lance Freeman (Freeman 2019a) recently wrote a history of the U.S. ghetto, in which he detailed segregation levels to the present day, showing that segregation grew during the postwar period when discrimination in housing and lending effectively blocked blacks from fleeing to the suburbs. Freeman further showed that while the Fair Housing Act of 1968 untethered black populations from the inner city to a large extent, today segregation remains a major issue. Kain (Kain 1992), for example, detailed policy proposals for decreasing unemployment in the 1980s and 1990s. In doing so, scholars still relied upon addressing high minority concentrations in the ghetto. Galster and Cutsinger (G. Galster and Cutsinger 2007) contributed an important set of nuances in the relationship between segregation and land use patterns. Importantly, they found a nonlinear relationship between black isolation index levels and the degree of compact metro form. They found that a quadratic functional form best fit their regression of the relationship between these phenomena, and that a medium degree of compact urban form reduced black spatial isolation more than a very dispersed or a very compact urban form. This makes intuitive sense when considering the interplay between the economies and diseconomies of urban agglomeration. They further enumerate the countervailing relationships between the dimensions of segregation and those of land use patterns or urban form.

Rothstein's (Rothstein 2017) recent work on redlining, segregation, and housing discrimination further developed the picture of urban poverty and isolation from job centers. Redlining was the federal government's New Deal-era practice of rating urban neighborhoods, which had been subjected to segregation by race, as high-risk investments and thus deterring lending and insurance institutions from doing business in those neighborhoods. This practice led to sweeping disinvestment, which likely influenced the trends measured by Kain (Kain 1968), and later by Massey & Denton (Massey and Denton 1993).

Ihlanfeldt (Ihlanfeldt and Sjoquist 1998) analyzed spatial patterns of wages and found a negative wage gradient as one travels away from the CBD. Lower-income black workers who accept a costly and time-consuming commute to suburban jobs, he posited, only do so because they cannot find sufficient relevant job opportunities in the inner city. Kain, Fauth and Zax (Kain, Fauth, and Zax 1977) analyzed 346,000 households in cities across the US and found that black households and workers were much less likely than white households and workers to own a vehicle and much more likely to take public transit to work. The high cost of owning and operating a vehicle, which was higher in the city than in the suburbs, combined with the dispersed nature of suburban employment locations to obstruct some urban households from employment opportunities. Those who worked in the suburbs obtained lower net wages, because of transportation costs, than those who both lived and worked near urban ghettos (Kain 1992). Freeman (Freeman 2019a) highlighted the plight of inner-city neighborhoods in the decades following the Civil Rights era, and the ongoing challenge of residential segregation (figure 1) and distance from needed employment opportunities. In the early 1990s, 87% of new lower-income jobs in service and retail sectors were located in the suburbs (HUD 1997).[4]

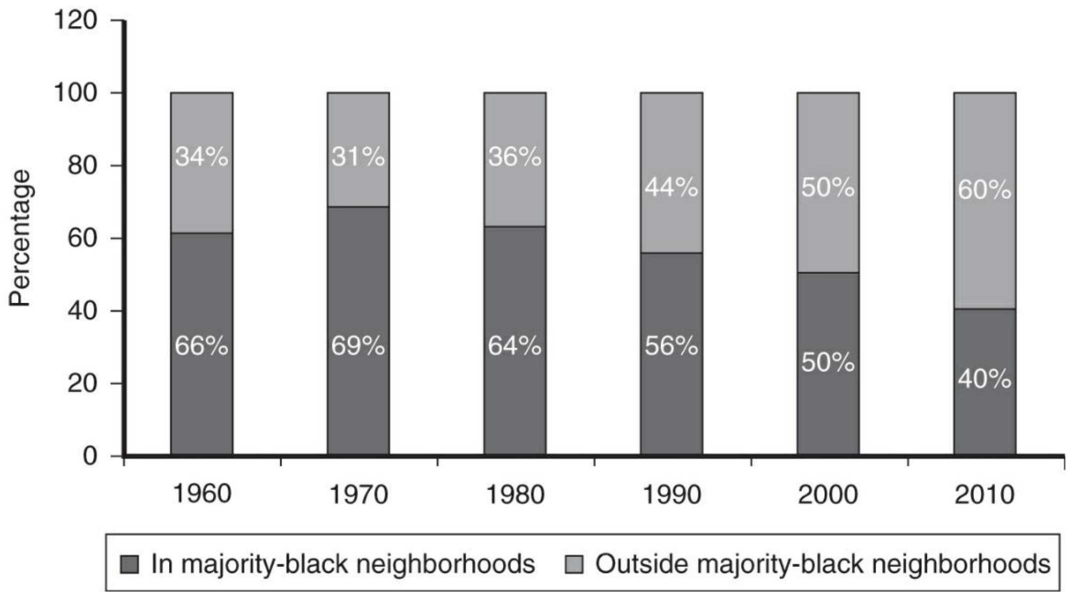

Figure 2. Proportion of northern blacks in majority-black neighborhoods, 1960-2010.

Source: Freeman (2019b) *& Logan, Xu and Stults* (Logan, Xu, and Stults 2014)

Moreover, Kain's thesis about racial segregation leading to reduction of employment can be generalized further to include the effects of sprawling development on employment accessibility for the entire labor force of a region in general. Sprawl has greatly isolated and separated land uses and resulted in ever longer and costlier commutes for all segments of the population from the 1950s to the present. Sprawl, concisely, has rendered the Alonso-Muth-Mills spatial equilibrium model (AMM) (Alonso 1964; Muth 1969; Mills 1972), of urban form nearly obsolete (Hajrasouliha and Hamidi 2017). This means that dispersed or polycentric urban models have a better goodness-of-fit to current U.S. cities (R. Cervero and Wu 1997; Hajrasouliha and

[4] For further information, see https://www.huduser.gov/portal/home.html. Accessed 4/30/2024.

Hamidi 2017). If Kain's hypotheses about segregation's resulting job isolation are true and relevant, further efforts to reduce spatial separation between the workforce and the workplace will lead to major benefits in terms of both equity and economic resiliency. Despite other findings in the spatial mismatch hypothesis literature, it appears possible that improved access to public transit can overcome the physical separation between the residential locations of workers and job locations, whether caused by segregation or suburbanization.

COVID-19 and the Future of Urban Form

The massive impact of the COVID-19 pandemic, and its impact on the city, has made many people concerned that compact urban design only exacerbates the challenges of communicable diseases to public health. Many urban scholars claim the opposite: that a city less dependent on the automobile will greatly improve resiliency to pandemics. This requires careful planning to meet such challenges as society faced in the last pandemic. Table X discusses some of the proposed strategies.

Table 1. Urban design interventions for pandemic

High-level interventions	Detailed urban design strategies	Parameters
Social distancing interventions	Encouragement to keep a defined physical distance	The probabilities of social distancing; The maximum node degree threshold to truncate the scale- free network
	Avoiding crowding	Interpersonal distance; Population density; Exposure density (a measure of both the localized volume of activity in a defined area and the proportion of activity occurring in non-residential and outdoor land uses); Lloyd's index of mean crowding
	School and workplace measures and closures	The number of people avoiding going outside, crowded places, visiting hospitals, using public transport, going to work, and going to school; Workplace closing
	Contact tracing	
Travel-related interventions	**Internal travel restrictions**	Stringency index; Traffic restriction rate; Control- threshold and adjusting- frequency; Reduction factor of interpersonal contact
Individual-level interventions	**Individual behavioral changes**	Mobility ratio quantifying the change in mobility patterns; Ridership; Percentage change of mobility in retail and recreation trips, in transit stations trips, in workplaces trips, in residential trips; Travel habits trend after lockdown, public transport habits trend; Trip reduction to groceries/pharmacies, parks, and transit stations; Variations in neighborhood activity; The mean value of the exponential distribution of the time spent at a given location; The frequency of individual travels
Neighborhood/ District-level design interventions	**Design of public/open spaces**	Compactness Index; Contagion Index; Landscape Division Index; Shannon' Diversity Index; Shannon's Evenness Index; Dilapidated building, visible utility wires; non-single-family home; Sanitation coherence index
	Pedestrian-friendly design	Presence of crosswalks and sidewalks; Single-lane Road; Street greenness
City-level design interventions	**Density**	Metropolitan population; Density of general hospital and commercial facilities; Percentage of urban land; The number of indoor sports and recreational facilities; Total building area, residential building area, commercial building area, and land use diversity; Variations in neighborhood activity
	Land use mixture	Land use mix index

	Transport accessibility	Transport accessibility; Rail- based transport accessibility; Road and subway station density; The number of bus stops and transfer stations; The shortest distance to Central Business Districts (CBDs); The number of intersections
	Spatial connectivity	Street connectivity

Adapted from (Yang et al. 2022)

Job-worker balance

Efforts toward a job-worker balance—most often referred to as "jobs-housing balance," has multiple justifications for its policy implementation, such as lowering emissions, freeway traffic, commuting time, vehicle miles traveled (VMT), increasing housing affordability through supply of appropriate levels and types of housing (Benner and Karner 2016a) as well as further increasing agglomeration economies through greater accessibility.

The effects of policies aiming at creating a greater balance in jobs and housing have been under studied, but travel demand research has shown that areas with a high accessibility to employment (i.e., that jobs are relatively near to housing) also tend to have shorter work trips (Stoker and Ewing 2014a). As the ratio between jobs and housing evens out, research has shown that within-community commutes significantly increase (Robert Cervero 1996).

Some scholars have concluded that improving employment accessibility by reducing travel time or distance to work is a key benefit of jobs-housing balance. This results in multiple benefits, from lower infrastructure costs for municipalities to lower transportation costs for households, among others (Robert Cervero and Duncan 2008). Some researchers have asserted that efforts spent on jobs-housing balance are wasted, politically costly, require great societal change while producing fairly little effect, and detract from more effective measures at increasing accessibility through reducing congestion (Downs 2004). However, accessibility is more than an absence of roadway congestion. The most effective measures of accessibility look at all modes of travel and the friction of distance that travelers must overcome.

The cost of automotive travel and the global problem of congestion suggest that transportation policies must look to travel modes in addition to automobiles for increasing regional access. Transit systems are cited as a key to a region's or neighborhood's degree of accessibility, as they reduce travel time compared with other alternative travel modes (Arthur C Nelson 2017b). Earlier research had found, on the other hand, that low-income households suffer lower rates of labor participation more from slow, inflexible, and limited availability public transportation than from "geographical disadvantage" (Sanchez, Shen, and Peng 2004). Downs (Downs 2004) also points to the importance of approaching transportation problems from all the available solution angles, including regulatory (e.g., prohibiting free parking), supply-side (e.g., more highway miles), and demand-side (e.g., congestion tolls) policies.

Accessibility can be defined as "the ease with which people can reach services, activities, and other important destinations" (Smith, Gihring, and Bibliography 2017; Ihlanfeldt 2020). Cervero and Duncan (2006) computed elasticities for the effect of job accessibility on vehicle miles traveled (VMT) and vehicle hours traveled (VHT). They found that VMT and VHT were reduced the most by access to occupationally matched jobs within a 4-mile distance of home. Ewing and Cervero's (Ewing and Cervero 2010) research on accessibility to work by auto and transit found elasticities with respect to VMT of -0.20 and -0.05, respectively. Only distance to downtown had a more profound effect on VMT, with an elasticity of -0.22. These results suggest that access is most effected by reducing distance between workers' residences and their workplaces (Ewing and Cervero 2010).

Agglomeration economies, which are heightened business activities due to greater proximity between firms within and across job sectors, are reduced through congestion and loss of housing and transportation affordability. Ongoing research has concluded that fixed-route transit systems (FRT), such as heavy rail (HRT), commuter rail (CRT), light rail (LRT), and streetcar (SCT) help to facilitate agglomeration economies and enhance economic development through heightened accessibility (Hibberd and Nelson 2018). Agglomeration economies provide greater economic resilience to a region, making its economy more resilient to shocks to the system, and transit and jobs-housing balance are key factors in those economies (A.C. Nelson et al. 2015). The effect of TOD on access accrues from both greater mobility and greater proximity. Moreover, the spatial mismatch between the location of housing and jobs is of concern in efforts to lower transportation costs, which are increasingly factored into housing affordability indices (Robert Cervero 1989),(Robert Cervero 1996); (Center for Neighborhood Technology 2015);(Arthur C Nelson and Ganning 2015)).

The effects of density, in population or in employment, differ depending on the type of density. Density in commercial land uses typifies the CBD, with the likelihood of congestion resulting from the concentration of commuting workers. Density in industrial uses can have congestion effects, due to cross-commuting, or signify a good level of internal (i.e., local) job travel from workers who live nearby, referred to as internal capture. One study hypothesized that the spatial distributions for industrial and commercial land uses take different forms, and therefore have different commuting patterns, and found empirically that 1) polycentric metropolitan areas aid in shorter commute times, and that 2) density effects differ between density types (Gordon, Kumar, and Richardson 1989). Residential density is important to the job-worker balance, for without it the clustering of employment does not lead to JWB.

The job-worker balance consists of more than just a one-for-one ratio of jobs per housing in a given area. A proper match between the kinds of housing, such as first-time buyer homes, apartments, condominiums, etc., and the wage and skill level of jobs in an area is a key to a proper balance. Some have termed this the "workforce housing balance," or "jobs-housing fit," as it denotes whether housing is affordable for workers to live near where they work, such as teachers or first responders working in higher-value areas (Robert Cervero 1989; Calthorpe and Fulton 2001; Benner and Karner 2016a; Arthur C Nelson et al. 2015). Moreover, as one study demonstrated, a balance of income between residents and workers is more indicative of internal capture, which refers to whether people can work in the same neighborhood in which they live, than is jobs-worker balance, as income balance allows workers to afford the housing close to their workplace (Stoker and Ewing 2014a; Stoker 2016).

Job-worker balance Methods Review

Many principles that scholars demand quantitative measures for are themselves vague and ill-defined. How do researchers get around the squishiness of such abstract notions as the "commute shed"? Multiple studies have produced sophisticated measures of the job-worker balance, using such methods as the transportation problem, linear regression, spatial regression, or multilevel analysis (Stoker and Ewing 2014a; Horner, Schleith, and Widener 2015; Schleith, Widener, and Kim 2016; Robert Cervero 1989; Weitz 2003). Some studies compare commuting times or distances across racial categories. Some correlate job accessibility with wages or employment levels. Some compare the labor markets of central cities to their suburbs (Ihlanfeldt and Sjoquist 1998). A longitudinal approach measures the degree to which growth in jobs matches growth in housing units (Weitz 2003). Cervero (Robert Cervero 1989) estimated a rule of thumb for jobs-housing matchup in a subregion, using a 3- to 5-mile radius from homes to workplaces as the standard. Multiple distances have been cited as rules of thumb in the literature. Nelson et al. (A. Nelson et al. 2015) recommend an alternative of travel time to work, following up with a review of the literature on public health-related issues of those who suffer from a commute more than ten minutes, including increases in obesity and losses of time to socialize or prepare meals. Their results indicate a social divide: the higher/lower the education level, the higher/lower the number of white non-Hispanics; and the higher/lower the income, the higher/lower the percentage of workers with a commute of 10 minutes or less.

Kain's (Kain 1992) critique of the SMH literature's methods highlights the fallacy inherent in overreliance upon segregation indices alone. Used widely in the literature, they nevertheless "provide no information about the relationship between black residential areas and the spatial distribution of jobs within metropolitan areas." The problem with many indices stems from their measurement of single aspects of segregation. Spatial association comprises a multidimensional phenomenon. Massey and Denton (Massey and Denton 1988) identified and empirically verified 5 spatial dimensions or attributes of what scholars have called "segregation," which is an inherently spatial phenomenon. Measuring the spatial distribution of social groups, these dimensions include:

- Evenness – the distribution of two groups across spatial units (e.g., census tracts or counties), measured as a proportion of one per the other.
- Exposure / Isolation – the degree of interaction possible between groups of different kinds due to their spatial distributions.
- Concentration – the amount of physical space occupied by a group.
- Centralization – the degree to which groups are spatially located near a region's center.
- Clustering – the degree to which groups adjoin one another in space.

Having empirically tested these dimensions with factor analysis, the authors noted that there was some degree of inter-factor correlation between them, but they are sufficiently independent to be considered unique and separate phenomena, each of which should be separately tested. The authors provided recommendations for the best indices to use (Massey and Denton 1988).

Galster and Cutsinger (G. Galster and Cutsinger 2007), in a factor analysis that measured the relationships between the dimensions of segregation and those of urban form, found that each of the 5 dimensions of segregation were affected differently by separate dimensions or groups of dimensions of land use spatial patterns. This has implications for the measurement of JWB. Isolation of the black population was reduced by job distribution. Black population concentration was increased by housing proximity. Centralization of the black population was positively associated with housing proximity, nuclearity, and housing unevenness (dissimilarity); and clustering was positively associated with density/continuity. It should be noted that centralization and centering were measured independently, the former being indicative of a location at region's center, the latter of a central place's disproportionate capture of land uses.

The literature also varies on what functions as an appropriate jobs/housing ratio. Two highly cited studies suggest a range of 0.75 to 1.25 (Margolis 1957), or 1.5 (Robert Cervero 1989). Distances from home to work provide the measure for many of these studies. Stoker & Ewing (Stoker and Ewing 2014a), pointing out the somewhat arbitrary nature of these generalized ratios, recommend determining an appropriate jobs/housing ratio on the basis of local data on workers per household. Likewise, Nelson et al. (A. Nelson et al. 2015) notes that due to the varying size of households, and the fluctuating number of workers per household, job-worker balance is a preferred measure. Stoker & Ewing (Stoker and Ewing 2014a) used a 3-mile buffer around a given census tract, thus creating commuter sheds that would be applicable to a majority of cities across the United States.

Many studies on the jobs-housing balance attempt to identify the optimal commute time or distance for each region as a spatial context, the commute shed. Cervero and Duncan (Robert Cervero and Duncan 2008) used cumulative-opportunities analysis (an accessibility measure), to find the best-fit distance for the optimal regional commute. Schleith et al. (Schleith, Widener, and Kim 2016) use the transportation problem to determine the *excess commute* (EC) for each metropolitan area. Park et al. (K. Park et al. 2020) tests which ratios produce the most optimal outcomes. Hajrasouliha and Hamidi (Hajrasouliha and Hamidi 2017) used cluster analysis to determine regional share of employment captured by each center and subcenter, following previous work (Arribas-Bel and Sanz-Gracia 2014; Cutsinger and Galster 2006). Square footage is considered too context specific. Instead, the number of jobs per relevant industry is used as a measure of relative drawing power of those sectors' activities (Robert Cervero and Duncan 2008). So, for example, a gravity model of retail would identify the number of service and retail jobs in a center, rather than using building square footage.

One further measure is important in studies of spatial mismatch and accessibility: internal capture, which is accomplished when workers both live and work within the same commute shed. Measuring this indicator requires a quantitatively measurable definition. The chosen scale of the commute shed can change the entire calculation results. Commute shed scale is itself highly dependent upon which travel mode is considered. Walking to work will produce a much smaller scale than automobile or transit use. The data required includes a set of origin-destination pairs for all individual commuters.

Urban Form, Accessibility and Affordability: Sprawl and its Discontents

The economic and social effects of urban form are considerable, and particularly for the present question of job-worker balance and employment accessibility. Geographers and urban planners have posited abundant theories of urban form. Among the theorized issues are the effects of 1) the chosen pattern of growth, 2) the relative density of the population, 3) the mix of land uses, 4) the methods of transportation facilitated by that pattern, and 5) the market efficiencies accruing to regions in which connected transportation networks bestow high regional accessibility. The anti-sprawl literature is extensive, and most urban theorists are debating how and whether to counteract the inefficiency and wastefulness inherent in low-density, single-use zoning, auto-dependent suburban and exurban development: sprawl. From the massive expansion of developed land to the billions lost in manpower and infrastructure cost on the congested highways of urban America, sprawl has myriad adverse outcomes. One of those includes a reduction in economic efficiency and vibrancy. Mondschein and Taylor (Mondschein and Taylor 2017) found that "the effects of congestion on access depend on whether congestion-adaptive travel choices (such as walking and making shorter trips to nearby destinations) are viable."

Location-efficient development, a specific variant of compact urban form, is a normative anti-sprawl prescription for urban accessibility. Florida (Florida 2017a) argued that "the real key to suburban renewal lies in two key, related factors—walkability and density." Dunham-Jones's analyses of suburban space concluded that

> metros with walkable suburbs have greater economic output and higher incomes, higher levels of human capital, higher membership in the creative class, higher levels of patented innovations and of high-tech industries and employees, higher housing prices, and higher levels of happiness. As our suburbs become more clustered, they'll become more economically energetic—with benefits for us all" (Dunham-Jones and Williamson 2011).

While today's suburbs need more urbanism, they formed to provide a way of life that many people found to be lacking in the city. Urbanism will be successful only to the degree that it meets the needs of the population and the economic engine that supports it. White flight and urban poverty can be theorized through the perspective of urban form and spatial economics, specifically, with modern modifications, through the Alonso-Muth-Mills spatial equilibrium model (AMM) (Muth 1969; Mills 1972; Alonso 1964), as well as the Central Place Theory (CPT) of Christaller and Losch (Christaller et al. 1933; Lösch 1954). The AMM model presents the urban spatial equilibrium (e.g., where the population lives, works, shops, etc.) as a tradeoff of each household between land, non-land goods, and transportation costs, subject to the constraints of the household budget. Business firms also must make a similar balancing act. The CPT models the urban economy in terms of the gravity effects of a central place, such as a central business district or smaller regional sub-center, based on what centralized goods and services it offers and how attractive these are to the surrounding markets. The implications for the economy are critical: if the city no longer has the same central goods that, according to the theory, pull people to the center, they will head for the locations that do have those central goods, with the associated shifts in economic gravity and health for the old and new centers.

Also of interest is the ways people and firms are maximizing their utility. Are there models that approach the nonmonetary items that are glossed over in the AMM model? Rosen's (Rosen 1974) hedonic model has some clues: the undividable "bundle of characteristics" that comes with each property is a key. Urban sprawl is partly due to people seeking characteristics that the industrial city no longer offered: space, social status, and connection with nature (Calthorpe and Fulton 2001). Moreover, as these pressures built up in the industrial city, white flight was facilitated by new technology, the automobile. The more well-to-do had always inhabited the outskirts of the US industrial city (as seen in models by Hoyt (Hoyt 1939) and Park et al. (R. E. Park et al. 1925); now they had technology that unchained them from the urban core as the friction of distance was reduced, and a new spatial equilibrium function would need to be fit to the auto-centric city. That function is increasingly polycentric, with metropolitan areas developing regionwide sub-centers, central places that function as miniature CBDs—centers of economic and social activity, supported by land use diversity and intensity and well-connected to the relevant regional networks. These networks include transportation, business, industrial, and social networks. They are identified as sub-centers through fitting their density and intensity to a distance decay function that measures distance from the CBD.

Accessibility

At the center of theories of urban form is the need for people to have access: to goods, to jobs, to food, to care, to an abundance of varied places and the opportunities they afford. Accessibility holds an important key to the sustainability of the city. As we shall see, transit services are critically important in urban planners' efforts to address this key, by counteracting the over-dependency on the automobile, the peak-hour commuting congestion, the economic drain, and the health impacts that have resulted from sprawling urban development. Social equity also benefits from transit, as low-income households must have reliable access to jobs (R. B. Cervero, Guerra, and Al 2017). Even as autonomous vehicles begin to be a viable travel option, public infrastructure will still need to be efficiently built, and people will still need public spaces to bring them together. Automated vehicles will still benefit from less wear and tear. People will still need the ability to have active transport options available, such as biking and walking. High-efficiency locations will need active travel options to mitigate the effects of automobile congestion. Increased revenues due to transportation and land use efficiencies should be used to further increase non-automobile travel options, such as lanes and dedicated paths for bikes and neighborhood electric vehicles (e.g., golf carts).

One of a household's primary needs is to have access to a job that provides the necessary income, and this need makes transit critical to the health of low-income households. Indeed, transit is one of the main reasons low-income households live in the city, as the costs of car ownership and operation are very high (Glaeser, Kahn, and Rappaport 2008). Employment opportunities for low-income minorities are enhanced by well-functioning transit (R. B. Cervero, Guerra, and Al 2017). Kain and other urban scholars have argued that isolation from job centers is one of the key challenges facing minorities in urban neighborhoods, as it obstructs their accessibility to adequate employment opportunities (Kain 1968; Robert Cervero 1989; Stoker and Ewing 2014a). Moreover, car use is more expensive to society than is usually acknowledged. At present, car drivers are not paying near the true costs of the use of public road infrastructure; rather, they are being subsidized by government funding, along with the subsidies to oil companies that help to lower the cost of gas at the pump. If the true costs of car use were passed to the public, transit would look to many people like a more reasonable alternative (Moore, Thorsnes, and Appleyard 2007).

Job-worker balance depends upon accessibility, the ease with which various land uses and needed services and resources are accessed, whether through mobility or proximity (R. B. Cervero, Guerra, and Al 2017). The accessibility paradigm "facilitates the evaluation of tradeoffs between land use, transportation and social needs." Accessibility combines aspects of both transportation and land use, and thus takes a holistic approach. Mobility and proximity, the two main components of accessibility, are "in tension with one another." They need to be balanced in a land use-transportation system to increase accessibility. Over-emphasis of one or the other impedes accessibility. Transportation planning bodies with an accessibility orientation focus on a clear definition of accessibility; they also base policy and program goals on accessibility; and, they define priorities using accessibility measures. These include cumulative opportunity measures, gravity-like metrics, utility metrics or space-time prisms. This is in contrast with mobility-oriented (i.e., automobile-oriented) transportation planning bodies, which emphasize network-optimization metrics and focus on congestion reduction and travel speed increases (Proffitt et al., 2019). To re-emphasize, to focus solely on mobility is to the detriment of overall accessibility. Many urban challenges could be ameliorated through a greater emphasis on planning for accessibility.

> It is difficult to overstate the importance of *accessibility* in making urban living more affordable and socially just. Across the globe, urban residents typically spend more on housing and transportation than all other goods combined. Poor access drains the few resources the poor have at their disposal. In Mexico City, the poorest fifth of households spend about a quarter of their income on public transit. Those on the periphery face daunting commutes that last an average of 1 hour and 20 minutes in each direction. In the United States, where transit supply is sparse in most neighborhoods, limited accessibility prevents many low-income people from finding work, reaching medical services, or shopping at well-stocked supermarkets… Despite the importance of cities and their inhabitants, too often the form, shape, and even culture of cities have become the unintended consequence of policies and investments to improve mobility. Truly transportation has become the tail that wags the dog. Putting people and place back at the center of how and why we invest in urban transportation is essential to improving humanity's overall social, environmental, and economic well-being in the twenty-first century" (R. B. Cervero et al., 2017).

There is an increasing recognition that auto-dependent transportation and land use is becoming less tenable as urban centers grow. This is because accessibility is a duality between proximity and mobility, and there is tension between these two components. Mobility depends upon applying transportation technologies that attempt to overcome the friction of distance (i.e., the train or automobile), while proximity allows more active modes of movement such as bikes or walking, which require safe and highly connected transport networks. When planners and engineers have emphasized one over the other, the result has been a loss of the other, and thus a decrease in overall accessibility. Mobility has been a revolutionary force, reducing proximity across the globe, and winning the day for the last century. If allowed to function, a true dialectic process will eventually bring more balance between these two aspects of accessibility. One may hope for the pendulum to swing back towards proximity, which has been happening somewhat in recent years through sustainability theories in planning, such as Smart Growth. Whether this remains the trend is yet to be seen. Major disruptive innovations in transportation, especially autonomous vehicles, have many scholars and planners envisaging the future as one of ever-growing sprawl, driven by the increases in mobility granted by the new technologies. This challenge must be met and counteracted by asserting the evidence that reducing vehicle miles traveled (VMT) has many positive results that are urgently needed: the reduction of greenhouse gases, increased public health through more active transportation, the reduction of society's reliance upon the vehicle-as-prosthetic-device, the benefits of more efficiently allocated public infrastructure, and the ability of people to get out of their cars and interact with others in the public square.

Location Efficiency

Location Efficiency (LE), which is described by the EPA and HUD as increasing accessibility in a location, site or neighborhood to a mix of everyday destinations, in a compact configuration close to transit stations, thus providing a mixture of transportation and destination options. People can bike, walk, drive, or take transit across or between these destinations to get to a high diversity of land uses, such as jobs, housing, entertainment, offices, retail, parks, and so on (Adkins, Sanderford, et al., 2017; Location Affordability Index (LAI), 2018; Rose, Jonathan, 2011). Calthorpe (Calthorpe, 2011) highlighted the multiple resiliency benefits of LE sites, all of which will aid in cities' response to climate change and other sustainability issues, from housing affordability to water infrastructure efficiency. The American Planning Association (APA), the Congress for the New Urbanism (CNU), Smart Growth America (SMA), and many others have taken up LE as one key solution to many sustainability issues facing the U.S. at present. LE is a concept needing further empirical testing to set relevant thresholds, but it is informative as a concept for urban utility.

Sprawl, the antithesis of LE, is growing with suburbanization and having a negative impact upon the jobs-housing balance. As the third wave of suburbanization of the 1980s, when offices moved to the suburbs to match the earlier first wave (residents) and the second wave (retail), many expected the result to be a better jobs-housing balance, but in fact commutes have lengthened in general since then (R. Cervero, 1989). Advocates of LE are pushing for greater levels of polycentric development, with centers and subcenters of intensified activity, to counteract sprawl (K. Park et al., 2020).

While many studies have found that compact development reduces VMT (Ewing & Cervero, 2001, 2017; Sardari et al., 2018), Cao et al. (Cao et al., 2009) argued that causality must be directly established to be accepted. While the built environment has its influence, there may be a confounding presence from a self-selection bias. Plenty of people may choose a walkable neighborhood because they like to walk, rather than deciding to walk because the built environment encouraged them to change their habits. Ewing et al. 2008 demonstrated that compact development may cut VMT as much as 30%. A series of 38 reviewed studies demonstrated with 9 different methodologies that SS and BE effects can be separated and ***while self-selection played a role in walking behavior, the BE also had a separate effect on walking*** (Cao et al., 2009).

Spatial Autocorrelation analyses

Spillover or adjacency effects are evident in economic processes, such as the location of jobs and housing, and the value of real estate (Can, 1992). Spatial autocorrelation, or spatial dependency, is one of the factors that cause these spillover effects. This study will lean heavily upon the spatial dependency inherent in the phenomena it will investigate, namely job-worker balance through spatial clustering of each component, and the concept of accessibility as the ease with which we can traverse across space to needed destinations.

Moran's *I* tests evaluate the presence and magnitude of spatial autocorrelation or spatial dependency, which is a measure of how close things are more related to each other than far things, per Tobler's First Law of Geography (TFL) (Tobler, 1970). Many studies measure this phenomenon in order to remove it from spatial analysis models, as it has been shown to cause major errors in those models (Getis & Ord, 1992); Anselin and Griffith 1988; Arbia 1989; Stoker

& Ewing 2014). Others, however, utilize spatial dependency through various measures to capture spatial association, the tendency of phenomena to cluster spatially (Getis & Ord, 1992). Can (Can, 1992) asked whether neighborhood effects directly determine housing prices, or is there a variation of marginal attribute prices across neighborhoods? Rosen's (Rosen, 1974) hedonic price function (HPF) analyzes housing as a commodity consisting of a bundle of attributes and determines whether neighborhood effects detail a uniform or segmented housing market. The key is whether neighborhood differentials produce varying or uniform prices for a given neighborhood characteristic; the former indicates a single price schedule for the region, while the latter indicates a segmented market, with schedules lying within the supply structures of submarkets in the metropolitan area. Typically, HPF has utilized submarket delineations, running the HPF within each submarket separately, which approach Can (Can, 1992) deemed arbitrary, offering an extension of Rosen's earlier HPF model by including a spatially lagged dependent variable that captured adjacency effects from the price of nearby market counterparts. Submarket delineation is partly due to spatial dependency. Geographically- weighted regression likewise modifies the HPF by allowing the covariates' parameters to vary across space, thus capturing variation due to spatial dependency (Yao et al., 2017).

Distance is a key variable of spatial analysis, and biases often occur in distance metrics, whether due to the use of coarse measures such as Euclidean distance, or due to use of simple centroids to represent polygons. In some contexts that involve larger distances the biases are small, but shorter distances require correction of the bias introduced by traditional distance metrics. Frequently the literature has utilized population weights by which the centroid could be modified (Duque et al., 2007, 2011; Jackson et al., 2010). Recent research has offered an approach based on a probability density function to assign points to be used as representative of a measured population within a polygon. This is an important improvement for aggregated data sets in which the locations of individual observations are not provided. The probabilistic approach accounts for population spatial patterns within the polygon to find the most representative location in the polygon for that particular population (Mu & Tong, 2020). This present study uses small enumeration units (census block groups) to minimize distance biases and acknowledges the limitations of this approach.

Polycentric Urban Regions

Agglomeration economies are one of the main impetuses for the existence of cities and towns. Urban areas reduce production costs through spatial proximity, but are greatly obstructed by congestion, which a balance of jobs and housing, along with greater accessibility through the presence of public transit systems, helps to relieve. Central Business Districts were the engines of industrial city economies and the regional tie point with other regions' economic centers. Then, the rise of the automobile untethered the American economy from the CBD. Businesses, following households, then spread ever-further into metropolitan regions. Urban sprawl and low-density zoning have been an obstruction of agglomeration economies to the extent that they have hindered centering. However, many arguably over-built cities have also raised the specter of agglomeration diseconomies resulting from congestion and excessive land costs. This has led to the growth of polycentric urban regions, the theory of which assumes that the CBD is supplemented by a regionwide network of subcenters, locations of significant relative increases in the intensity of land uses and transportation infrastructure. The polycentric urban development model stands in contrast with the *Edge City* phenomenon identified by Garreau, in which large centers at the edge of metropolitan regions are disconnected from the CBD by vast distances filled with urban sprawl, and thus do not act much like interconnected subcenters that provide synergistic effects to the economy and workforce (Meijers 2005, Park et al. 2020). Moreover, the debate over urban form has benefitted from more clarity in defining polycentricity as a phenomenon distinct from low-density dispersed development (Ewing, 1997; Gordon & Richardson, 1997; Hajrasouliha & Hamidi, 2017).

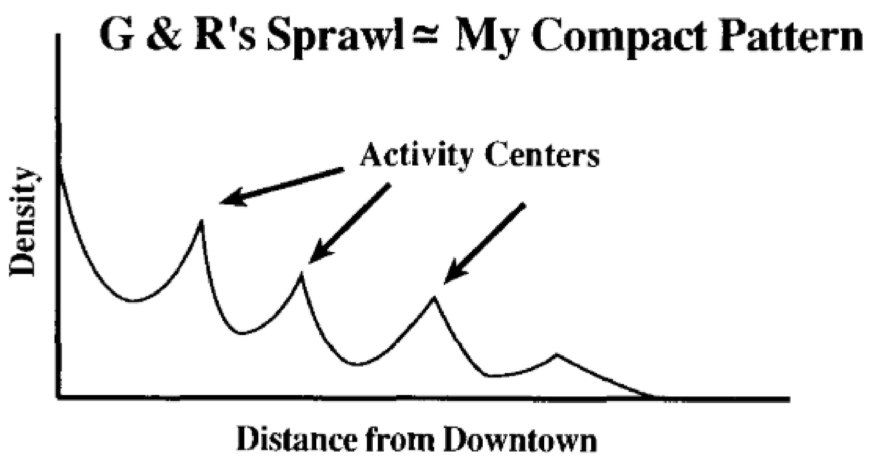

Figure 3. Ewing's clarification of compact polycentric development (Ewing, 1997).

To begin major execution of polycentric development, there is a need for greater implementation of quantitative criteria for defining centers in planning documents. To build metropolitan regions in more high-efficiency polycentric land use and transportation patterns, these criteria must be quantitatively defined. There is a gap in the literature involving this need for such criteria, in threshold format. Recent literature has produced some of the first threshold-based criteria for the 5 Ds of the built environment that create centers (Adkins, Sanderford, et al., 2017; K. Park et al., 2020). Job-worker balance is an important component of the polycentric development paradigm. Earlier typologies of centers evaluated centering on the bases of contiguity of enumeration units and minimum employment density thresholds.

Cervero and Wu (R. Cervero & Wu, 1997) found that the most salient challenge concomitant to decentralized and polycentric growth is "less spatial and more modal," consisting of higher vehicle miles traveled (VMT) caused by greater numbers of solo commuters. This result is only to be expected in metropolitan areas that do not provide sufficient (or any) transit-oriented polycentric development. Subcenters, which can be designed with higher density and land use mix, provide a basis for a regional transit network.

Transit-Oriented Development

Recent literature on Transit-Oriented Development (TOD) sums up the concept through fitting three broad characteristics in combination: "mass transit technology, efficient transportation, and high-density development" (Thomas & Bertolini, 2020). To this brief overview, some characteristics should be added, including high land use mix and accessibility areas with a range of housing and transportation options, which enhances affordability and resiliency (Calthorpe, 2011; Calthorpe & Fulton, 2001).

The myriad proposed benefits of TOD include greater accessibility to regional destinations and decreases in vehicle miles traveled, congestion, air pollution, and greenhouse gases. They also include increases in public health through more physical activity and socializing, increases in the range of mobility options, transit ridership and revenue, access to jobs, and higher property values. So far, however, there is a need for more evidence that TOD projects have increased workforce accessibility to workplaces and vice-versa. This study will work towards filling that gap.

Today's advocates of Transit-Oriented Development (TOD) tout its multifaceted sustainability solutions, and its particular strength in each of these areas; not least its ability to increase affordability for residents by reducing transportation costs through greater local and regional accessibility to multiple land uses, particularly employment centers, thus also increasing economic opportunity and workforce resiliency (Chapple & Loukaitou-Sideris, 2019; A. C. Nelson et al., 2019). Moreover, compact development may slow traffic but still bears positive transportation and accessibility outcomes (Shen et al., 2012). The increase of accessibility to local and regional opportunities, including both jobs and nonwork activities, is at the heart of the positive effects of transit systems, and particularly those with TODs. The literature shows that greater transit accessibility confers upon a property a value premium that is due to the reductions of travel costs, both in terms of lost time in congestion and the expense of automobile transport (Bartholomew & Ewing, 2011; R. Cervero, 2004; Ewing et al., 2018; A. C. Nelson & Ganning, 2015).

In the early era of urban and suburban streetcar routes, these routes were owned and operated by private companies and funded through sale of surrounding land parcels. This was the case in the US, as well as the London Underground heavy rail, and is still the case in Asian cities such as Tokyo and Hong Kong (Thomas & Bertolini, 2020; Warner, 1978).

In the age of the automobile, the transportation-land use connection still remains strong and has a direct influence on housing affordability (Giuliano, 1995; Handy, 2005) and employment opportunity (R. Cervero, 1989). TOD advocates point to its direct handling of these two issues and their interconnection as key to its merit. The impact of transit stations upon urban neighborhoods and upon transportation networks varies by transit mode (e.g., light rail or bus rapid transit); the amount, intensity and design of resulting development; and relative increases in accessibility to employment opportunities (R. Cervero, 1989; A. C. Nelson & Hibberd, 2019a; Thompson, Michael and Smart, 2017).

The profound challenges of TOD implementation include the design and policy complexity, the wide variability in market response among transit modes and real estate types, disjointed and uncoordinated local policy regimes, the challenge to design financially feasible developments, the population displacement and loss of affordable housing, unrealistic expectations for its revitalizing development outcomes, and the gap between market demand and the supply of TOD (Downs, 2005; A. C. Nelson & Hibberd, 2021a). These challenges vary widely between regions. A greater deal of coordination is needed between governing bodies at all scales—local, regional, and state—to be able to present a coherent policy regime that can also be tailored to regional and local contexts. The disjointed policy and planning regimes of US cities today cause decision making to be siloed (Downs, 2005). Transportation, land use, housing development planning are all conducted separately across a multitude of municipal, county, and regional governments, as well as private sector actors (Thomas & Bertolini, 2020).

The variables of project feasibility are a serious barrier, as well. Purchasing, compiling, and developing land and the real estate are major barriers to TOD (Chapple & Loukaitou-Sideris, 2019; Thomas & Bertolini, 2020).Tax-increment financing districts (TIFs) and density bonuses are helpful tools but must frequently be combined with many other tools to reach financial feasibility of TODs (A. C. Nelson, 2014; Thomas & Bertolini, 2020).

In sum, despite scholars and other actors having positively identified the main obstructions to the implementation of TODs, such policies and their implementation, and private land and real estate markets have not been transformed to alleviate these challenges. Further, one may argue that TOD has not been sufficiently widespread in implementation to determine the mechanisms and mitigating responses to transit displacement, or to test the validity of the theorized benefits, and that the barriers are too high to allow the market to respond to and test the efficacy of major innovations such as TOD. Uncoordinated regulatory and governance regimes seem to have combined against innovation.

Approaches to Place Typology

Three main constructs exist for transit-area place typologies, 1) situating the station in the context of the urban hierarchy, 2) characterizing the station's strength as a node in the transportation network and as a place with land uses that draw people in, modulated by the friction of distance, and 3) measuring the station's degree of interconnectivity with the surrounding neighborhood's transportation networks and land uses. An extensive review of these three paradigms is provided by Nelson et al. (A. C. Nelson et al., 2020).[5]

A recent place type analysis by Dr. Kristina Currans used the following indicators of the built environment to create types of transit station area places. They are listed under their data sources. These are found in the literature to describe the Ds of the built environment (Bartholomew & Ewing, 2011; Ewing & Cervero, 2001, 2010; K. Park et al., 2020):

Longitudinal Employer-Household Dynamics (LEHD, 2017)[6]

- Jobs per acre
- Proportion of jobs that are retail and arts

American Community Survey (ACS, 2017, 5-year)[7]

- Total population per acre
- Total households per acre

[5] Thanks to Dr. Kristina Currans for these insights on station typology.
[6] See https://lehd.ces.census.gov/. Accessed 4/30/2024.
[7] Visit https://www.census.gov/programs-surveys/acs/. Accessed 4/30/2024.

- Percent of households with no kids
- Percent of owner-occupied housing

Smart Location Database[8]

- Intersections per square mile
- Proportion of intersections with 3 to 4 vertices

Similar sets of variables are used by Ewing and Hamidi (Ewing, Reid, and Hamidi, 2014), the US Environmental Protection Agency (EPA 2021)[9], and the US Department of Housing and Urban Development (HUD 2021)[10] to describe the built environment in the context of urban sprawl, compact development, and location affordability. The analysis applied was Jenks natural breaks, with 5 categories for each of the above listed variables, breaking the distribution of each variable into rankings from low to high, scored from 1 to 5. These variables were then summed for each census block group and reclassified into four categories from 1 = most suburban to 4 = highly urban, or more precisely, from low to high land use mix and accessibility (A. C. Nelson et al., 2020).

Transit-Induced Gentrification

There is a recent but burgeoning literature debating the impacts of transit systems and TOD on gentrification and population displacement. It is related to the older branch of research related to hedonic evaluation of transit impacts on land value dynamics (Higgins & Kanaroglou, 2016). How closely and intensely is TOD related to displacement? Displacement is theorized to happen in course of the land bidding process:

1) A transit station is announced.
2) The increase in accessibility attracts businesses and households.
3) The competition for sparse transit-proximate land spurs a bidding process.
4) Higher resulting land values increase rents, forcing out lower-income households and businesses that reside in the neighborhood or excluding those seeking to locate in the neighborhood.

This theorized process holds true only if the competition is tight enough to spur an intense bidding process. Densities must also increase. This requires a strong and growing regional economy. Many stations suffer the opposite fate: no takers for higher-access parcels. Further, the bids must push up the price far enough to urge rent hikes that outpace the savings in transportation costs that come with the station's accessibility increases. Empirically, the research indicates that the effects of transit on land values vary (greatly) by transit mode, the length of

[8] See https://www.epa.gov/smartgrowth/smart-location-mapping. Accessed 8/25/2021.
[9] Visit https://www.epa.gov/. Accessed 4/30/2024.
[10] See https://www.huduser.gov/portal/home.html. Accessed 4/30/2024.

time that has passed since the announcement of the development of the station, the surrounding land uses and building types and their intensities, the design of the station area's built environment, the relative increase in regional accessibility and reduction of transportation costs conferred by the transit system, environmental amenities, the level of economic growth occurring in the region, and TOD-supportive land use policies, among other often omitted factors (Handy, 2005; Higgins & Kanaroglou, 2016; A. C. Nelson & Hibberd, 2019b, 2021a). In effect, much more than the creation of transit stations is involved in displacement risks for transit-proximate communities.

The literature on gentrification "eligibility" for neighborhoods cite the following criteria of neighborhood dynamics as risk factors (Chapple & Loukaitou-Sideris, 2019):

1) socioeconomic status - "low income"
2) disinvestment history - "inner city"
3) increase in median income
4) increase in educational attainment
5) percentage of white residents
6) investment indicators or proxies - e.g., property sales

These criteria are not all required universally in the literature. Chapple et al. (2019) argued that the literature for the US does not equally consider the impacts of public and private investment in neighborhoods as the drivers of gentrification; rather, it focuses more fully upon the demographic indicators of change. The literature, however, contains some helpful research regarding the impact of public and private investment (Anguelovski, 2015; Downs, 2005; Ewing & Cervero, 2017; Wolch et al., 2014; Zuk et al., 2018).

Investment usually arrives after a neighborhood reaches some level of economic viability. Lees et al. (Lees et al., 2008), for example, theorized the stages of gentrification, which begin on a small scale with "risk-oblivious" individuals who invest in a single property using their own toil and funds, primarily for a place to live (banks have redlined the neighborhood, so loans are unavailable). As the stages progress, redevelopment and popular interest progress sufficiently to attract investment in a neighborhood from more "risk-averse" private and public institutions, many of which had abandoned the area in earlier years. Disinvestment may prove to be the single greatest precursor to gentrification, but more research is needed to reach a conclusion. The literature on transit system investment is mixed in conclusions, but the empirical evidence—which still needs expanding—tends largely toward the conclusion that transit systems are not significantly displacing people.

Kim et al. (Kim et al., 2021) found that introduction of an LRT station in 12 different systems across the US between 2000 and 2010 resulted in greater labor participation without increases in median gross rent. This important study used control areas to compare to LRT stations as the treatment and showed that fluctuations in median gross rent were not due to LRT station proximity but were caused by other factors. This was determined by comparing the trend in median gross rent between treatment and control groups and finding no significant difference between them. Nelson and Hibberd (A. C. Nelson & Hibberd, 2021b) also found that minority population growth is robust very near transit stations of several transit modes (light rail, bus rapid transit, streetcar, heavy rail, and commuter rail transit), but that growth is not paired with significant income increases. Moreover, these trends comport with the findings of Delmelle et al.

(E. C. Delmelle et al., 2021; E. Delmelle & Nilsson, 2020), who found that low-income individuals are more likely to move, wherever their neighborhood may be. They found, however, that low-income individuals are not more likely to leave transit-proximate neighborhoods, after controlling for various confounding population characteristics. They further pointed out that metropolitan and local contexts significantly impact the trajectories of transit-proximate neighborhoods.

These trends do not support the concern over transit-induced gentrification. Some reasons for this may include small housing units near TODs and the savings in transportation costs accruing to location-efficient neighborhoods. They may also be due in part to municipal development tools as alluded to above, such as density bonuses or subsidies designed to alleviate rent pressures. These results hearken back to long-standing trends in studies of population migration dynamics, in which rates and propensities to move are based on a variety of household and regional characteristics. These include age, income, tenure choice, family size and events in the life course (e.g., marriage, job gain or loss) along with race and ethnicity, regional economic sectors, tax rates, and average commute time (Carrillo et al., 2016; Clark & Dieleman, 1996; Plane, 1993).

To the strong causal effects of demographic characteristics, we may add overall gentrification pressures. The larger concern, however, may go to those neighborhoods struggling with the most intense levels of poverty. Those neighborhoods rarely suffer from gentrification; rather, their struggle is with the negative externalities of poverty (Florida, 2017). Gentrification pressures are mostly suffered in "superstar cities" (i.e., major attractors of investment and super-urbanization) and in localized patterns of low- to moderate-poverty neighborhoods across metropolitan areas. Some neighborhoods may experience intense gentrification pressures, but that pressure can be modeled with a steep distance decay curve. This indicates a great deal of spatial heterogeneity within and between metropolitan areas with regards to gentrification pressures.

More consistent is the ongoing decline of many high-poverty non-gentrifying neighborhoods. "When all is said and done, chronic, concentrated urban poverty is a far bigger problem than gentrification and remains the most troubling issue facing our cities" (Florida, 2017).The poorest neighborhoods may suffer most not from gentrification, but from the need to address environmental justice needs: greater access to needed land uses—grocers, schools, medical care, jobs and transportation infrastructure—and greater protection from pollutants and dangerous land uses such as vacant parcels, dilapidated buildings, landfills and Superfund sites (Bullard, 2007). A greater problem for TOD may be a need to focus more on higher levels of "livability-opportunity-access," which improve quality of life, reduce carbon emissions, and result in lower transportation costs per household. Research has shown that these positive externalities of TOD have not been socio-economically inclusive (Appleyard et al., 2019).

Transit stations have been shown to increase access without exerting significant financial pressures upon residents. The more than 4,000 transit stations across the US present massive land opportunities for transit authorities or private companies that wish to fund transit through the time-tested means of transit-area real estate development, just as is done at large scale in Tokyo and Hong Kong, as well as in Australia, the UK, and even South Florida and Denver, Colorado (Renne, 2017).

From the literature, some questions arise requiring further research.

- What are the mitigating or inducing factors of TIG-related displacement? In cases of TOD without TIG, what was the planning process, the civic involvement, the investment approaches? When do other public or private investments—greenways and bike lanes, and so on—not induce problematic increases in rents and property taxes?
- Do gentrification studies consider the tradeoffs between housing and transportation costs? What are the strongest offsets to higher rents? Is there an average rate of tradeoff between housing costs and transportation costs that occur in TODs, which can be used as a threshold under which housing cost increases should be kept?
- What about regional differences in regionwide location efficiency? Does a widely distributed transit network help reduce gentrification? Does the distribution of firms, housing by type, and greenways or green infrastructure help reduce gentrification? Are there ownership & lending frameworks that could support an anti-gentrification market?

The Basis for Choosing TOD in an Auto-Driven Society – Relative Market Efficiency & Bounded Rationality

The decisions made by households and firms are based on tradition and culture, as well as (or perhaps instead of) what is most economically beneficial. Agglomeration economies have driven the rise of cities across the globe, increasing wealth and well-being overall, but the struggle between mobility and proximity has been won by the former as far as the constraints upon our mobility infrastructure will allow (Glaeser, 2011; A. Nelson et al., 2015). We are now facing the diseconomies of agglomeration in many places, and the will to improve upon this situation is obstructed, not just by economics, but by the limits of our ability to come to a reasoned course of action as a society.

Some of the challenges we face in implementing more efficient urban form include a lack of understanding of the following: The auto mobility revolution has not been free of cost, nor has it been driven solely by private action, despite its cultural fetishization as an icon of the independent American spirit. It has been supported by massive federal subsidies to build highways and single-family housing units. Add to this the high per-unit cost of utilities and other public infrastructure to the homes and businesses of the vast sprawling areas of the suburbs and exurbs across the country. This has not resulted in greater accessibility for all segments of society. Instead, the automobile-as-prosthetic-device has become a minimum requirement for households to function at a basic level. Nonetheless, the great American suburb can be upgraded with higher accessibility, rather than replaced, to the benefit of all (Dunham-Jones & Williamson, 2011; A. C. Nelson, 2013b)

Certain segments of American society viscerally reject the implementation of transit and compact urban spaces. They cite the cost of such development and the perception that they will lose the autonomy and liberty of mobility gained by auto use. At present, the notion of transit-oriented development pushing aside the auto-driven suburbs is beyond the realm of feasibility. In the cities with the highest transit use, being Boston, Chicago, New York, San Francisco, Seattle, and Washington, D.C., mode share was just above 5% before the pandemic decline in ridership.[11]

The automobile has dramatically changed the entire world. According to a recent report by the Transportation Research Board, in the years of the 21st century, in which transit systems have been increasingly advocated and implemented across the US, the overwhelming majority of transportation miles have been traveled in light-duty passenger vehicles, with aviation taking most of the remaining mode share. Commercial buses capture a minute fraction of mode share, with transit capturing a liliputian blip (National Academies of Sciences, Engineering, 2024). Yet, as research has shown, congestion is greatly reduced by the presence of transit systems (Anderson, 2013). This certainly improves the liberty of movement for the modern American.

The job-worker balance and the attraction of the market toward TODs depends not only upon the relative accessibility benefits, but also upon the choices of individual households and firms regarding where to locate their real estate. The rationale for decisions people and firms make influences strongly the outcomes of their market searches and activity.

The neoclassical economic theory's long successful implementation is evident, to the immense benefit of industrial societies for generations. However, such models are always simplifications of reality; as such, they should regularly be re-evaluated and improved where possible. The neoclassical theory's main principle stems from instrumental rationality, or mechanical rational choice, which rests upon the assumption of utility maximization, which can only be made when the market itself is run efficiently—with all actors having perfect market information, the ability to easily enter and exit the market without transaction costs, and where many buyers and sellers are present and are internalizing their externalities, both positive and negative. These assumptions are the basis of the optimal (theoretical) market situation, but like so many other assumptions of models and theories, are neater and simpler than the reality on the ground. Excess stock, monopolies, the cost of insurance or legal services, insider or insufficient information, free riders, and the like often obstruct the optimal and efficient function of the market (A. C. Nelson et al., 2017).

In relying upon the neoclassical theory scholars neglect key realities, including the difficulty of implementing rational utility maximization, and that as a general rule, "the higher the stakes, the less often we get to do something," such as choose where to live or locate our firm. That infrequency leads to the bad judgment of inexperience. "Either the real world is mostly high stakes or it offers myriad opportunities to learn—not both." Further, the literature shows that increasing the stakes of a decision does not lead humans to make more rational and optimal decisions (Thaler, 2016).

The alternative is behavioral economic theory, which incorporates the limits of human information gathering, analysis, and reasoning. It assumes that we rely to a significant degree upon emotion and casuistic reasoning in decision making, rather than the assumption that our actions stem from rational decisions that lead to an optimal set of choices (Selten, 1990).

[11] Rowlands, DW, and Tracey Hadden Loh "Ensuring the intertwined post-pandemic recoveries of downtowns and transit systems." Brookings. https://www.brookings.edu/articles/ensuring-the-intertwined-post-pandemic-recoveries-of-downtowns-and-transit-systems/. Accessed 1/14/2024.

Critiques of behavioral theory analysis include the difficulty of operationalizing it, plus the neglect of structural constraints, such as obstacles placed by institutions (Cadwallader, 1975)

Bounded rationality is the theory that people operate upon limited information and distorted views of reality in their decision-making, and that their behavior is built typically upon their perception that their choices are rational, but they do not always achieve rational decisions because of a lack of information or a simplified and distorted understanding of the world (Cadwallader, 1975).

For transportation geographers and planners, spatial perception and behavior is an important area of study. Scholars have done important studies on environmental perception, measuring such phenomena as designative and appraisive aspects of spatial perception. Appraisive perceptions of space attach cultural value and emotion to places, while designative perceptions attach general characteristics to places (Lopez & Lukinbeal, 2010; Lynch, 1960). Others have worked on the question of cognitive distance, which is a measure of the individual's subjective perception of distance (Cadwallader, 1975). This mental perception is what people typically act upon, rather than an objective measure of distance.

Satisificing theory asserts that actors such as planners, developers and consumers may settle on satisficing by making choices based on a limited, bounded rationality utilizing a locally bound set of information and a desire to fulfill aspirational goals, or act on intuition or irrational alternative criteria not considered by the neoclassical economic tradition. Moreover, they often settle on a heurstically-made and suboptimal choice that minimizes physical and mental energy and time spent in the search. The same decision-making criteria hold true when the influence of other actors in the market is considered. Satisficing decisions are made upon the basis of the characteristics of the organism, such as their ability to adapt to situations, but also upon the basis of the structure of the surrounding environment. Therefore, the structural characteristics of the environment will influence an organism's adaptive (satisficing) decision making process. (D. C. Read et al., 2019; Simon, 1956).

There is a need for greater focus in the literature on the satisficing nature of decisions in regards to housing and transportation, which have long been theorized as existing in a tradeoff relationship in the Alonso-Mills-Muth (AMM) model (Alonso, 1964; Mills, 1972; Muth, 1969) and preceding theories: if the drive for more land is greater than the need for a centralized location, people will trade less accessibility for more land, and vice-versa. Some locations, moreover, involve further tradeoffs that reduce a household’s access to nonhousing goods such as food or health care.

However, these theories have not conceptualized these tradeoffs as bounded heuristic choices made in the presence of an inefficient market. The local maxima of heuristic searches resulting from the bounded rationality basis of satisficing decisions include imperfect, irrationally-based and inefficient tradeoffs between housing, transportation, nonhousing goods and other nonmonetary characteristics. These decisions are casuistic in nature; they rely upon making extrapolations from distinctions between small numbers of cases based on simple decision rules. They are also contingent, qualitative, superficial and small in nature, relying exclusively upon easily obtained information within the limits of the motivation level of the actors (Selten, 1990).

Satisficing decisions, the heuristic searches mentioned above, are often continuous and discrete at the same time, but may not get modeled or even theorized as such. An example is mode choice and time of day for a commute to work. Further, many such choices have to be made jointly. One example of a set of joint continuous-discrete decisions consists of the selection of a structure's size and its regional location. Because these decisions must be made at the same time and place, they are made jointly, and cannot be separated. Rosen (Rosen, 1974) acknowledged that the individual attributes in the "bundle of characteristics" possessed by a given structure could not be separated from each other, as others had previously modeled them (Lancaster, 1966). These complex trade-offs are made frequently without the requisite information needed, and therefore often result in inefficient outcomes.

Also important to the question of the efficacy of TODs is whether self-selection has biased studies that indicate that compact development directly reduces VMT. Is the decision to drive less caused by living in a more walkable TOD, or is do people choose TODs because they already want to walk more and drive less? Studies show that self-selection is a factor, but that taking this bias into account, people are still driving less because they moved to a TOD (Cao et al., 2009).

Conclusion

Addressing the need to increase employees access to work and firms' access to workers requires first understanding the city as a complex system with many key attributes. To function well, the city must include a myriad variants of housing, employment, amenities, functions. For the transportation system to optimally function, it must be coordinated with the built environment and a host of different types of land uses. There must be diversity in land uses at a human scale in neighborhoods that connect well with their surrounding blocks. This requires smaller city blocks and lots of intersections. It requires a road and street hierarchy that serves all transportation modes safely. There must be public spaces. There must be a sufficient density to support active transportation and transit. Destination accessibility must be adequate to support efficient daily activity by the workforce.

To build such a city, the very sinews of human cooperative institutions must be stretched and their capacity expanded. This also requires behavioral models that can predict human economic choices. Such efforts have their limitations, however, and the number of people advocating for incremental approaches to urban policy and development are growing. Indeed, bounded rationality and the limits of human capacity urge us toward incremental movements. Time frames in planning are long. The behavioral theory of economics is giving us a more accurate view of human perceptions and activity, and their impact on the market. It is also highilghting the need for agents to have access to high levels of quality information for decision making.

On the other hand, the principles on which JWB is grounded have a sufficient evidence base at present to suggest that efforts to develop urban areas using locatin efficient principles are not entirely whimsical. They may not be the panacea some advocates tout them to be, but so far there are positive results accruing from our efforts to address urban sprawl, spatial mismatch, and expensive, inefficient auto-centric urban form.

The scholarship on urban form and economics has produced some promising theories, as well as empirical results. So far, the polycentric urban region configuration can improve on the efforts of sprawling/edge city developments to increase access to all of the attributes of the region, from higher agglomeration levels at multiple centers, to better access to cheaper land. Centering with an added emphasis on regional connections between centers turns sprawl into agglomeration without the excess density of a large monocentric city. Regions with multiple interconnected centers can expand opportunities for households and firms to locate in compact and relatively high-intensity places where they can interact with many kinds of land uses and people, all while avoiding the extremes of agglomeration diseconomies, specifically congestion and overpriced land.

Gentrification due to transit stations does have its effects, but displacement is less likely in smaller regions than the big city. Fears of low-income or minority populations getting pushed out of a transit station neighborhood solely due to the introduction of the station itself have been unfounded in most cases. Larger development trends in our urban centers and the global economy's local impact may have a substantially greater impact on land prices than TOD (Florida, 2017).

As transit systems are further constructed across the country, careful implementation will likely increase location efficiency and accessibility, particularly between workers and their jobs. This does not mean that the liberty of modern Americans to hit the open road in an automobile will be curtailed; rather, the agglomeration economies and returns to efficiency in our infrastructure will make us better off. Indeed, the economies of scale and centering may well restore the open road to our congested cities.

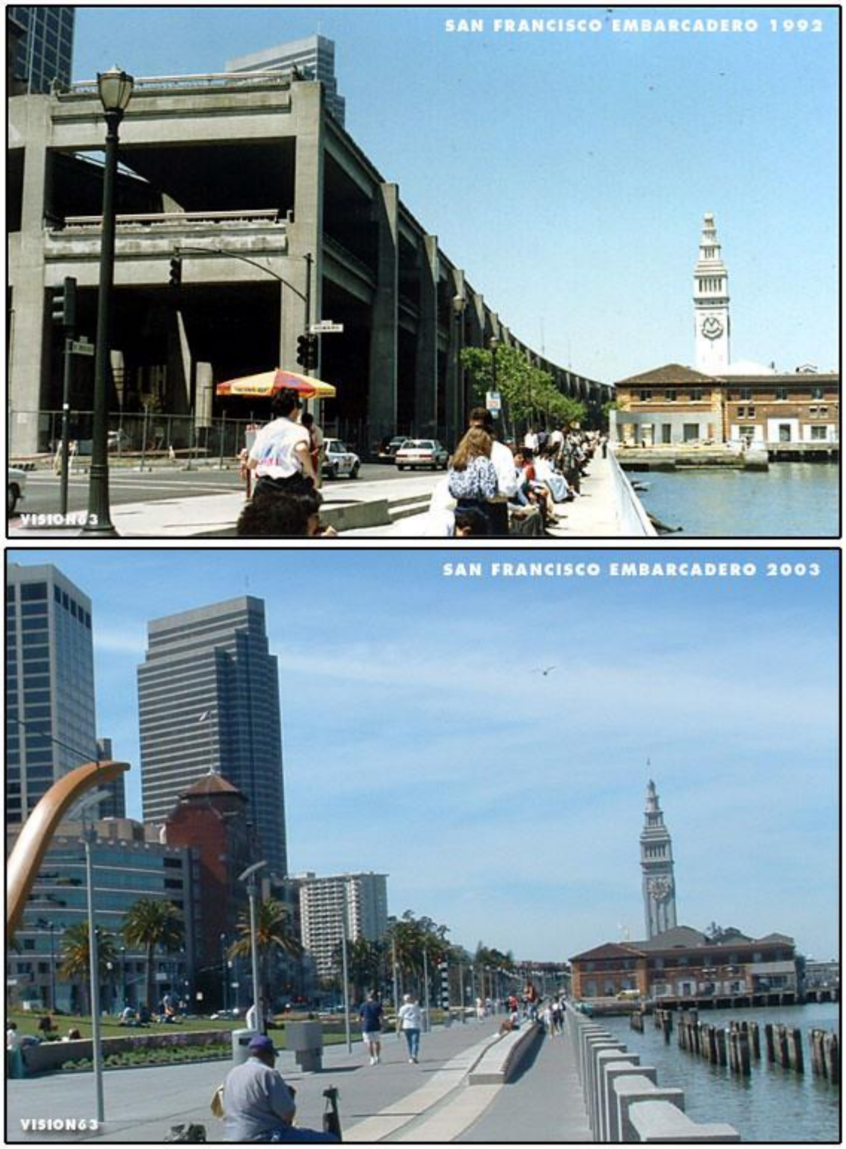

Figure 4. Embarcadero before and after freeway removal. [12]

[12] Russel Mondy, Flickr. https://www.flickr.com/photos/v63/228932719. Accessed 1-3-2024.

Job-Worker Balance – Refining JHB Theory to Elevate Transportation and Land Use Policy

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Highlights

- Proposes JWB theory based on internal capture of work trips within a commute shed.
- Demonstrates efficacy of income match in influencing JWB to reduce VMT.
- Presents useful best practices and pitfalls of OLS and SAR regression methods.
- Empirical positive association between polycentric design and internal capture.

Job-Worker Balance – Refining JHB Theory to Elevate Transportation and Land Use Policy

Jobs-Housing Balance (JHB), the balance between the number of homes and the number of jobs in a prescribed geographical area, is the subject of a large literature. This article updates standard JHB theory which fails to link land use and transportation policy. A more accurate metric, job-worker balance (JWB), is defined as a measure of accessibility for both workers and their job locations. JWB is the colocation of workers and the firms for which they work within a context-appropriate commute shed. After presenting the JWB theory and showing its superiority to JHB, the article crafts JWB metrics that are applied to the Denver metropolitan area. The analysis includes determining the appropriate explanatory variables based on valid empirical metrics through ordinary least squares and spatial regression analyses The paper concludes by finding for the Denver metropolitan area, a 3-mile commute shed is best at internal capture of work trips as it is positively associated with the jobs-labor balance ratio, income match, proximity to transit, and the degree of centering, land use mix, and accessibility. Various statistical tests address spatial heterogeneity, autocorrelation, and heteroskedasticity. The method can be applied elsewhere to estimate appropriate JWB commute sheds.

Keywords: Jobs-housing balance, jobs-worker balance, transit-oriented development (TOD), internal capture, income match, spatial mismatch, jobs-housing fit, polycentric development, spatial autoregressive modelling, land use mix and match

1. Introduction

As cities and suburbs have grown, planners have noted that many populated neighborhoods are spatially isolated from job centers. This increases the burden of commuting and negatively affects the employment rate in a neighborhood. The automobile has profoundly increased human mobility. Auto-centric suburbanization, in turn, has greatly changed the spatial structure of the metropolitan area, pushing many land uses farther and farther away from each other. Notwithstanding the mobility explosion granted by the automobile, the concomitant land use trends have led to ever-longer commutes at ever-greater distances traveled, and at increasing expense.

Jobs-Housing Balance (JHB) policies attempt to bring people and jobs closer together; they seek to bring jobs-rich, housing poor areas more into balance by adding housing; and housing-rich, jobs-poor areas into balance by adding jobs to the area. However, the underlying theory has led to the use of metrics that are misleading and do not produce the desired policy decision basis. As will be discussed, a balance in raw numbers of housing units and jobs does not lead directly to shorter commutes, to public transit use, or to more active modes of transportation. As such, the theory and concomitant metrics need to be refined.

The desired balance underlying the JHB theory requires accessibility at the level of the individual worker or firm. Metrics that accurately measure the phenomenon will reach specific objectives: first, they will identify degrees of accessibility for individual workers to their workplace; second, they will identify accessibility levels for individual workers classified by income and job sector. Third, they will identify the degree to which a geographic area provides a firm with housing attainable by its employees' wage levels. The article will propose an accessibility-based approach to measuring the degree to which people and their jobs are able to co-locate in space.

Job-worker balance (JWB) is a refinement of JHB theory, which has been a key goal of the normative transportation planning literature. JHB has been operationalized as a raw balance of workers' housing and jobs by location, and sometimes converted into ratios of jobs per household, which is acknowledged as only the potential for balance. However, when the relationship between workers and their workplaces is modeled as internal trip capture it indicates the degree of job accessibility in a commute shed, which is a defined optimal zone or distance from home in which captured commutes both start and end. In the literature, it is also referred to as "self-containment" (R. Cervero, 1989, 1996). JWB as trip capture is measured for each individual worker as origin-destination pairs between home and the workplace to identify the proportion of commutes that occur within a commute shed. Yet, this refinement of JHB, itself very rare in the literature, needs further refinements, which the article will discuss below.

There is a discontinuity between JHB and JWB as internal capture. Figure 1 demonstrates this issue. It is a bivariate map of jobs-housing balance index and short commute index, which presents a visualization of the geographic patterns revealed by a cross-tabulation of the two indices. Each index provides a ranking of highest to lowest values of the variables for the Denver metro area. CBGs that are yellow or blue indicate a high score in only one of the two indices; brown indicates high scores in both indices. The map demonstrates that the indices are not perfectly correlated; many CBGs that are high in one index are low in the other index. This pattern suggests a need to refine the JHB literature. While there is a correlation between JHB and reduction of the costs of commuting in the literature, the variation in this relationship across a metro area can be considerably non-stationary. This tells us that high values of JHB do not lead to short commutes. The B+T Index, shown in figure 2, ranks jobs-housing balance (the "B") and commute time less than 15 minutes (the "T") for the Denver area from highest to lowest and normalizes the rankings to a scale from 0 to 100. The map shows that the majority of CBGs score less than 35 on the index.

The goals for the paper are to recommend an updated theory of JWB, based on recent literature, which should be defined as the colocation of homes for workers of all wage groups and the firms for which they work within a context-appropriate commute shed; also, to review the literature about the variables, methods, best practices and pitfalls of the search for valid empirical metrics; and, provide a spatial regression analysis of JWB in the Denver metro area that helps further our understanding of the interaction of the T and the D in TOD, or Transit-Oriented Development, a paradigm based on the interaction between transportation and the built environment (BE) (Thomas & Bertolini, 2020). In the process of the analysis, we will discuss best practices for dealing with spatial heterogeneity, autocorrelation, and heteroskedasticity.

The hypothesis for the study is that internal capture at a 3-mile commute shed will be positively associated with the jobs-labor force balance ratio, income match, proximity to transit, and the degree of centering, land use mix, and accessibility. These characteristics will be discussed below.

The next section of the article reviews the JHB literature. This is followed by formal development of the JWB theory and its extension to transit-oriented development (TOD). The paper continues with a research design that is applied to the Denver metropolitan area as a proof-of-concept. Results are presented followed by a discussion of implications of the results for transportation and land use policy.

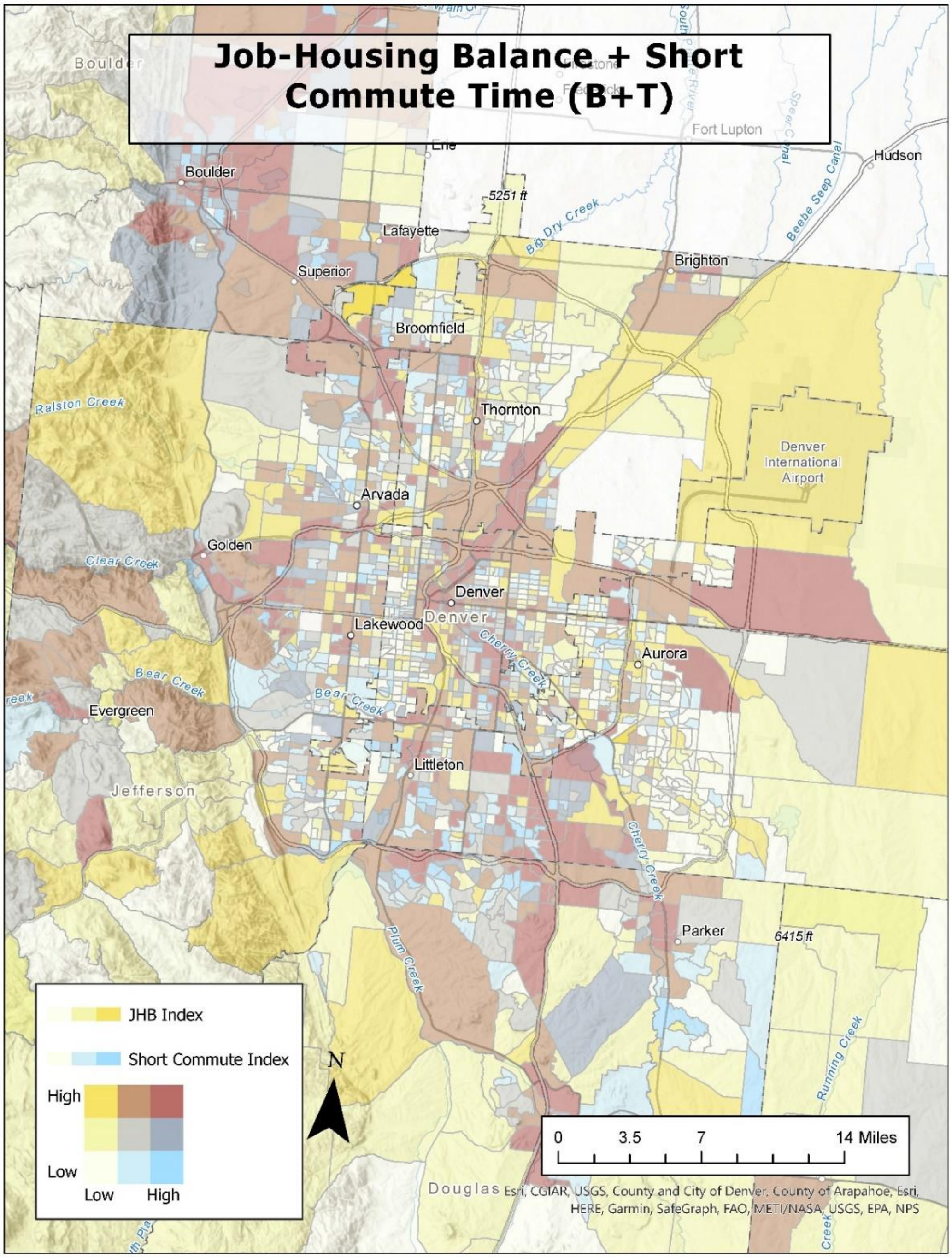

Figure 5. Bivariate map of jobs-housing balance index and short commute index.

The map demonstrates that the indices are not perfectly correlated; many CBGs that are high in one index are low in the other index. CBGs that are yellow or blue indicate a high score in only one of the two indices; brown indicates high scores in both indices.

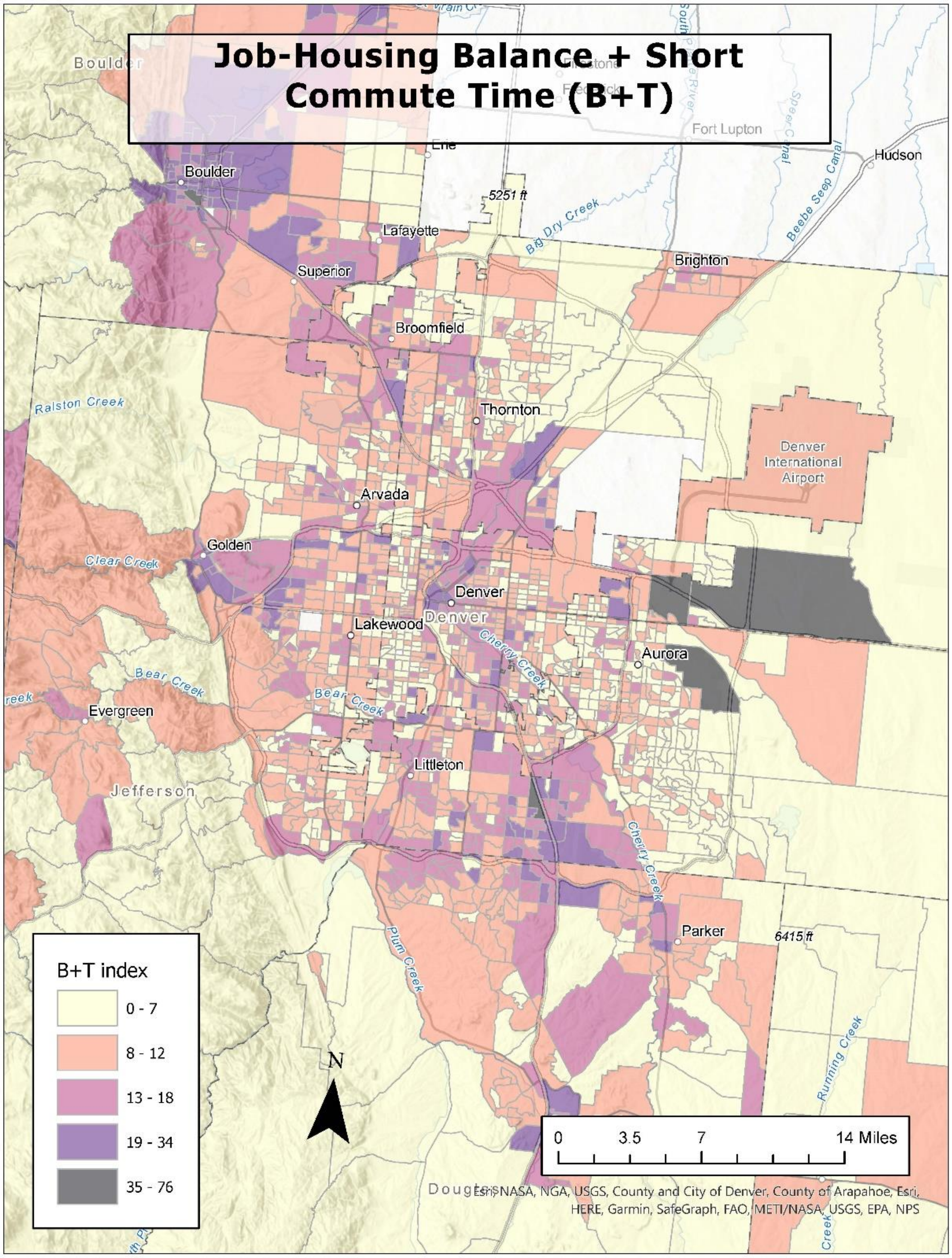

Figure 6. The B+T Index ranks jobs-housing balance (the "B") and commute time less than 15 minutes (the "T") for the Denver area from highest to lowest and normalizes the rankings to a scale from 0 to 100. The map shows that the majority of CBGs score less than 35 on the index.

2. Literature Review

The genesis of interest in jobs-housing balance emanates from work pioneered by John Kain that is characterized as the spatial mismatch between where lower-income people live, where they work, and highlights the travails they endure to make a living (R. Cervero, 1989; G. Galster & Cutsinger, 2007; Ihlanfeldt & Sjoquist, 1998; Kain, 1968, 1992). Massey & Denton (1993) show empirically that black Americans, as an important example, have been highly isolated throughout the 20th century, diminishing their access to employment. Moreover, the spatial pattern persists. Where they ended up in the city reflects the complex, and in some cases, endogenous phenomena involved in the economic, social, and cultural life of the city.

The spatial mismatch hypothesis (SMH) has evolved into a literature focusing on jobs-housing balance (JHB). Policies with this approach in mind seek to balance local numbers by locating jobs and housing in close proximity. (R. Cervero & Duncan, 2006; Weitz, 2003). JHB operates under the assumptions that there is a widespread shortage of affordable housing near employment centers, and that workers will be willing to live near workplaces when they are able to find housing within their price ranges. It is also an issue of policies of land use and transportation; particularly development, zoning, land use mix restrictions, and auto-centric transport systems (Levine, 1998; Weitz, 2003).

The JHB construct is too simplistic, however, because of its focus on ratios of raw numbers of jobs to housing units but not the level of data resolution needed spatially, let alone identifying the appropriate classifications of jobs by sector or wage levels. These limitations are noted by Stoker and Ewing (2014). Some studies, for example, compare commuting times or distances across racial categories. Sultana (Sultana, 2002) found that employment spatial patterns exhibited racial segregation in certain parts of the Atlanta metro area. Black workers in Atlanta have longer commutes from the central city than other groups because low-status jobs are found largely in outlying suburbs. In southern Atlanta, White workers held a much larger portion of the jobs than of the local residences. These spatial patterns of segregation led to longer commutes to workplaces in these areas. Hu (Hu, 2019) found that in Los Angeles there exists a disparity in the relationship between job accessibility and probability of employment across various racial/ethnic categories. White and Black access to jobs is not related to employment probability, while access has plausible and significant effects among Asian and Hispanic workers. This pattern would likely differ in other metro areas across the US.

Efforts to refine JHB have attempted to correlate job accessibility with workers' wages, occupation sectors, skill levels, or the rate of employment of an area's workers. These include Sultana, (Sultana, 2002) who concluded that average commute times are longer for workers in areas where housing costs do not match their income levels; job sector and, as stated above, racial categories also correlated with longer commute times. Stoker and Ewing (Stoker & Ewing, 2014) used a dissimilarity index to quantify the degree of match between employees by wage level and housing by cost—which they labeled income match—and found that job accessibility increased as income match increased. Other research also found workers' job sector, wage and skill level, and an area's employment levels, to be highly relevant (Blumenberg & King, 2021; Blumenberg & Siddiq, 2023; R. Cervero, 1996; Immergluck, 1998). This literature indicates that the ties between jobs and workers are much more nuanced than the JHB theory explains. This calls for an updated JWB theory that incorporates accessibility by job sector, wage, and skill level.

Other studies have attempted to link accessibility of central city and suburban labor markets to employment outcomes, with the complex nature of the city obstructing the comparison. While critics such as Ellwood (1986) argued that "race, not place" was the reason for urban poverty, Kain's original hypotheses centered the issue on geographic isolation from work as a key result of racial discrimination. Ihlanfeldt (Ihlanfeldt et al., 1998) found that the literature comprised four categories for testing the SMH. These include 1) commuting times by race, 2) correlation between wages or employment and job accessibility, 3) discrepancies in the labor market between suburbs and inner city, and 4) job vacancy. They found that the SMH also functions within the trade-off between the cost of land and that of commuting, which is integral to classical urban economic theory. From the literature, they concluded that individual metro areas must assess the degree of severity of spatial mismatch within their individual regions; that the existing literature has not discovered the cause of the mismatch aside from accessibility in general; and that mismatch patterns are now affected by class-based, as well as racial, segregation. Their policy prescription categories are broken into the two components of accessibility: those that improve proximity, and those that improve worker mobility.

Many studies also emphasized the need to address multifarious other issues regarding accessibility, labor markets, and employment outcomes: accessibility via different travel modes (coined the "modal mismatch"), the effects of transportation infrastructure and residential segregation, and the effects of demographic controls such as poverty, gender, and the size of the workforce in a geographic area (Blumenberg & Manville, 2004). Others argued for the need to account for the ratio between job vacancies and local potential applicants, and the match of skills between an area's jobs and its local workforce (the "skills mismatch") (Browne, 2000; Kasarda, 1988).

Early studies measured JHB temporally. Others used longitudinal approaches to measure the degree to which growth in jobs matches growth in housing units (Weitz, 2003) within arbitrarily prescribed spatial units. For instance, Cervero (1989) estimated a rule of thumb for jobs-housing matchup in a subregion, using a 3- to 5-mile radius from homes to workplaces as the standard. Multiple distances have been cited as rules of thumb in the literature. Some research (A. Nelson et al., 2015; Putnam, 2000) recommends an alternative of travel time to work. Brookings noted that a 90-minute commute would, on average, give low-income suburban neighborhoods in the US access to just 25% of metro area jobs, which drops to a 4% share if commute time drops to 45 minutes (Kneebone, 2017).

Many studies on JHB attempt to identify the optimal commute time or distance for each region, the commute shed, as a spatial context. Cervero and Duncan (Robert Cervero et al., 2008) used a variant of cumulative-opportunities analysis (an accessibility measure), summing jobs within 1-mile distance bands around residents' locations, choosing the best-fit distances as the optimal regional commute. Schleith et al. (2016) use the transportation problem to delineate the minimum and maximum optima for commute distance in a given metropolitan area as baselines for observed commutes, to determine the *excess commute* (EC) for each metropolitan area. Park et al. (2020) tests which jobs/housing ratios produce the most optimal outcomes.

The literature varies on what functions as an appropriate jobs/housing ratio. Two highly cited studies suggest a range of 0.75 to 1.25 (Margolis, 1957), or 1.5 (R. Cervero, 1989). Nelson et al. (A. Nelson et al., 2015) notes that due to the varying size of households, and the fluctuating number of workers per household, a job-worker balance is a preferred measure, which is what this paper theorizes and formalizes.

A zonal definition is also needed for the ratio. To reach an optimal economic production level, one researcher argued, a labor market-shed (or commute shed) of 30 minutes is not as optimal as 60-minutes, due to the sprawling nature of many urban areas (R. Cervero, 2001). Stoker & Ewing (Stoker & Ewing, 2014) based their analysis on a cluster of census tracts consisting of those tracts within a 3-mile buffer of a given census tract, as a general distance. Benner and Karner (Benner & Karner, 2016a) argued that a hard distance threshold is easily interpreted and provides clear counts of affordable housing units. Cervero (R. Cervero, 1989) estimated a rule of thumb for jobs-housing matchup in a subregion, using a 3- to 5-mile radius from homes to workplaces as the standard. Nelson et al. (A. Nelson et al., 2015) recommend an alternative of travel time to work of 10 minutes or less.

As we move away from the simplicity and limitations of JHB, we aim to frame JWB as a measure of spatially small-scale internal capture because this gives us the degree to which workers both live and work locally. Ewing and Cervero's (Ewing & Cervero, 2010) highly cited meta-analysis acknowledged internal capture as important to travel outcomes research but could not include its study in a meta-analysis, given insufficient prior research articles. Internal capture is not mentioned in Aston et al.'s (Aston et al. 2021) update to Ewing and Cervero's meta-analysis, which is consequently framed as an analysis of built environment (BE) impacts on transit use, rather than the larger context of "travel" that Ewing and Cervero (2010) used. The built environment (BE) here refers to the density, intensity, design (including scale), and diversity or mixture of roads, intersections, city blocks, land uses, and other dimensions of human-built spaces and places. This distinction between travel and BE is important, as the BE is the context in which travel occurs, and can affect which travel modes are feasible, and to what degree land uses can be accessible via proximity.

Also missing from the literature is income match and a similar index, the jobs-housing fit (Benner & Karner, 2016a; R. Cervero, 1996; Stoker & Ewing, 2014). This fit or match refers to housing costs that fit the wage level of those people who work in the area. Stoker and Ewing (Stoker & Ewing, 2014) demonstrate that internal capture can be explained in large proportion by income match. Recent research has shown that housing affordability is a major factor in whether a worker both lives and works in the same jurisdiction (Benner & Karner, 2016a). The greatest obstruction to housing affordability may be the inability to supply enough (attainable) housing units, especially in the best, most optimal locations. Cervero (R. Cervero, 1996) found that housing-rich cities were more balanced than job-rich cities. "Jobs-rich" has become synonymous with "housing cost burdened."

Commute shed measurement is important for its measurement of internal trip capture, defined as workers both working and living within the same commute shed. The results of such measurements are highly dependent upon the scale at which the commute shed itself is measured, which is itself highly dependent upon which travel mode is considered. A walking commute is far smaller in spatial extent than an auto commute. Land use mix and regional accessibility levels account for a significant proportion of intrazonal trips (Bhatta & Larsen, 2011). The trick for JWB theory, modeling, and application is to estimate the spatial extent of a commute shed that meets specific, objective criteria. This is discussed next.

2.1 The Interaction Between JWB and TOD Theories

JHB only measures raw counts of jobs and housing in each geographic area usually in terms of ratios. For our purposes, we find that some of the travel outcomes literature has used trip capture to operationalize JWB, a balance between workers and housing, through zonal (commute shed) metrics that derive a ratio of the workers who live there and the jobs to which they commute in the same zone. This is the key to JWB theory.

Similarly, a key policy goal of Transit-Oriented Development (TOD) planning and policy is to maximize internal trips within the TOD zone, largely through the design of the built environment (BE) – the density of street intersections and the scale of land uses, for example (Gulden et al., 2013). This leads to trip generation reductions, sometimes substantial in nature, varying by destination land use (Clifton et al., 2015; Ewing et al., 2011). Trip generation rates in TODs have been measured at as much as 40% reduction (or more) from expected rates from the suburban-calibrated ITE trip generation metrics, and particularly at peak hours (R. Cervero & Arrington, 2008). Metrics vary by the zone or size of TODs, however, which range typically between one quarter mile (400 meters) to one-half mile (800 meters) (Guerra et al., 2012) or even one kilometer (A. C. Nelson et al., 1997). Some have even argued for one mile (1600 meter) or larger capture areas for TODs; policy regarding allowable density of businesses and housing, parking supply and other BE design issues hold an influence on the optimal zones of TODs (Canepa, 2007). Logically, the larger the zone the higher will be the capture rate. The question we aim to resolve below is how large should the zone be, based on objective measures?

Regional structure has also become an important factor in the TOD literature. This can be described as a continuum from monocentric, to polycentric, to dispersed development (Hajrasouliha & Hamidi, 2017). Polycentric design relaxes the assumption of a monocentric city in the bid-rent model of Alonso (Alonso, 1964), Muth (Muth, 1969) and Mills (Mills, 1972), in which all employment was located at the center of the urban area, in the Central Business District (CBD). It instead posits a multi-centered regional structure, with the assumption that a polycentric urban region (PUR) will allow the combination of increased density and intensity with reduced congestion and network-based synergies (E. Meijers, 2005). This structural arrangement should by theory improve JWB via internal capture of work trip rates by increasing the number of regional centers where high land use mix and accessibility exist.

Well-known meta-analyses exist regarding travel outcomes of the BE (Aston et al., 2021a; Ewing & Cervero, 2010). These include variables regarding transportation network attributes (Aziz et al., 2018), transit station proximity, vacancy rate, distance from the CBD, place typology, and intersection density. Demographic controls that are common in the literature are listed in table 2.

Self-selection can be controlled for with sociodemographic controls (e.g., income or employment status), using stated preference surveys, instrumental variables that represent residential preferences, sample segmentation, or longitudinal study design (Aston et al., 2021a).

2.2 JWB – Refining JHB Theory to Elevate Transportation and Land Use Policy

The foregoing establishes shortcomings in JHB literature. This section goes beyond JHB by formalizing JWB theory. Rather than account for the raw numbers of available housing units or ratios as JHB does, JWB needs to account for workers categorized by economic sector as well as by different wage levels within a zone. JWB would also measure the percentage of those who are able to both live and work in the same commute shed. JWB metrics would then ascertain whether internal capture at a specified commute shed, measured by distance or travel time, will be positively associated with the jobs-labor force balance ratio, income match, proximity to transit, and the degree of centering, land use mix, and accessibility. Each of these characteristics will be reviewed next.

A formalized theory of Jobs-Worker Balance (JWB) that incorporates the elements discussed above is here presented. The JWB evaluates the accessibility of workers to relevant employment within a distance from home that reduces the burden of commuting and therefore opens access to jobs. That distance comprises an optimal zone within which "internal capture" of workers' homes and their locations of employment may occur. The JWB accounts for travel mode, job sector match (and therefore skill levels) between workers and jobs, available labor force, income match between jobs and workers, demographic categories, regional urban structure, the intensity and design of the local built environment (BE) and other controls deemed relevant by local policymakers and analysts to the regions under study. The optimal zone might be found either by travel time or by distance; one might be more optimal than the other in any given regional context. Testing the internal capture criterion against a range of possible distances or travel times becomes a necessary aspect of the JWB, which is highly context specific. The theory is operationalized below for application to the Denver metro area case study.

The jobs-labor force balance ratio removes from consideration the portion of the population that is not part of the labor force. This corrects for the differences in labor force-aged population between zones or regions. It also captures an important issue novel to the balance literature, which is that many workers hold more than one job, which means there are more jobs than workers. Income match is measured for each commute shed, with the resident workers of each commute shed classified by income. It measures what percentage of workers in each income level live in the same commute shed as they work. For example, must teachers or policemen working in downtown areas commute excessively to get to work? The proximity to transit for the workers of a commute shed serves as a control for the BE, as well as measuring a normative planning goal in the context of JWB; that is, whether a commute shed's workers have access to transit as an alternative to driving. The degree of centering is another important control for the BE, as traditionally most jobs were in or near the CBD; this remains an important influence on a region's spatial and economic patterns. The intensity of land use mix and accessibility of a commute shed is a direct measure of the BE of the area. These measures directly account for the two main characteristics of accessibility, which are the degree of mobility and proximity of a geographic location.

These hypothesized characteristics for measuring JWB will be incorporated into the forthcoming analysis. Specifically, it will explore the following questions and hypotheses:

To what extent can balance between workers and their jobs be modeled as internal capture of work trips within a commute shed, taking into consideration the labor force, income match, and BE characteristics?

The article's hypothesis is that internal capture will be positively associated in each commute shed with income match, employment of the labor force, centering, intensity of land use mix and accessibility, and proximity to transit. The Denver Metro Area will serve as a case study region, given its relative geographic uniformity.

2.3 Research Design

An exploratory stepwise regression of cross-sectional data will produce a model for the Denver case study area for the year 2019. The data sources include Census employment and demographic sources, as well as transit feed data; all are prepared via GIS processing. Diagnostic tests will determine whether spatial heterogeneity or dependency is present in the result, which must be corrected using spatial autoregressive modeling (SAR).

Next, we will discuss the general model. Then, we will review the data and its preparation for analysis. We will then review the case study area and time frame. Subsequently, we will discuss the statistical method.

2.4 General Model

The general regression model for empirical testing is constituted as follows:

$$\mathbf{IC}_i = \mathbf{f}\ (\mathbf{JWB}_i, \mathbf{C}_i, \mathbf{PT}_i, \mathbf{WR}_i, \mathbf{DB}_i)$$

Where:

$\mathbf{IC}_i$, the dependent variable, is internal capture for each commute shed, *i*,
$\mathbf{JWB}_i$ is a set of attributes for job-worker variables for commute shed, *i*,
$\mathbf{C}_i$ is a set of attributes for access and centering in commute shed, *i*,
$\mathbf{PT}_i$ set of dummy variables used to identify the place types within commute shed, *i*,
$\mathbf{WR}_i$ is a set of workers by their workplaces and residences within commute shed, *i*,
$\mathbf{DB}_i$ is a set of street network-based distance bands, or intervals, from the nearest transit station to block groups with commute shed, *i*.

2.5 Modeling Data

The data preparation required the following: vehicle and commuting data were gathered from the US Census Bureau's American Community Survey (ACS) 2019 5-year data sample, at the block group aggregation level, which mitigates somewhat the effects of MAUP. Census Bureau Urbanized Areas (UA) are also employed in the study. The data tables for jobs and workers were gathered from the U.S. Census Bureau's Longitudinal Employment-Housing Database (LEHD) 2019 job data tables for census block groups.

To calculate internal capture of work trips and other study metrics, a Near Table was generated in ArcGIS Pro, which measures the distance between each origin census block group, *i*, and every other census block group destination, *j*. This table is equivalent to an origin-destination matrix. Joined to this distance matrix, the LEHD Origin-Destination (OD) tables, providing origin and destination block IDs and jobs numbers, were aggregated to the block group level and combined with the Worker Area Characteristics (WAC) and Resident Area Characteristics (RAC) tables to gain detailed job and worker data by sector for each origin-destination pair. Using this table, an iterative routine in R established variable sums for each commute shed. ACS data tables were joined to the LEHD block group data. Wage and sector groupings for workers and jobs in the LEHD data are identified using the NAICS codes. Table 2 details the list of variables included in each vector in the general model. The study used the General Transit Feed Specification (GTFS) static files for light rail transit (LRT) station point location data and the routes to which each station belongs. The street intersection variables were selected and calculated from the US Environmental Protection Agency's (EPA) Smart Location Database, version 3.

3 Cluster analysis of place type variables

This article will utilize a recent place type analysis by Currans (A. C. Nelson et al., 2020), which used the following indicators of the dimensions (the "Ds") of the built environment (BE) and demographics to create types of transit station area places. They are listed under their data sources (Bartholomew & Ewing, 2011; Ewing & Cervero, 2001, 2010; K. Park et al., 2020):

Longitudinal Employer-Household Dynamics (LEHD 2017)

- Jobs per acre
- Proportion of jobs that are retail and arts

American Community Survey (ACS 2017, 5-year)

- Total population per acre
- Total households per acre
- Percent of households with no kids
- Percent of owner-occupied housing

Smart Location Database

- Intersections per square mile
- Proportion of intersections with 3 to 4 vertices

Similar sets of variables are used by Ewing and Hamidi (Ewing, Reid, and Hamidi, 2014), the US Environmental Protection Agency (United States Environmental Protection Agency, 2023), and the US Department of Housing and Urban Development (HUD 2023).[13] The analysis applied was Jenks natural breaks, which classified the variables into four categories from 1 = most suburban to 4 = highly urban, or more precisely, from low to high land use mix and accessibility (A. C. Nelson et al., 2020).

3.1 Study Area & Time Frame: Denver Case Study

The Denver Metro Area for the year 2019 will serve as a case study time and region, given its relative geographic uniformity. This is necessary due to the confounding influence of mountains or coastlines on spatial regression. It is hoped that further research will extend to other regions with more spatial complexity. This will require further adaptation of the theory here presented.

Spatial heterogeneity acted as an obstruction of the study's regression analyses. The first attempt to model JWB was to fit data from the Seattle MSA. The highly variegated landscape, which lies along the west coast of the United States, produced massive variations in applicable metrics. These variations resulted in a biased OLS model that requires further research beyond this paper. The Denver MSA was chosen as a second alternative due to its much more uniform landscape, and the extensive spatial coverage of light rail transit in the region. Running an area restricted to 4 miles from the transit stations under study, as well as within the UA, finally produced a meaningful model, but one still obstructed by heteroskedasticity and spatial autocorrelation in the error term. Therefore, SAR regressions were run to correct these biases.

4 Statistical Method - OLS and SAR Regression

An exploratory stepwise regression identified options for the best OLS models available from the data set, which variables are significant, what the best fit models are, and whether they pass the standard diagnostic tests. Certain diagnostics that test for spatial autocorrelation were run, to determine whether the study should calibrate spatial lag and spatial error models to correct for spatial bias. See table 1 for the list of candidate variables used in the stepwise regression.

Spatial cross-sectional data sets require the assumption of complete spatial randomness (CSR) across the data distribution. There is no actual case when spatial dependence does not play a role in a cross-sectional data set. When spatially dependent variables break the assumptions of OLS regression, such as observations that are i.i.d. and uncorrelated with the error term, corrections are needed. Spatial autoregressive modeling (SAR), pioneered by Cliff and Ord (Cliff & Ord, 1973) and Anselin (Anselin, 1988), is designed to correct spatial bias in regressions. SAR models apply a spatially lagged dependent variable to the covariates, or a spatial lag to the error

[13] See the website: https://www.huduser.gov/portal/home.html. Accessed 4/30/2024.

term. If both are recommended by the diagnostic tests, which are run on an initial OLS model, a solution is to run a spatial lag regression with HAC standard errors, which instruments the error matrix with a precision-weighted matrix. Table 4 lists the instruments. This adjusts the error matrix for both spatial dependence and for heteroskedasticity (Kelejian & Prucha, 2007).[14]

The SAR models are specified as follows,

$$Y_i = \beta_0 + \rho W Y_i + \sum_{i=1}^{N} \beta X_i + \varepsilon \tag{1}$$

$$Y_i = \beta_0 + \sum_{i=1}^{N} \beta X_i + \varepsilon_i \tag{2}$$

$$\varepsilon_i = \lambda W_{\varepsilon_i} + \mu \tag{3}$$

To use the spatial lag term, a spatial weights matrix, **W**, that models the spatial relationships between observations may assume various spatial interaction forms between each spatial observation in the data. The spatial lag term, $\rho W Y_i$, in equation 2 fits the spatially lagged dependent variable to the regression, by estimating the value of the lag coefficient, ρ, to test for resulting reductions of spatial bias. The spatial error regression approach in equations 2 and 3 estimates the spatial error coefficient, λ, to fit the spatially lagged error term, $\lambda W_{\varepsilon_i}$ plus the global error term, μ, and is tested in like manner as the spatial lag term. Lagrange multiplier tests evaluate whether spatial bias is reduced by introducing one or more of these corrective variables (Zhang & Wang, 2013)

The SAR models differ in important ways from the OLS model. After using the HAC estimator from (Kelejian & Prucha, 2007), the problems of spatial dependence and heteroskedasticity in the error term are resolved, as shown by the Anselin-Kelejian Test being statistically insignificant.

Results and discussion are presented next.

Table 2. Candidate Variables for JWBI by Variable Subgroups, Justification & Sources

Variables	Description & Justification	Selected Literature	Expected Sign
Job-worker Variables			
Internal capture (Dependent variable)	Workers living and working in the same commute shed as % of total.	(Kain, 1968; K. Park et al., 2020; Stoker & Ewing, 2014)	N/A

[14] Discussed in an online lecture by Luc Anselin. https://youtu.be/Mjsh5JcuAR4. Accessed 7-11-2023.

Dissimilarity Index of income match and sector match for place-based jobs	Degree to which local employment wages & sectors are matched with workers' wages & job sectors	(Stoker & Ewing, 2014)	+
Jobs-Labor Force Balance	Degree to which a commute shed is balanced between labor force and jobs.	Ewing and Hamidi 2014	+
Access & Centering Measures			
Distance band to nearest FRT stations by mode;	Node and place attributes of neighborhood transit stations.	(A. C. Nelson & Hibberd, 2019b),	+
Distance to CBD (Gi*)	Measures strength of economic effect of CBD. Employment cluster with highest Gi* z score. Internal capture is highly affected by regional economic structure.	(Aston et al., 2021a; Ewing & Cervero, 2001; K. Park et al., 2020)	-
Distance to employment subcenter (GWR)	Measure of polycentric development Internal capture is highly affected by regional economic structure.	(Bertolini, 1996; Hajrasouliha & Hamidi, 2017; K. Park et al., 2020)	-
Share of workers commuting by transit, share commuting by automobile	JWB highly dependent upon commute mode and shed. Link between station proximity and mode choice to work.	(A. C. Nelson & Hibberd, 2019b; Stoker & Ewing, 2014)	+
Vehicles per Household	Vector proxy for automobile dependency	(R. Cervero & Duncan, 2008; A. C. Nelson & Hibberd, 2019b)	-
Place Type Variables			
Intersection density, and proportion 3- or 4-way intersections	A measure of urban compactness and walkability.	(Ewing, Reid, and Hamidi, 2014; A. C. Nelson et al., 2020; Stoker & Ewing, 2014)	+
Strength of employment, occupied housing, and population density	Higher JWB results in lower VMT and VHT and greater use of non-auto travel modes. Clustering of housing should increase JWB.	(R. Cervero & Duncan, 2008; Ewing, Reid, and Hamidi, 2014; Hajrasouliha & Hamidi, 2017; K. Park et al., 2020))	+
Proportion of all employment from Arts-Ent-Rec sectors	Urban centers typically possess higher proportions of this economic sector group.	(Nelson et al. 2020)	+
Percent owner occupied housing	Owners usually live in low-intensity places	(Nelson et al. 2020)	-
Percent of households with no children	Households with children are a smaller proportion in higher-intensity places.	(Nelson et al. 2020)	+
Land use mix (entropy score)	Land use mix supports job-worker balance.	(Ewing and Hamidi 2014)	+
Workers by Residence and Employment Location			
Worker location by sector group	Categorized vectors of employment, they are a necessary input to capture demographic interactions. Firms compete for location.	(Ewing & Cervero, 2001; Kain, 1968; A. C. Nelson & Ganning, 2015)	None
Worker residence by sector group	Vector of workers' residences. Worker demographics greatly affects commute.	(Kain, 1968; A. C. Nelson & Ganning, 2015)	None
Median HH income	Self-selection control	(Aston et al., 2021a)	+

Table 3. Candidate Variable Explanations and Descriptive Statistics

Variable Code	Variable	Min	1st Q	Med	Mean	3rd Q	Max	Std Dev
ICpct3m	Internal capture percent at 3 miles	6.4	15.2	16.6	17.3	18.4	29.6	3.64
MedHHinc	Median household income	0.0	52,725	73,281	79,978	100,383	250,001	40,545
White_Pct	White percent of population	0.0	42.9	68.4	61.8	82.9	100.0	25.20
TotalHH	Total households	0.0	379.5	537.0	598.8	752.5	5,158.0	345.79
HHnoKids	Households with no children	0.0	252.0	363.0	431.5	545.5	3,991.0	283.08
OnePersHH	Single-person households	0.0	77.0	138.0	197.4	265.0	2,249.0	185.69
OwnOcc	Owner-occupied	0.0	194.0	294.0	336.2	435.0	3,400.0	237.34
VehPerHH	Vehicles per household	0.0	0.9	1.0	0.9	1.0	1.0	0.10
SinParHH	Single-parent households	0.0	16.0	42.0	55.6	80.0	581.0	53.60
HHnoVeh	Households with no vehicles	0.0	-	17.0	44.5	54.5	814.0	70.21
Intdensity	Intersection density	7.8	75.5	95.5	93.7	112.6	156.6	27.88
PctOwnOcc	Percent owner occupied	0.0	39.0	65.5	60.6	86.1	100.0	28.42
PctHHnoKid	Percent households with no children	0.0	60.8	71.0	70.6	80.7	100.0	14.92
Pct_3or4leg	Proportion of 3-leg to 4-leg intersections	0.0	5.0	13.8	17.8	25.0	114.7	18.07
CarShare	Car share of trips (%)	0.0	76.3	83.7	81.4	89.3	100.0	12.06
TransitShare	Transit share of trips (%)	0.0	1.6	3.8	5.4	7.4	40.3	5.76
Pct_ArtsEn	Percent Arts and Entertainment jobs	0.0	0.0	-	1.9	0.8	87.0	6.61
PopDensAcr	Population density per acre	0.0	6.4	9.6	11.4	13.8	63.6	8.34
EmpDensAcr	Employment density per acre	0.0	0.5	1.5	6.2	4.4	552.4	25.94
HouseDensAcr	Housing density per acre	0.0	2.5	3.7	5.0	5.5	42.1	4.86
Entropy	Entropy	0.0	0.4	0.5	0.5	0.6	0.9	0.18
DIsectors	Dissimilarity index of jobs by sector	0.0	0.1	0.1	0.1	0.1	0.4	0.05
DIwages	Dissimilarity index of jobs by wage	0.0	0.0	0.1	0.1	0.1	0.3	0.04
JLB	Jobs-labor force balance	0.3	0.7	0.8	0.8	0.9	1.0	0.14
MCBD	Miles to CBD	0.0	3.7	6.6	6.9	9.8	18.1	3.76
MsubCBD	Miles to sub-CBD	0.0	0.3	1.1	1.3	2.0	5.0	1.11
NetDis05; NetDis1	Network distance to transit station dummy	NA	NA	NA	NA	NA	NA	NA

5 Results and Discussion

Following the stepwise regression, the study used a model that contains the key covariates, which were those that were found to be significant. Other variables could be added to the model from the long list of candidates found in the literature, but the study results were chosen according to the principle of parsimony. This approach helped to avoid multicollinearity through elimination of correlated and therefore redundant covariates (Blumenberg & King, 2021). The model also includes theoretically important variables not included in the exploratory regression model chosen for the study.

The functional form of each independent variable should be chosen according to the theoretical relationship of the independent variable to the dependent variable. Sometimes, functional forms are also applied to raw data to conform them more closely to a normal distribution. Attempts were made to improve the study's model fit by changing the functional forms of skewed variables, but most variables did not improve upon transformation to log, natural log, exponential, or square root forms. Taking the natural log of the dependent variable resulted in an unusable biased result.

A correlation matrix established which variables had sufficiently low correlations to be used without multicollinearity bias. A VIF test of < 7.5 for each explanatory variable and multicollinearity condition number of < 30 verified the correlation matrix results. The OLS model diagnostics tests also indicate that multicollinearity is not an issue, and the Jarque-Bera test being insignificant indicates sufficient normality in the model residuals, but heteroskedasticity and spatial autocorrelation exist in the residuals. The heteroskedasticity in the OLS model is corrected using robust standard errors and significance tests, as shown in Table 3.

In the OLS model, it appears that internal capture is positively associated with income match or wage-level diversity, and that internal capture is negatively associated with match by sector. The network distance of 0.5-miles or less from a transit station is significant at $p<0.10$. This indicates that proximity to the stations is positively associated with internal capture. The other variables chosen, aside from a network distance from 0.5 to 1 mile from transit, are significant at $p<0.01$, and have the expected signs. This result supports the hypothesis that BE characteristics of compact city design are positively associated with internal capture of work trips at a 3-mile commute shed distance. However, the statistically significant K(BP) diagnostic test indicates that the model suffers from heteroskedasticity and/or a spatial dependency bias.

A global Moran's *I* test also indicates that a SAR is needed to control for spatial dependency in the data. Lagrange Multiplier diagnostic tests and robust tests indicate that both spatial lag and spatial error models should be run. Figure 1 is a map of the residuals, which indicates spatial patterns of high or low residuals among neighboring census block groups. These patterns break the OLS assumption of an uncorrelated error term.

Heteroskedasticity is addressed by using robust standard errors and p scores. Spatial dependence must be addressed using a SAR that accounts for a lack of structural integrity in the data across spatial locations.

Table 4. Results of OLS Model

Summary of Outputs								
Variable	**Coef**	**Std Error**	**t-Stat**	**Prob**	**Robust _SE**	**Robust _t**	**Robust_ Pr**	**VIF**
Intercept	26.00	0.45	58.13	0.00***	0.47	54.89	0.00***	--------
MEDHHINC	0.00	0.00	3.07	0.00***	0.00	3.07	0.00***	1.27
MOD MA	0.43	0.14	3.08	0.00***	0.14	3.12	0.00***	1.14
HIGH MA	1.17	0.26	4.45	0.00***	0.24	4.77	0.00***	1.16
NETDIS05	1.01	0.31	3.25	0.00***	0.32	3.18	0.00***	1.08
NETDIS1	0.14	0.20	0.72	0.47	0.20	0.71	0.48	1.08
DISECTORS	-30.70	1.74	-17.69	0.00***	2.09	-14.69	0.00***	1.93
DIWAGES	7.51	2.17	3.47	0.00***	2.33	3.22	0.00***	2.52
JLB	-1.83	0.44	-4.15	0.00***	0.46	-4.00	0.00***	1.07
MCBD	-0.50	0.02	-21.90	0.00***	0.02	-23.21	0.00***	2.03
MSUBCBD	-1.05	0.06	-18.54	0.00***	0.05	-19.51	0.00***	1.08

Diagnostics			
Dependent Variable	ICPCT3M		
N = 1143		AICc	4899.5
Multiple R-Squared	0.68	Adj R-squared	0.68
Joint F-Stat	246.5	Prob (>F)	0.00***
Joint Wald	2074.36	Prob (>chi-squared)	0.00***
K(BP)	57.2	Prob (>chi-squared)	0.00***
Jarque-Bera	2.3	Prob (>chi-squared)	0.32

*** p<0.01, ** p<0.05, * p<0.10

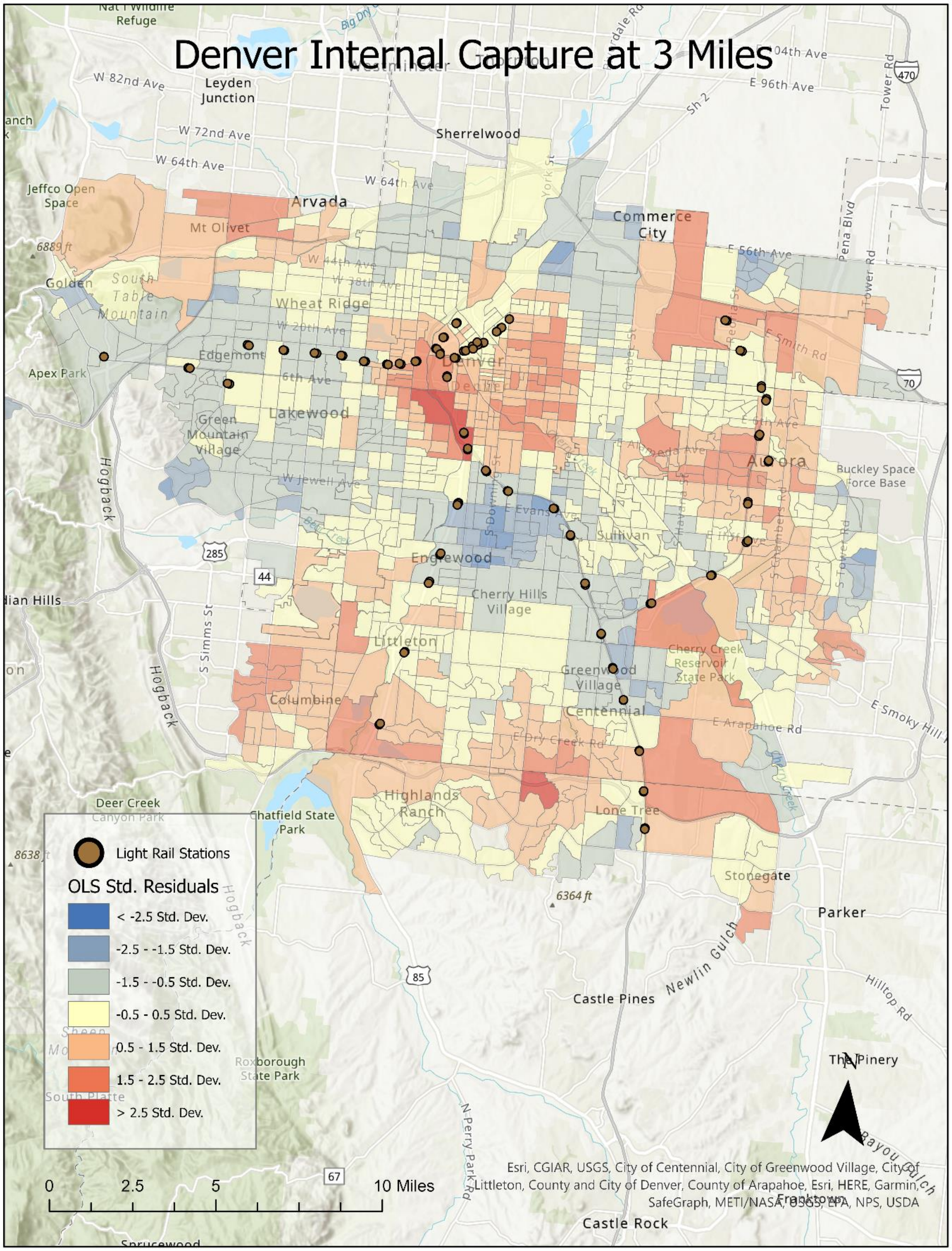

Figure 7. Standardized Residuals of OLS model demonstrates spatial autocorrelation. High and low values cluster together in space beyond the expectation of a random process.

Table 5. Results: Spatial Lag Model

Summary of Outputs

Spatial GMM Lag Model: HAC Robust Standard Errors					**Sensitivity Analysis**			
Variable	**Coef.**	**Std. Error**	**z-value**	**Robust Prob**	**Coef.**	**Std. Error**	**z-value**	**Robust Prob**
CONSTANT	4.08	1.45	2.81	0.00***	4.62	1.54	3.01	0.00***
W_ICpct3m	0.84	0.06	15.02	0.00***	0.82	0.06	14.31	0.00***
MedHHinc	0.00	0.00	2.42	0.02**	0.00	0.00	2.66	0.01***
MOD MA	-0.04	0.08	-0.47	0.64				
HIGH MA	0.14	0.14	1.04	0.30	0.18	0.12	1.46	0.14
NetDis05	0.28	0.16	1.67	0.10*	0.30	0.16	1.83	0.07*
NetDis1	-0.04	0.09	-0.42	0.67				
DIsectors	-8.18	1.89	-4.33	0.00***	-8.74	1.92	-4.56	0.00***
DIwages	2.35	1.36	1.73	0.08*	2.46	1.38	1.78	0.08*
JLB	0.04	0.29	0.15	0.88	0.00	0.30	0.00	1.00
MCBD	-0.09	0.03	-3.12	0.00***	-0.10	0.03	-3.28	0.00***
MsubCBD	-0.21	0.06	-3.50	0.00***	-0.23	0.06	-3.57	0.00***

Summary and Diagnostics

Data set:	Denver	Observations:		1143	Data set:	Denver	Observations:		1143
Spatial Weight:	Queen contiguity, IDW, squared	Variables:		12	Spatial Weight:	Queen contiguity, IDW, squared	Variables:		10
Spatial Adaptive Kernel:	11 neighbors, Gaussian kernel	DF:		1131	Spatial Adaptive Kernel:	11 neighbors, Gaussian kernel	DF:		1133
Dependent Variable:	ICpct3m	SPATIAL DEPENDENCE TEST			Dependent Variable:	ICpct3m	SPATIAL DEPENDENCE TEST		
Mean dependent var.:	17.29	Anselin-Kelejian	VALUE	PROB	Mean dependent var.:	17.2912	Anselin-Kelejian	VALUE	PROB
S.D. dependent var.:	3.64		1.44	0.23	S.D. dependent var.:	3.6407		2.47	0.12
Pseudo R-squared	0.93				Pseudo R-squared	0.9242			
Spatial Pseudo R-squared	0.67				Spatial Pseudo R-squared	0.673			

*** p<0.01, ** p<0.05, * p<0.10 Instruments: W_DIsectors, W_DIwages, W_JLB, W_MCBD, W_MedHHinc, W_MsubCBD, W_NetDis05, W_NetDis1, W_MOD_MA, W_HIGH_MA

The results of the SAR models differ in important ways from the OLS model. After using the HAC estimator from (Kelejian & Prucha, 2007), the problems of spatial dependence and heteroskedasticity in the error term were removed, as shown by the Anselin-Kelejian Test being statistically insignificant.

The result confirms most aspects of the hypothesis, namely that internal capture of work trips is positively associated with income match, the match between sector workers and sector jobs, centering, intensity of land use mix and accessibility, and proximity to transit.

However, results for the JLB and place type variables are not consistent with expectations. For the JLB, this may indicate that the spatial neighborhood, the commute shed, used to create the metric for this study was too small, and that the JLB should be measured on a larger scale. The neighborhood-scale place type variables were not significant in this model, either, which may indicate that in the Denver region these neighborhood-scale characteristics are less influential on internal capture of work trips than more regional-scale characteristics like centering and sub-centering. The result may be due to spatially constraining the observations to the mostly uniform block groups of the most urban areas of the Denver region.

A sensitivity analysis (table 4) indicates that the model is structurally sound after removing 2 of the variables found to be not statistically significant. Those variables that were found significant in the first iteration were also significant in the latter version. The place type for High MA, moreover, was positively associated with internal capture and nearly statistically significant in the sensitivity analysis.

Locations within the first half-mile network distance of the LRT stations are positively associated with internal capture, compared to the referent of distances greater than 1 mile from the stations, as was a greater mix of jobs by wage group. Moreover, by removing the dummy for network distance from transit stations of 0.5 to 1 mile, the sensitivity analysis shows an increase in the significance of the first half-mile distance band. This changes the referent of the transit station distance to everything beyond a half-mile distance. Locations within a half-mile of transit stations are positively associated with internal capture compared to distance beyond a half-mile.

MedHHinc controls for self-selection, indicating that after controlling for demographic groups that choose to live in a neighborhood that is designed for internal capture, there is still a significant effect of the other variables on internal capture.

DIsectors is highly negatively associated with internal capture, which suggests a spatial separation between neighborhoods with lots of sector mix and those with high internal capture. This suggests that commute sheds with high internal capture have a specific and limited mix of land uses by sector. DIwages is positively associated with internal capture; areas where there is a greater level of income match allow for more workers to live and work in the same commute shed.

Centering in Denver is positively associated with internal capture. Both the main CBD and subcenters have statistical significance, and the latter is more influential than the former. Polycentric development is having a positive influence on reducing the negative impact of commute trips in the region.

6. Implications for Transportation and Land Use Policy

The study advocates for a JWB theory based on internal capture of work trips within a commute shed, incorporating income match as an essential element. It provides insights into the theory and methodology that will further empirical analysis regarding the JWB. It presents a list of candidate variables based on a broad review of the JWB literature and chooses a parsimonious set of variables based on theory and diagnostic testing. It demonstrates the efficacy of income match in the effort to increase internal capture. It also empirically demonstrates positive association between transit-oriented polycentric development and internal capture of work trips. The choice of methods used in a study impact research results in profound ways. Diagnostics for OLS and SAR have become crucial tools for choosing from among the many options for regression models. The study presents useful best practices and pitfalls of OLS and SAR regression methods, utilizing adjustments to spatial dependency and heteroskedasticity.

The case of Denver MSA is useful as a comparison with other TOD cities. Densities are relatively suburban for much of the region, yet the hypothesis test was mostly confirmed. The place type index has a positive effect on internal work trip capture for 3-mile commute sheds but is not quite statistically significant. The place types are relative to each MSA, and Denver has yet to implement sufficient densities to achieve the full effect. The continued addition of "gentle density" and land use mix and match in centers across the region will increase the efficacy of TOD and the internal capture of larger percentages of work trips.

Policy implications include a need to identify gaps between jobs and housing for each subgrouping of a classification of workers, distinct in income, sector, skill, and demographic profile. A need also exists to emphasize accessibility more strongly through proximity rather than just mobility; when these two aspects of accessibility are out of balance, accessibility decreases. That is, despite the growing ubiquity of the automobile, commuting costs in time or distance also continue to grow. Policies should emphasize efforts to advance both aspects of access to work, particularly through modes of transportation alternative to the automobile, which overwhelmingly dominates land use and transportation policies and the current urban landscape.

This study also highlights a need to increase gentle density and "missing middle" housing on the local scale, and polycentrism across each region. Each of these approaches will improve the level of attainability of housing near TODs. The former increases the housing supply, while the latter increases in number the locations across each region that benefit from agglomeration economies through greater proximity to localized assets, along with access to a range of networked assets of the regional economy and community, particularly jobs and housing.

It advocates for a localized analysis of the JWB, allowing policymakers and analysts to determine what constitutes an appropriate balance between jobs and workers in a specific region. This approach is necessary given the wide variability of US urban regions in terms of size, population density and makeup, and economic sectors, among other factors. It indicated, for example, that Denver workers of some, but not all, economic sectors get to enjoy JWB. The results indicate that increasing that match between workers and jobs at the sector level will increase internal capture, thus giving more workers access to employment.

It confirms other recent research (A. Nelson et al., 2021) that suggests that TOD stations are only being fully utilized at the station itself; that even the normative half-mile context of the TOD is only aspirational at this point. This identifies a great deal of untapped potential in existing TODs that can be used through increasing the land use mix and match to provide a greater level of local-scale balance between specific groups of workers and their jobs.

Additionally, increasing the intensity of the place types, our model results suggest, will make TOD neighborhoods more plausible contexts for JWB. This can be done without excess density, and the model results indicate that currently there is a lot of room to improve the JWB with incremental and gentle increases in land use mix and intensity.

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Chapter 4: Temporal Analysis of Balance Between Employment and Worker Concentrations in Transit Neighborhoods with Logistic Regression

Abstract

The job-worker balance (JWB) is an accessibility problem and must therefore be modeled using both mobility and proximity among its characteristics. For the last century the "mobility turn" has dominated our discourse and our policies, especially as the automobile has turned our urban form upside down, replacing proximity and agglomeration, the key ingredients of urban centering, with mobilities and their overwhelmingly disruptive (and costly) infrastructures. This paper analyzes the spatio-temporal changes in concentrations of jobs and workers at the CBG level before, during, and after the Great Recession, using proven spatial dependency measures. The analysis utilizes regional and local clustering patterns of jobs and workers using an interrupted time-series analysis before, during and after the Great Recession. Will we see a difference in the trends between the transit neighborhoods and the region as a whole? Location-efficient urban form incorporates the two characteristics of accessibility, building on the dimensions of compact urban form. The next-generation urban region enables JWB by expanding the monocentric city paradigm, creating interconnected polycentric regions. Logistic Regression, which analyzes dependent variables of the Bernoulli distribution, will analyze the relationship between residential and commercial land use agglomeration. Spatial dependence is a key focus of the methodology, as a direct measure of spatial association between observations.

Key words: data imputation, spatial dependency, JWB, accessibility, TOD, transit.

Introduction

The job-housing balance (JHB), which is an approximate equivalency in numbers of jobs and workers' housing in a zone or neighborhood, is a raw magnitude of balance, but should be conceptualized and analyzed as an accessibility problem. Accessibility can be measured in terms of mobility or proximity, and for the last century the "mobility turn" has dominated our discourse and our policies, especially as the automobile has turned our urban form upside-down, replacing proximity and agglomeration with mobilities and their overwhelmingly disruptive (and costly) infrastructures (Sheller & Urry, 2006). While many and profound are the positive results of the automobility revolution, some negatives include urban sprawl, colossal debt at all levels of government, and spatial mismatch between a potential workforce in the urban center and jobs that have moved to the suburbs in large numbers (Kain, 1968; Sultana & Weber, 2007). Mobility without proximity has given the world an incomplete accessibility, making the car and all its related infrastructure the costly prerequisite not merely for ease of movement, but to living a regular life in the post-Ford era.

A more complete urban form incorporates all the dimensions of location efficiency (LE), which include accessibility, among other important characteristics (Adkins, Sanderford, et al., 2017). They are referred to in the literature as the 5Ds of urban form: density, land use diversity, design of the built environment, destination accessibility, and distance to transit. The 5D dimensions incorporate both characteristics of accessibility, which are proximity and mobility (R. Cervero & Kockelman, 1997; Ewing & Cervero, 2001).

A typology of place has taken shape around these dimensions of urban form, built on the degree of land use mix, intensity, and accessibility a place has. Higher levels of each constitute more location efficiency, which supports transit use and other forms of active transportation. This in turn alleviates auto congestion and supports greater agglomeration economies.

This course provides people with their highest accessibility need, which is access to jobs. In an accessible urban region, workers living near their jobs can choose to commute by car, or they may opt for an alternative mode of transport. Whatever their choice, greater proximity reduces the cost of friction entailed in traveling from home to work.

Transit-oriented development and multiple associated paradigms focus on both mobility and proximity. Seen as both nodes in regional transportation networks and places offering vibrant mixtures of land uses within human-scaled proximity to one another, transit-oriented developments (TODs) aim to increase accessibility, especially between workers and firms (Bertolini, 1996).

Polycentric urban regions put the concepts of agglomeration and proximity into an expandable format applicable to the entire region. The traditional urban economy was built upon employment and commerce concentrating in a single urban center, the Central Business District (CBD), and workers and firms alike trading off between more abundant land outside the CBD and maximizing access to the highly competitive and costly land market in the CBD. The cost of friction of mobility between land parcels and the CBD modulated the tradeoff choices (Alonso, 1964; Mills, 1972; Muth, 1969). In polycentric regions there are multiple subcenters where agglomeration economies can accrue through higher-intensity concentrations of employment and other land uses that lead to lower marginal costs of production (Fujita & Thisse, 2002). These centers, which function as concentrations of economic, social, and civic activity, are connected by various types of infrastructure into synergistic urban networks (Calthorpe & Fulton, 2001; E. Meijers, 2005). TOD for corridors (CTOD), following the polycentric model, expands the focus from each individual station to a series of stations and their connecting corridors; each station can provide a unique set of land uses and forms that complement the rest of the corridor and all its nodes (Liu et al., 2020).

Planners and policymakers have multiple justifications for focusing efforts on spatial balance between jobs and workers. For example, agglomeration economies, in large part the basis of metropolitan growth, accrue from higher accessibility, whether due to greater mobility through the alleviation of congestion, or the reduction of distance between interdependent land uses. Decades of highway building have shown that induced demand on new road lanes quickly swallows up the extra travel capacity by diverting street traffic to the new highway capacity (R. Cervero, 2002). For this reason, metropolitan planning organizations (MPOs), in charge of regional transportation infrastructure in metro areas across the U.S., are increasingly investing in local projects in compact land development that increase proximity and reduce urban sprawl (Sabouri et al., 2019). Additionally, urban resilience is enhanced as workers can reduce transportation costs and utilize multiple modes of transportation, which become feasible when proximity increases between workers and their places of work.

Transit systems can aid in alleviating congestion, facilitate greater proximity between land uses, and assist in balancing jobs and workers. Station areas around fixed-route transit systems (FRT) are capturing jobs across many metropolitan areas (A. C. Nelson et al., 2019).

Moreover, Location Efficiency (LE), the optimal configuration of the built environment, is enhanced through job-worker balance. Some scholars have advocated in the wake of the COVID-19 pandemic for LE planning to increase public health resiliency during such crises (Hejazi et al., 2023; Mouratidis, 2022).

This article presents a temporal study of spatial association and concentration of jobs, housing, and transit systems in four widely disparate U.S. regions before, during, and after the Great Recession. It proposes to provide further empirical study of transit-related economic resilience in terms of the jobs-worker balance around transit stops in Atlanta, Cleveland, Eugene-Springfield, and Minneapolis. It captures change in spatial concentration over time, rather than directly measuring job-worker balance at each period. Moreover, this study classifies workers and jobs by income level. As elaborated by Stoker and Ewing (Stoker & Ewing, 2014) identification of clustering of both jobs and workers at a given income level within transit neighborhoods (called income match) provides a more complete picture of job-worker balance than a general count of jobs and workers.

Literature Review of Urban Theory

An unintended consequence of building our cities around the automobile includes isolating some workers from jobs. Kain's spatial mismatch theory posits that suburbanization exacerbated joblessness through a lack of access to jobs for isolated black populations in urban ghettos (Kain, 1968). Disinvestment in urban redlined districts impoverished many people as "safe investments" were sought in the greenfields of the suburbs and the aging urban centers were left without the necessary revitalization. (Rothstein, 2017).

Environmental justice literature calls attention to the need for all demographic segments of society to be at optimal health to buttress a region's resilience to shocks (Island Press & Kresge Foundation, 2016). Accessibility, particularly to employment, is a key element of urban resilience. Real estate markets may favor transit-accessible locations during and after a recession, as found in Nelson et al. (Arthur C. Nelson et al., 2019), which identified a gap in the resilience literature that concerned the relation between public transit and economic resilience.

The CBD formed as the import and export point for economic activity in and out of the region. It also became the focal point of activity within the region. Factories were focused in the CBD, attracting workers from across the region to commute into the center. Urban economists have modeled urban regions using the elements of land, proximity, the cost of distance, and the budget constraint of households and firms as keys to the calculus undergirding urban pattern formation in the monocentric city. This calculus, because it has led the decision-making processes of government capital investment policies and location decisions of private firms, has also largely determined workers' access to jobs and their costs of commuting.

Von Thunen's seminal economic model was based on an agricultural economy (Thünen & Wartenberg, 1966) while later work modified his theory to fit an industrial city (Christaller et al., 1933; Hoyt, 1939; Lösch, 1954; R. E. Park et al., 1925). In a self-organizing market-based system, the agents that create the geographic patterns of the region do so by making tradeoffs between proximity to the urban center and access to larger amounts of land outside the center, which can be purchased at a lower cost per acre than in the center. To increase market efficiency through agglomeration, agents with high income elasticity of demand for access, those who value proximity more than land, are willing to pay higher land rent for property near the urban center. The willingness to pay varies by land use and how much land is needed to successfully function within the constraints of dynamic market equilibria between supply and demand. The friction of distance is the key modulating factor in this tradeoff. This bid-rent theory has long been at the center of urban economics (Alonso, 1964; Mills, 1972; Muth, 1969). Agglomeration economies accrue to urban centers, such as increased efficiency of production in and between firms in a single economic sector, and intellectual mixing between agents across various sectors (Anas et al., 1998; Fujita & Thisse, 2002; A. C. Nelson, 2013b).Thus came the monocentric city of the early industrial period. Further, by reducing the friction of distance to the CBD, the streetcar increased the size of the workforce that could reach the jobs at the industrial center. This in turn led to the significant growth of the CBD in many cities (Moore et al., 2007).

With the friction of distance constraint being shattered by the automobile, the economic elements of urban centers began to disperse into the suburbs and edge cities of metropolitan areas. There has been some debate regarding its effects upon urban economies. Scholars have argued that this dispersal is a setback. Costly urban sprawl, or inefficient and isolated land use, resulted from the incredible boost in transportation technology and has led, ironically, to ever-longer commute times (Duany et al., 2010; A. C. Nelson, 2020). Agglomeration diseconomies result from congestion of transportation infrastructure, which can occur when cities get too big, and can lead to loss of agglomeration economies due to inefficient land use configurations of parcels outside the urban center, leading to the excessive concomitant need for synthetic mobility between land uses (Moore et al., 2007; A. Nelson et al., 2021). Urban sprawl has led to a loss of economic efficiency, as land uses across the region have become prohibitively costly to access, given the mobility requirements.

Other scholars have argued that dispersed development is a net benefit to the region, and that automobility has effectively canceled the friction of distance for commuters, as commute times have not increased during decades of growth in regional size (Sultana & Weber, 2007). Others argue that spatial structure has a limited effect on commute times, and that sociodemographic characteristics of households are more influential than urban form on commute times (Giuliano & Small, 1993; Schwanen et al., 2003). Subsequent evidence suggests that subcentering is an ongoing need as it increases proximity and helps to alleviate agglomeration diseconomies (E. J. Meijers & Burger, 2010). Further, commute times have substantially increased in recent years. (R. Cervero, 1996).

Central Place Theory provides guidance: the main central place provides central goods and services, including employment, for which people are willing to travel from anywhere in the region to access. Many goods offered at the main center, however, can be more efficiently offered at subcenters in the region, subcenters that have a lower gravitational pull, so to speak, than the main center, but provide important agglomeration economies of their own (Moore et al., 2007). Many attempts have been made to add subcenters to monocentric regions, some functioning better than others. As Edge Cities and Edgeless Cities alike reduce economic efficiencies in the region, it becomes important to ask what makes a polycentric region more efficient than a sprawling one? Edge Cities, for example, exist at the regional periphery, disconnected from the networks of the CBD, while TODs are intended to tie the region together with highly efficient centers of activity that are also linked with the regional transportation network. (Calthorpe & Fulton, 2001; Lang & LeFurgy, 2003; E. J. Meijers, 2007).

The ongoing importance of economic centers in the post-Ford city has led to the growth of polycentric urban form. While many U.S. cities still exhibit the monocentric form, most consist of a mix between monocentric, polycentric, and dispersed urban form; monocentric form applies mostly to smaller cities, while those with the greatest growth in recent decades have grown into dispersed or polycentric forms (Hajrasouliha & Hamidi, 2017). Subcenters can increase agglomeration economies by increasing land use efficiency across the region by relaxing the requirement to place all jobs in the CBD but also maintaining the benefits of centering and avoiding the pitfalls of dispersed development. This has facilitated the growth of urban regions considerably beyond the size of the legacy monocentric pattern (Moore et al., 2007).

Theory

Accessibility has long been studied using the gravity model, which measures the attraction between origin and destination in terms of the weight of each, divided by the friction of distance between origin and destination. The weights may include the worker population at the origin and the jobs they work at the destination, among many other possible kinds of weights (Plane & Rogerson, 1994). This acknowledgment of the friction of distance has been overridden by the mobility revolution; yet it continues to function in the economic implications of urban policy decisions, whether or not they have taken this cost into account.

Tobler's First Law, "everything is related to everything else, but near things are more related than distant things" is the description for spatial autocorrelation (Tobler, 1970). We test clustering of jobs and workers using Tobler's Law as a paradigm. We test to see if growth in clustering of jobs correlates with clustering growth in workers, and whether these clustering dynamics are more intense near transit stations. Scale is the critical issue that defines clustering per se, and this will be taken into account in the study (Anas, Arnott, and Small 1998b)

Neighborhood-scale spatial clustering of both jobs and workers in transit neighborhoods indicates market choices in favor of this pattern. Changes in local indicators of clustering over the time period of the article will indicate greater clustering if the market reacts to shocks by taking a more location efficient configuration.

Resiliency theory suggests that clustering will increase due to the synergies and efficiencies of central places over more dispersed locations. However, some dispersal of certain types of land uses, when combined with centering of those that benefit from it, appears to be more efficient than centering all land use types (Jones 2017b). These may include some residential types as well as some, not all, manufacturing. In these cases, special use districts may be a useful strategy for coordinating these land uses with the rest of the region (Calthorpe & Fulton, 2001)

Research Question & Design

What impact did the presence of FRT have upon the job-worker balance before, during, and after the Great Recession? How did this vary across income groups,

economic sectors and station-area place type? How did this correlate with dynamics in polycentric development between time periods?

- Hypothesis 1: jobs will continue to be attracted to transit throughout the time period, with higher-income jobs requiring less space outbidding other sectors for station area space.
- Hypothesis 2: Polycentric development will intensify, particularly near transit stations, across the years, as a market response to economic shocks.
- Hypothesis 3: Clustering of both jobs and residences will be stronger over time at transit stations, demonstrating that JWB is easier to achieve in partnership with transit network connectivity.

General Model:

The general regression model for empirical testing is constituted as follows:

$\mathbf{SDW}_i = \mathbf{f}\ (\mathbf{SDR}_i, \mathbf{WAGE}_i, \mathbf{PT}_i, \mathbf{C}_i, \mathbf{DB}_i, \mathbf{D}_i)$

Where:

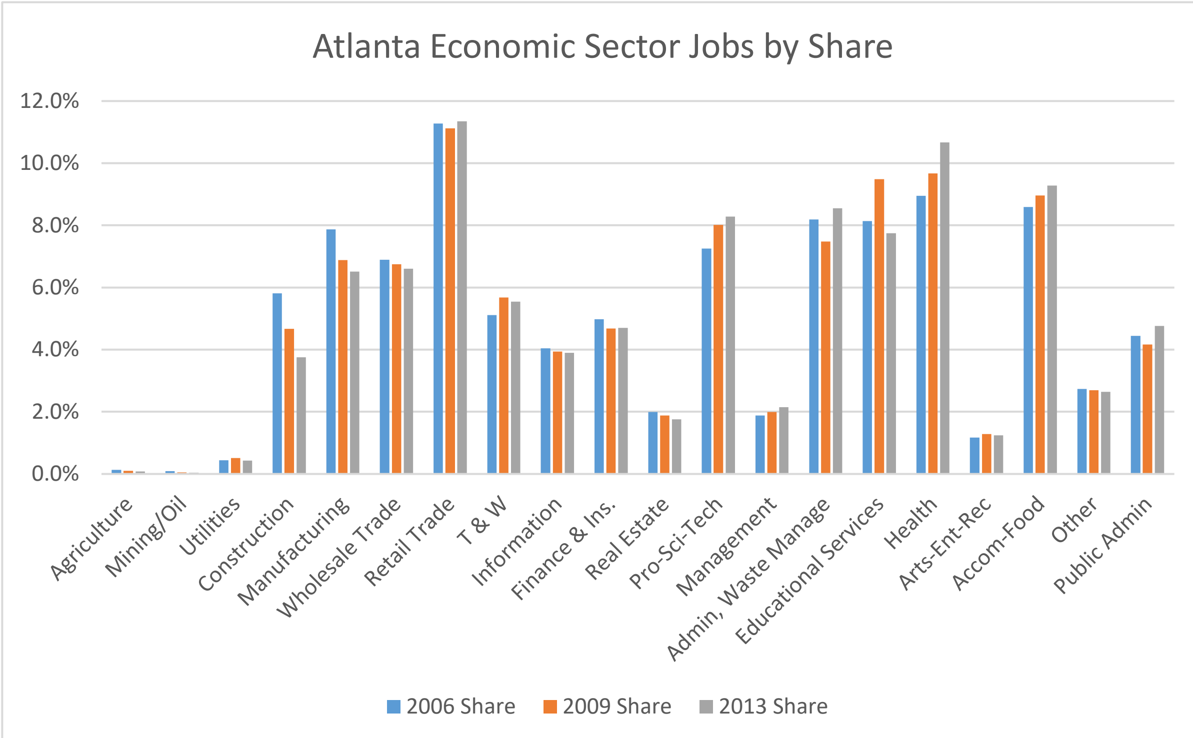
$\mathbf{SDW}_i$, the dichotomous dependent variable, is presence or absence of statistically significant spatial dependence (i.e., clustering) of the location of workers' jobs for each CBG, *i*,
$\mathbf{SDR}_i$ is spatial dependence of workers' residence locations in CBG, *i*,
$\mathbf{WAGE}_i$ is a vector of jobs by wage level as percentages of total jobs in CBG, *i*,
$\mathbf{PT}_i$ is a vector of variables used to identify the place types within CBG, *i*.
$\mathbf{C}_i$ is a set of attributes for access and centering in CBG, *i*,
$\mathbf{DB}_i$ a vector of quarter-mile distance bands from the nearest transit station to CBG, *i*.
$\mathbf{D}_i$ is a set of demographic controls to be used in sensitivity analysis, for CBG, *i*.

Study Area and Time Frame

The selected metropolitan area provides a case study region with a unique context within an important spatial and network pattern of interaction with the rest of the country. Nelson et al. (A. C. Nelson et al., 2015a) has noted that CRT routes have had an insignificant or slightly negative impact on real estate values in their vicinity in the past, which makes Cleveland's heavier form of rail an important study. Cleveland is an icon of the Rust Belt Fordist economic engine and represents the Great Lakes region and international trade networks with Canada.

Each region in the US has a unique profile in terms of what sectors dominate the regional economy, as well as landscape and topography. Some sectors capture about the same share in each region. For example, arts, retail, and public administration each capture similar shares in both regions. Cleveland has long been a major regional and national hub. Cleveland is ideally situated for interstate and international shipping and has a large share in manufacturing among US regions. In terms of topography, Cleveland, on the shores of Lake Erie, is mostly flat, but has some major topographical interruptions to the regional flow of commuters, such as the Cuyahoga River valley and the surrounding hills.

The question for this study is whether transit's presence before, during, and after the Great Recession (2006, 2009 and 2013) had any effect on spatial clustering in workers' locations. Did the case study city respond to the economic shocks of the recession by pulling resources toward the transit stops, and pooling them from across the region, thus restructuring the regional economy in terms of housing values and density, as well as job quality and density? This paper therefore analyzes the spatio-temporal changes in concentrations of jobs and workers at the CBG level before, during, and after the Great Recession, using proven spatial dependency measures. The analysis requires understanding of the degree to which workers and job clusters are near each other and transit stations, and what occurs at the same time in the regionwide sector shares. Will we see a difference in the trends between the transit neighborhoods and the region as a whole?



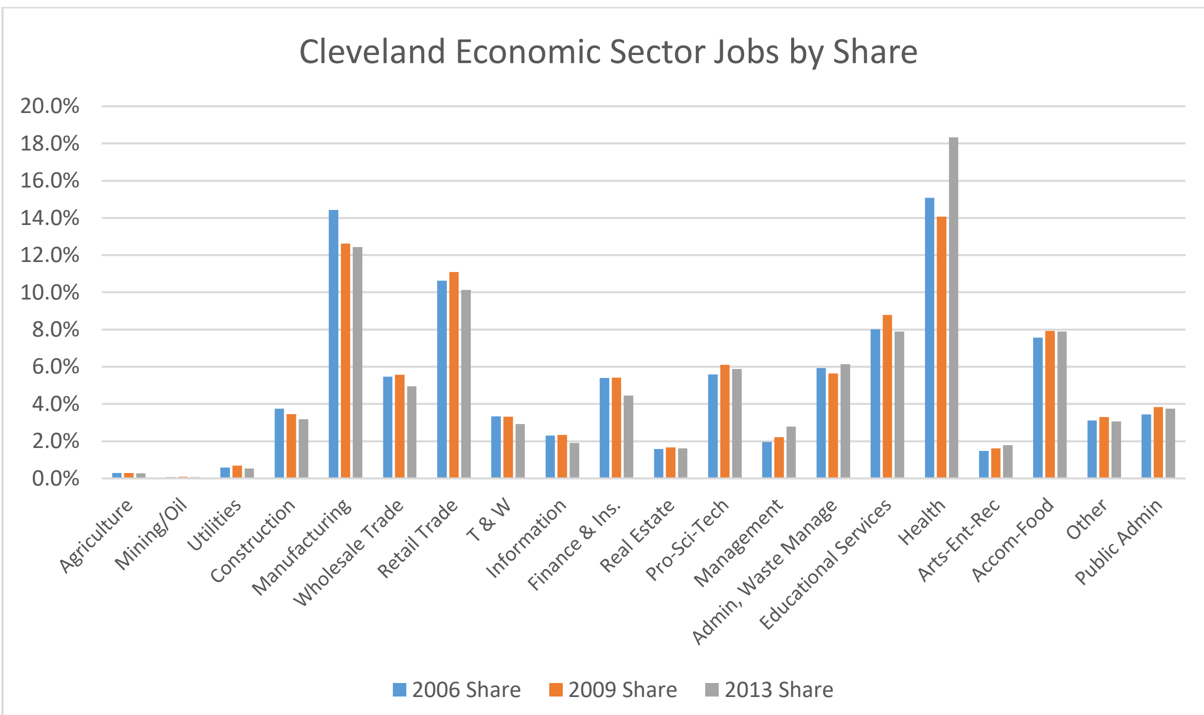


Figure 8. Cleveland and Atlanta economic sector by their share of the economy across the study years.

Methods

This study will analyze the spatial clustering (autocorrelation) of jobs and workers over time both at the regional scale, and within close proximity to transit stations and determine how much change in clustering has occurred. It will determine whether each station is within or near a center or subcenter. The study will review change across three years, before, during, and after the recession in terms of clustering of jobs and housing across four variegated metropolitan regions, and then compare that change to the change that occurs in the neighborhoods around a given transit stop. The study will evaluate whether the neighborhoods around a transit line exhibit increases in clustering. It will use the Moran's *I* and the Getis & Ord Gi* statistics for worker and job location at three different time periods. The kernel size for Gi* will be determined by the distances with peaks in autocorrelation in the global Moran's *I* test. It will compare significant clusters that meet a minimum threshold of 20 workers per acre (Hajrasouliha & Hamidi, 2017). Using logistic regression, it will then identify relationships between residential uses and employment uses within proximity to fixed-guideway transit (FGT) stations.

To provide detail about jobs by wage level, jobs are classified by wage percentages of total jobs. A logistic regression ascertains relationships between statistically significant employment clusters and worker residential clustering within proximity of transit. Various controls will explain variance due to built-environment and demographic patterns. The supposition is that LE transit neighborhoods are populated in large part by high-income jobs, and that this trend will show growth in the study cities after the recession and during the years of recovery.

Modeling Data

Transit systems for this study were derived from General Transit Feed Specification (GTFS) static files, which most transit authorities across the United States provide in accordance with the Google GTFS data standard. Transit authorities prepare their data about stops and routes along the various modes of public transportation available in their communities, including local, express, and rapid bus routes, commuter rail transit, light rail, streetcar rail, and heavy rail subway-metro systems. The stop times table is the lookup table that allows the user to join the other tables together. The GTFS standard tables were processed through ArcGIS Model Builder. The data tables for jobs and workers were gathered from the U.S. Census Bureau's Longitudinal Employment-Housing Database (LEHD) job data tables for CBGs were downloaded from the U.S. Census Bureau's On the Map website in shapefile format. The LEHD Origin- Destination Employment Statistics (LODES) tables provide full counts, rather than samples, of wage and salary jobs covered by unemployment insurance, with strict enforcement of privacy for individual respondents. These tables provided the variables for study about the location of jobs and their pay level, as well as workers and their pay scale. The former are found in the Work Area Characteristics (WAC) files, detailing the workplace location and other data for the employees that are enumerated in the file. Jobs totals are provided, along with a breakout of jobs by age of employee, by pay ranges, and by jobs according to the North American Industry Classification System (NAICS) job sector categorization. The Residence Area Characteristics (RAC) file provides data on the residence location of workers, including the same variables as the WAC file, but from the basis of the residence location of the enumerated workers, which may or may not include the residence CBG. Benner & Karner (Benner & Karner, 2016a) point out the limitations of the LEHD earnings classification, including the lack of an index to inflation and the significant variation in the number of workers who fall into each category as one controls for metropolitan statistical area. This study will utilize a classification of income based on NAICS job sectors, following Nelson and Ganning (A. C. Nelson & Ganning, 2015), as seen in table 1 above.

The census block group scale of data is a relatively fine spatial scale at which to run the analyses of local spatial dependency trends. The LEHD data set is a complete census of the variables covered, and therefore do not suffer from small sample size issues often mentioned for data at the census block group scale.

In order to reduce spatial variability due to the greater distances between census block groups outside the urbanized areas of the regions, this article will remove a portion of the CBGs from the study, those outside the boundaries of the Census Bureau's Urban Area boundary. Further, it will take its data solely from the counties that contain the fixed-guideway transit systems in each metropolitan area. Further, the data are confined to the transit-served counties of each metropolitan area.

To deal with missingness in the data, the study will perform imputations of data variables based on the mechanisms behind missing values unique to each variable. The method of dealing with missingness varies based on the mechanism of each variable. These mechanisms include data missing completely at random (MCAR), which indicates that the values are missing for reasons exogenous to any patterns in the data values of each variable; missing at random (MAR), which indicates that the null values are dependent on the variables' distributions or other patterns and can be imputed using information from existing observations. Not included in the variables of this study is the issue of null values in the class of missing not at random (MNAR), in which the null values are not predictable via statistical techniques and are often missing due to information sensitivity (Jadhav, Pramod, and Ramanathan 2019).For example, LEHD data values are null in many enumeration units, indicating that there are no values for jobs, residences, etc., in those units. These can be considered missing completely at random. In the case of the variable "c000," which is total jobs (at firms' locations), a null value would indicate no presence of jobs, and the null value could be imputed to be 0. Many studies simply omit null values, which can seriously reduce sample size. Other studies benefit from data imputation or creating plausible values through data statistical fit. Methods include simple mean imputation, k nearest neighbor, regression, and others. Mean imputation replaces the null values with the variable mean, median, or mode. It can be problematic and yield biased estimators unless imputation recovers less than 10% of the data, and variables have low correlations (Jadhav, Pramod, and Ramanathan 2019). This study will utilize the median imputation in most cases, aside from those LEHD variables set to null instead of zero that can be reasonably set to zero.

Approaches to Place Typology

For its analysis of place typology, this study follows a recent place type analysis by Dr. Kristina Currans, who used the following indicators of the built environment to create types of transit station area places. These are found in the literature to describe the Ds of the built environment (Bartholomew & Ewing, 2011; Ewing & Cervero, 2001, 2010; K. Park et al., 2020):

Longitudinal Employer-Household Dynamics (LEHD, 2017)[15]

- Jobs per acre
- Proportion of jobs that are retail and arts

American Community Survey (ACS, 2017, 5-year)[16]

- Total population per acre
- Total households per acre
- Percent of households with no kids
- Percent of owner-occupied housing

Smart Location Database[17]

- Intersections per square mile
- Proportion of intersections with 3 to 4 vertices[18]

The analysis applied was Jenks natural breaks, with 5 categories for each of the above listed variables, breaking the distribution of each variable into rankings from low to high, scored from 1 to 5. These variables were then summed for each census block group and reclassified into four categories from 1 = low land use mix and accessibility to 4 = high (A. C. Nelson et al., 2020). This study uses the variables separately rather than as classes based on the Jenks breaks approach.

Spatial Clustering Methods

Moran's *I*, a global measure of spatial autocorrelation, a spatially weighted version of the Pearson correlation coefficient (Jackson et al., 2010), is the most appropriate analysis to begin with, as it determines overall levels of spatial clustering in a given region or total study area. Then, if it identifies statistically significant clustering, this finding indicates that more neighborhood-level measures can be used (and at what distance band), such as the Getis & Ord Gi* statistic, which identifies neighborhood-level hot or cold spots of a given variable, assigning z scores and p values for quantification.

The Getis & Ord Gi* metric measures the degree of association resulting from the concentration of weighted points or areas and the other weighted points or areas within a given neighborhood, which is defined by distance *d* from the origin *i*. The index is based on the value of a chosen variable scaled by the distance between origin and destinations.

[15] See LEHD website: https://lehd.ces.census.gov/. Accessed 4/28/2024.
[16] See ACS website: https://www.census.gov/data.html. Accessed 4/28/2024.
[17] See https://www.epa.gov/smartgrowth/smart-location-mapping. Accessed 8/25/2021.
[18] Proportion of intersection density here is calculated from the multimodal intersections with 3 or 4 legs as a proportion of total intersections, both multimodal and auto-oriented.

The count of significant clusters of workers that are near significant clusters of jobs inside the transit neighborhoods (based on peak Moran's *I* distance bands and/or half-mile distance bands) is compared to the counts for the rest of the region. The variables will include jobs at different wage levels and workers at different wage levels.

While many studies have shown that the difference between Manhattan and Euclidean distance has a negligible effect on spatial measures, Cervero (R. Cervero, 1989) used travel time rather than Euclidean distance as a stronger measure for impedance in a gravity model. Moreover, Schleith et al (Schleith et al., 2016) used network distance to improve measures of cost and the impact on various modes of travel. This article will use Euclidean distance as an appropriate measure for its specific questions.

Logistic Regression

The study's approach, logistic regression, is based on the maximum likelihood estimator (MLE), which is necessary because of the assumptions that the dependent variable, which is binary, breaks the assumptions of the OLS linear regression method. These include the normality of the dependent and explanatory variables, as well as that of uniformity in the error variance, or homoskedasticity. The assumption of a linear relationship between dependent and explanatory variables is also broken, given the dichotomous nature of the Bernoulli distribution on which logistic regression is based. The Bernoulli distribution is a measure of successful trials of the outcome variable. Logistic regression transforms that distribution into a probability distribution of successful trials, or more precisely, a logit distribution, which is a logarithmic transformation of the odds. That is, the link function transforms the dichotomous variable with the "natural logarithm of the odds for success," (Mahmood 2024) as seen in the equation:

$$logit(p) = mx + c \tag{1}$$

$$ln\frac{p}{1-p} = mx + c \tag{2}$$

Where p is the probability, $\frac{p}{1-p}$ is the odds, or probability of one group divided by the probability of the other group, *m* is the vector of coefficients of the independent and identically distributed (i.i.d) explanatory variables, *x*, and *c* is the y-intercept. An error term, *ε,* is included in the estimated model.

Assumptions that still apply to the MLE distribution and therefore to logistic regression, include low multicollinearity between explanatory variables, independently distributed variables (no hierarchical nesting of the variables), additive terms, dealing with any outliers, and spatial stationarity. These must be diagnosed and made to be true if we are to trust the outcome of deviance (the MLE approximate cognate of standard error) and significance testing of our model results. Interpreting the coefficients, we see that for every one-unit change in an explanatory variable, the probability changes a specific amount, which varies for each vector of explanatory variables.

This method uses odds rather than probabilities. Odds are a ratio between probability of a successful outcome to a trial and a failed outcome. Taking the logarithm of the odds ensures that values are positive, and that there is a linear relationship between dependent and explanatory variables. The literature frequently uses the odds ratio as a metric, which is a ratio between the conditional odds of successful trials and those that are unsuccessful; or put differently, the slope of the change in odds between group 1 and group 2; or the conditional odds of the target group divided by the conditional odds of a non-target group (Osborne 2015).

Analysis Process

Next, a logistic regression analysis will regress significant employment clusters on residential clusters and distance to transit. Sensitivity analyses will add controls. Significant positive residuals per distance band will denote the sub-centers, which will be graphed per distance band by station type over time.

The analysis process will proceed as follows: First global spatial autocorrelation analyses will establish whether there is a presence of autocorrelation in employment variables in the region, and at what scale it exists. This becomes a useful parameter for local measures of spatial autocorrelation, such as Gi* or Local Moran's *I.* This will produce 6 cluster analyses: 2 (residence/workplace) * 3 time periods.

Interesting spatial patterns emerged in the case city. In the process of analyzing the clustering size of jobs and workers' residences, lots of different scales exhibited statistically significant clustering. For the first pass the algorithm determined the scale. This pass returned a really large scale of clustering. Cleveland's larger clustering pattern is at about 8 miles. This is too large a scale for this study's questions, so the second pass was set to start at half a kilometer and increment a half-kilometer 15 times. The results were useful. Because the results all had statistically significant z scores, it indicated that significant clustering is happening at all of the distances, but the trick is to find a distance at which there is a peak in the clustering z score. In some cases, there was a peak, and in other cases there was no peak, but the results were significant, nevertheless. This process highlights the needed iterative process between the algorithms and the content expert. The analysis of the job clustering will be conducted at a relatively smaller scale than the highest-intensity distances found by the algorithm, which in the case of Cincinnati is on the scale of approximately 8 kilometers. The smaller scale of the case cities, which is still statistically significant, is from 1 to 5 kilometers.

Geographically-weighted Regression (GWR) analysis of subcenters will regress job density on distance to the traditional CBD. 12 GWR calibrations will occur, for 4 regions over 3 time periods. This process identifies statistically significant clusters of jobs as a function of the distance to the CBD.

Logistic regression analysis of the relationship between job location clusters and worker residence clusters with relevant model controls, e.g., centers/subcenters, proximity to transit, and place type will seek to explain the patterns of job clustering across the Cleveland region. Regressing job centers on workers' residential centers and distance to transit will measure their association over time. Sensitivity analysis will apply additional demographic and BE controls where available by year from the US Census Bureau.

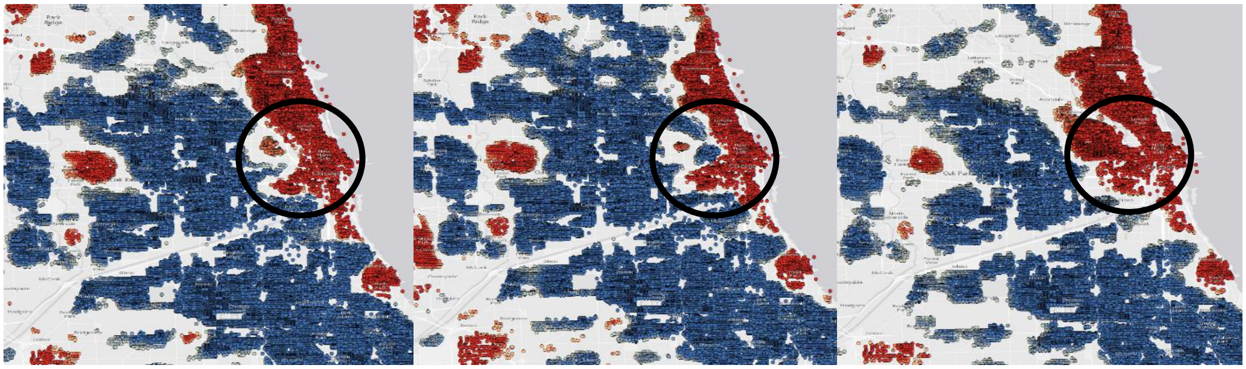


Figure 9. Map Series from a preliminary study (Hibberd & Nelson 2018): Gi for High-Income Housing in Chicago Before, During, and After Great Recession (years for images, left to right: 2002, 2009, 2014), with statistically insignificant features removed. Downtown Chicago circled in black outline.*

CBG groups with workers' residences with a 95% confidence level from the Gi* metric will be evaluated for proximity to transit *and* to worker residence. One might expect the result of the longitudinal comparison of the figures for 2002 to be that the number of workers in these locations will have increased through the period approximately in accordance with population increase regionwide.

Sensitivity analyses will be performed by adding relevant demographic controls for 2009 and 2013, such as percent white population, vehicles per household; and built environment (BE) variables for land use mix and accessibility, such as percentage of jobs that are in the retail or arts sectors, households per acre and intersection density.

Northings (Ycoord) and eastings (Xcoord) are included in the model to reduce the presence of spatial dependence. These variables do so by controlling for spatial location.

Results and Discussion

The following were measured across the three annual time periods of the study:

- Moran's *I* of employment
    - There were also statistically significant patterns on a smaller scale that are more relevant for this study. These are not the strongest clustering patterns in the region, but they are nevertheless a valid pattern.
- CBD locations, which are based on downtown centers.
- Job subcenters for separate wage levels across time periods. This is based on regressing job density by wage level on distance to the main CBD.
- Logistic regressions, with tables of the results of each regression: wage level, year, and sensitivity analyses. Job centers [concentrations in each CBG] regressed on residence centers and transit station distance bands.

- Sensitivity analyses results for demographic variables.

An exploratory analysis that regressed a continuous version of the dependent variable on the candidate variables produced a variety of results, varying greatly across the time periods. This highlights the great variability even within transit-served urbanized city zones. VIF scores revealed the following: Cleveland showed collinearity between distance to the CBD, distance to regional subcenters and job accessibility. This may be due to the small size of the study area in each metro.

Correlations for Cleveland in 2013 showed that the workers' residential areas are highly correlated with each other across the 3 wage levels, and that they are not highly correlated with workers' job locations. High correlations are above 0.7 and are statistically significant. It also showed that median household income was highly correlated with the percentage of the population that was white. It showed that distance to subcenters was highly correlated with distance to the CBD and with job accessibility. Therefore, it becomes necessary to either remove or instrument these variables. This study chose the former option. This is somewhat problematic, given the theoretical prominence of all these variables.

Table 6. ***.*** *Highest Distances of Spatial Dependency*

Global Moran's *I* Results

City	Dist. (Km)	Z score	Distance (Km)	Z score	City	Dist. (Km)	Z score	Distance (Km)	Z score
Cleveland			Smaller Scale		**Cleveland**			Smaller Scale	
WAC 2006	3	11.75	2	12	RAC 2006	8	45	1	5
WAC 2009	3	12.25	2	16	RAC 2009	8	55	1	10
WAC 2013	3	9.5	2	15	RAC 2013	8	42	1	5

Table 7. Variables in the Model

Variable Code or Name	Variable Description and Justification	Source	Expected Sign
Spatial Dependence and Economic Variables			
SDW – dependent variable	Dichotomous spatial dependence of workers' jobs.	GIS/LEHD	NA
DSDR	Distance to significant residential clusters.	GIS/LEHD	-
Xcoord, Ycoord	Eastings/Northings of CBGs. Controls for spatial dependency.	GIS/NHGIS	
PctLwr	Percent lower wage jobs in the CBG.	GIS/LEHD	
PctMid	Percent middle wage jobs in the CBG.	GIS/LEHD	
PctUpper	Percent upper wages jobs in the CBG.	GIS/LEHD	
PctLwrR	Percent lower wage residences in the CBG.	GIS/LEHD	
PctMidR	Percent middle wage residences in the CBG.	GIS/LEHD	
PctUpperR	Percent upper wages residences in the CBG.	GIS/LEHD	
Centering and Access Variables			
DSUB[19]	Distance to Subcenter – a measure of polycentricity.	GIS	-
DCBD	Distance to CBD – a measure of centering.	GIS	-
JobGravity	Gravity – access to jobs within a 45-minute commute.	SLD	+
Place Typology Variables			
PctHHnoKid	Percent households with no children, attracted to High MA areas.	GIS/ACS	+
JobsAc	Jobs per acre – metric of development intensity.	GIS/ACS	+
PrpRetArts	Proportion of jobs that are retail and arts - A measure of development intensity.	GIS/LEHD	+
TotalHHAc	Total households per acre	GIS/ACS	+
PctOwnOcc	Percent of owner-occupied housing - High MA areas typically have less.	GIS/ACS	-
IntSqMile	Intersection density per square mile. Built environment potential for development intensity and active transportation.	SLD	+
Prp3_4legs	Proportion of intersections with 3 or 4 vertices - Denoting grid-style roads	SLD	+
Demographic Controls			
MedHHinc	Median household income	ACS	+
White_Pct	White percent of population	GIS/ACS	+
OnePersHH	Single-person households	ACS	+
PctHHnoVeh	Percent Households with no vehicles	ACS	+
CarShare	Car share of trips (%) = Auto trips / Total Workers	GIS/ACS	-
TransitShare	Transit share of trips (%)	GIS/ACS	+
Transit Variables			
DFGT 1/4-mi., ½-mi., etc.	Distance to Fixed Guideway Transit Stations – Quarter-mile Dummies	GIS/GTFS	+

[19] Subcenters are considered those meeting two criteria: 1) a centering score of 2.5 or more standard deviations, and 2) a density of 20 or more jobs per acre.

Logistic Regression Results

There were separate regression runs across three separate years, and three separate wage levels. Further, the regressions are presented in two stages; the first focuses on employment and land use patterns, while the second expands upon the first by adding theoretically important demographic variables.

The resulting estimates of the dependent variable (the Y-hat variable) can profitably be compared to the actual reality, which can be taken from the data observations. In the measure of *concordance*, or the measure of match between observed and predicted estimates, a confusion matrix will compare predicted and actual values of the dependent variable, and then a ROC curve will measure the fitness of the model from the confusion matrix. Four possible cases exist: 1) those predicted as true that are actual positives, 2) those predicted as false that are actual positives, 3) those predicted as false that are actual negatives, and 4) those predicted as true that are actual negatives. These results are cross tabulated according to a decision rule that sets a range of thresholds determining the "true" and "false" results of a trial. Concordance is reported for each regression.

Pearson correlations show various instances of collinearity between variables. Correlation tests show that distance to the CBD, regional job accessibility, and distance to subcenters across the region are often highly correlated, and therefore related phenomena. Significant exceptions to this pattern exist by region, however, and these phenomena can often be considered orthogonal. Percentages of jobs were too correlated across the wage categories to analyze in the same model; therefore, separate models were run for each category.

In some instances, collinearity between variables indicates similarities between the variables on the ground. For example, in Cleveland for the year 2009, distance to subcenters, distance to the CBD and job accessibility were all high correlated, and job accessibility was chosen as the proxy to represent all three variables. It is theorized that the collinearity between these variables is due in part to the geographic size and development patterns of Cleveland. However, these variables were not so collinear in other years, and were used in analyses for 2006 and 2013. In 2009 Cleveland's variables of the percent of households without vehicles and the percentage of owner-occupied housing were highly negatively correlated.

Also peculiar was the distance to residential clusters. In 2009 Cleveland's clusters were all too distributed throughout the urbanized area of the region to be found very far from any of the area's census block group boundaries, from which the distance measurement was taken. It had to be removed from the variable list.

Wald test compares each model to a baseline of the intercept-only model. The latter is calibrated and used as a basis for comparison. The variance-covariance matrix of the coefficients of the logistic regression is used as a basis for comparison. The F distribution is used, with the null hypothesis that the full model is not statistically significantly different from the intercept-only (or null) model.

Deviance residuals were checked for reasonable distributions, with medians approaching zero and minimum and maximum values at approximately 3 deviations. The results used for this study fall approximately within those parameters.

Northings (Ycoord) and eastings (Xcoord) are included in the model to reduce the presence of spatial dependence. These variables do so by controlling for spatial location. While they are found to be statistically insignificant, they remain in the models for their corrective effects.

Two versions of the logistic regressions are presented. The first constitutes employment and land use place type variables. The second, which is the sensitivity analysis, tests which demographic variables are relevant to the question. While many variations were found in the tests for significant variables, several variables were nearly always significant.

The following tables present the standardized coefficients and their level of statistical significance.

Table 8. Cleveland Logistic Regressions by Wage Category – Employment and Land Use Variables for 2006

Cleveland 2006											
Low Wage				**Mid Wage**				**Upper Wage**			
	Est.	**SE**	**Pr.**		**Est.**	**SE**	**Pr.**		**Est.**	**SE**	**Pr.**
(Intercept)	-5.00	0.42	***		-5.06	0.43	***		-5.03	0.43	***
JobsAc	0.80	0.18	***		0.85	0.19	***		0.87	0.18	***
D3b	-0.87	0.25	***		-0.94	0.26	***		-0.87	0.26	***
MSUB	-0.51	0.31			-0.39	0.32			0.22	0.39	
Prp3_4legs	-0.26	0.20			-0.27	0.20			-0.29	0.25	
PrpRetArts	0.22	0.26			0.00	0.20			0.16	0.20	
PctLwr	-0.36	0.27		PctMid	-0.07	0.18		PctUpper	0.41	0.21	*
PctLwrR	-0.35	0.15	*	PctMidR	-0.50	0.15	***	PctUpperR	-0.45	0.18	**
Xcoord	-0.08	0.30			0.04	0.30			-0.29	0.17	
Ycoord	0.07	0.39			0.08	0.39			0.30	0.30	
DFGT 1/4-mi.	2.36	0.54	***		2.54	0.56	***		2.01	0.40	***
DFGT 1/2-mi.	2.14	0.60	***		2.21	0.61	***		1.89	0.57	**
DFGT 3/4-mi.	0.87	0.87			0.94	0.88			0.78	0.63	
DFGT 1-mi.	1.01	0.86			0.92	0.86			0.62	0.89	
								DSDR	0.66	0.88	**
McF.R^2	0.35	LnLik.	-126	McF.R^2	0.36	LnLik.	-124	McF.R^2	0.38	LnLik.	-119
AIC	279.6	-2LnLik	251.6	AIC	275.8	-2LnLik	247.8	AIC	268.6	-2LnLik	238.6
BIC	350.1	Con	0.89	BIC	346.3	Con	0.98	BIC	344.2	Con	0.9
Df.diff	-13	Wald	***	Df.diff	-13.0	Wald	***	Df.diff	-14.0	Wald	***
LogLik.diff	-66.9	n.obs	1141	LogLik.diff	-68.8	n.obs	1141	LogLik.diff	-73.5	n.obs	1141
Chisq	134.0			Chisq	137.8			Chisq	146.9		
p.value	0			p.value	0.00			p.value	0.00		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Diagnostic codes: McF.R^2 = McFadden's pseudo R-squared,; Con = concordance, Df.diff = degrees of freedom difference , LogLikdiff = log likelihood difference , Chisq = chi squared value for likelihood ratio test. LnLik = log likelihood, -2LnLik. = -2 log likelihood.

In 2006, for all wage categories, residential concentrations were negatively associated with job clusters. Upper wage concentrations were positively associated with job clusters. Jobs per acre were a strong positive control for job clusters. Intersection density was significant and negatively associated with job clustering.

Subcentering, centering and job accessibility were all highly correlated, with MSUB standing as proxy for the 3 variables, as well as proxy for distance to residential clusters (DSDR). This is an imperfect proxy because it does not capture all of the characteristics of the other variables, but its correlation with the other variables tells us a good deal about it.

The lack of significant associations between job clusters and those testing place typology for human scale—the number of 3 or 4-leg intersections, the proportion of retail and arts jobs and therefore land uses—tells us that other considerations of the regional economic system took precedence over human proximity and walkability. However, proximity to transit has the expected sign and is significant across the wage groups up to half a mile from the station.

In 2009, jobs per acre and job accessibility were significant and positively associated with job clustering. Job accessibility served as proxy for distance to residential clusters (DSDR), and centering variables of distance to the CBD and distance to subcenters. Low wage job percentages were not associated with job clustering, while mid-wage residential locations were negatively associated, and upper-wage job locations were positively associated with job clusters. As in 2006, proximity to transit stations continued to be positively associated with job concentrations up to a half-mile distance from the station. Intersection density was negatively associated with job concentrations, likely due to the development patterns of parcels with job clusters.

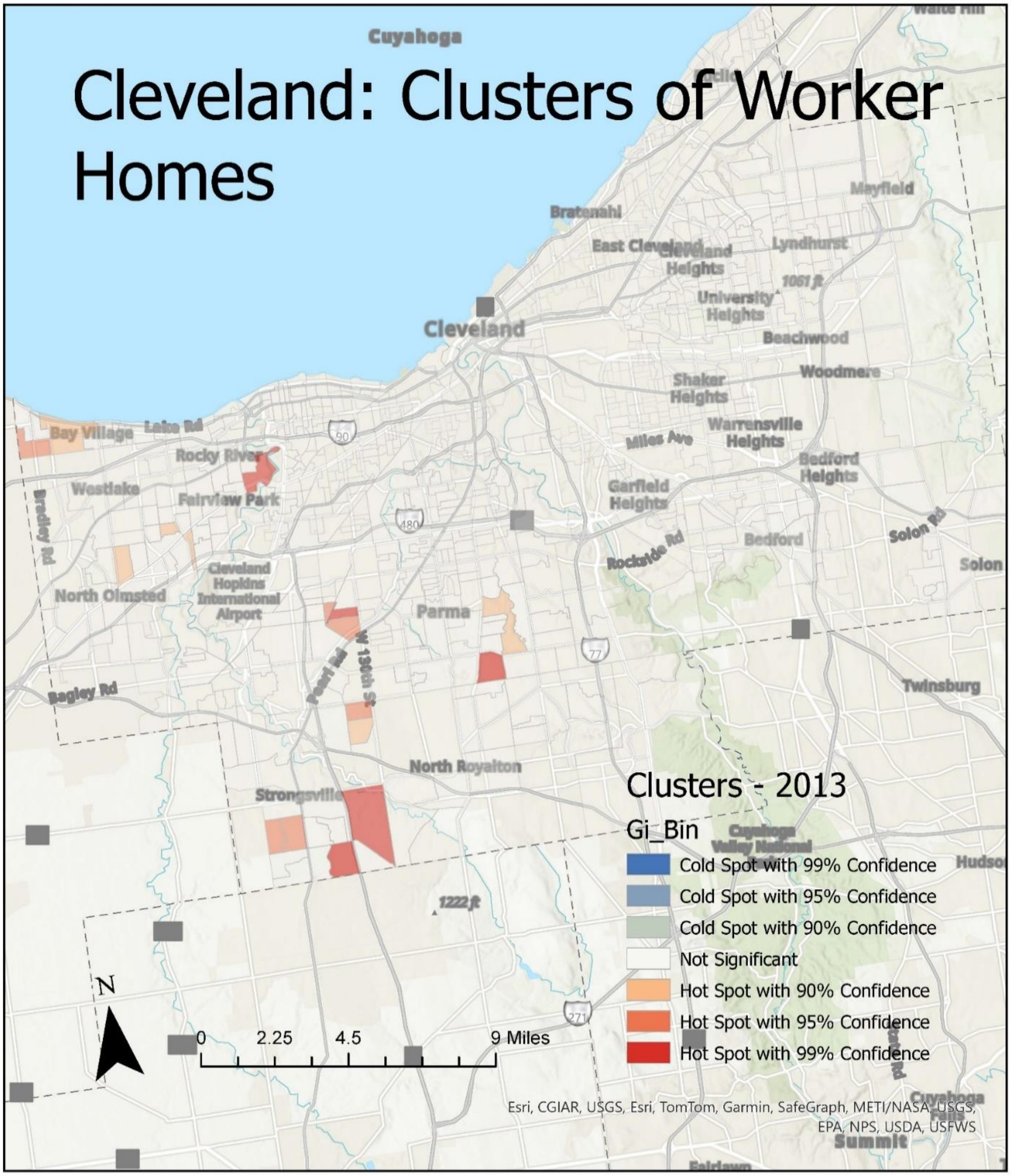


Figure 10. Cleveland residential clusters, derived from Gi analysis.*

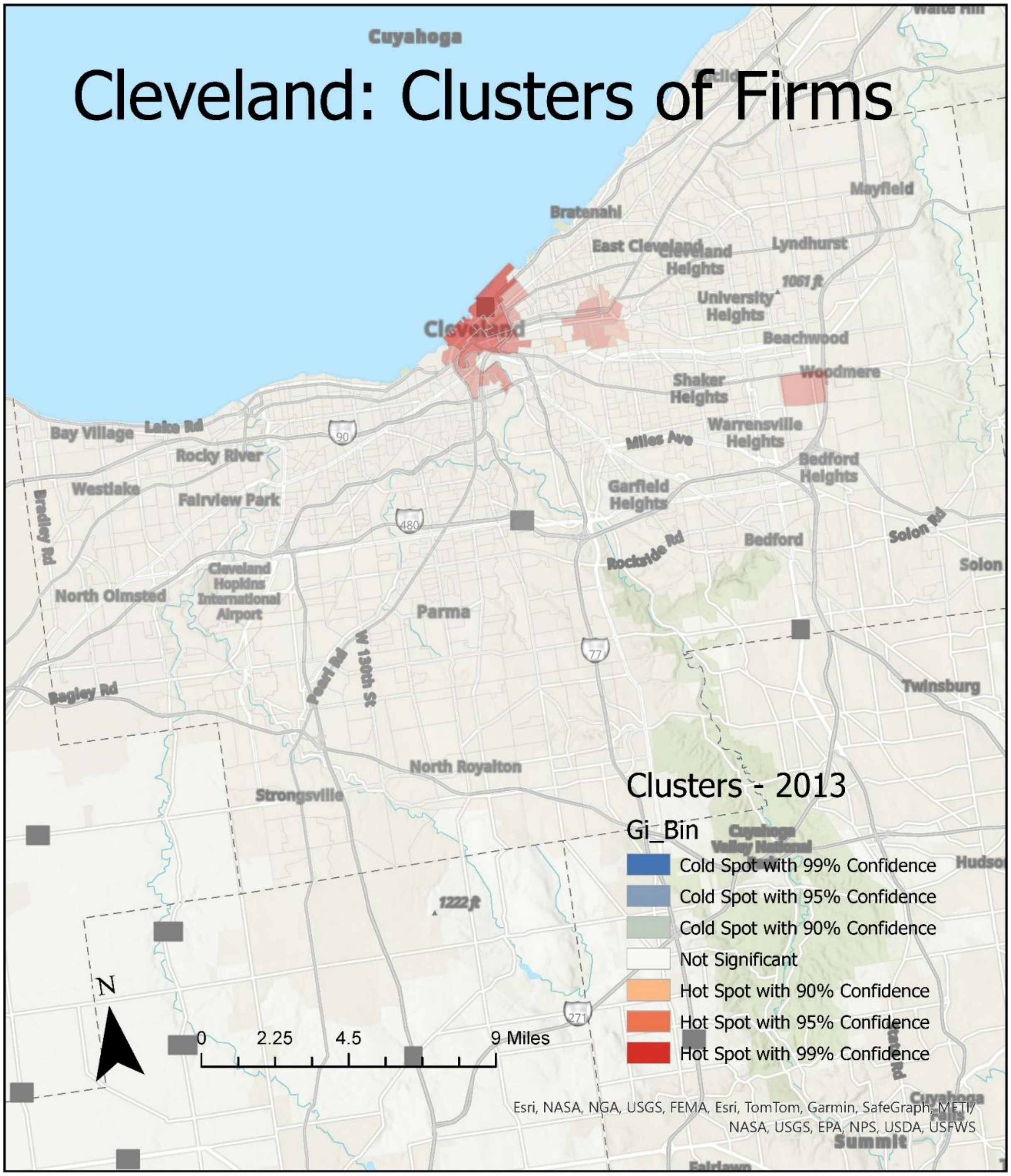


Figure 11. Cleveland job clusters, derived from Gi analysis.*

Table 7 (cont.). Cleveland Logistic Regressions by Wage Category – Employment and Land Use Variables for 2009

Cleveland 2009											
Low Wage				**Mid Wage**				**Upper Wage**			
	Est.	**SE**	**Pr.**		**Est.**	**SE**	**Pr.**		**Est.**	**SE**	**Pr.**
(Intercept)	-5.00	0.44	***		-5.01	0.44	***		-5.22	0.47	***
JobsAc	0.45	0.14	**		0.54	0.16	***		0.51	0.15	***
D3b	-0.87	0.28	**		-0.96	0.29	***		-0.79	0.28	**
D5ar	0.82	0.26	**		0.73	0.27	**		0.80	0.27	**
Prp3_4legs	-0.02	0.22			-0.04	0.22			0.00	0.22	
PrpRetArts	0.50	0.34			0.08	0.23			0.37	0.25	
PctLwr	-0.56	0.36		PctMid	-0.29	0.24		PctUpper	0.62	0.21	**
PctLwrR	0.12	0.18		PctMidR	-0.40	0.18	*	PctUpperR	0.26	0.22	
Xcoord	0.25	0.33			0.21	0.33			0.36	0.34	
Ycoord	-0.12	0.41			-0.09	0.42			-0.05	0.41	
DFGT 1/4-mi.	1.42	0.61	*		1.54	0.62	*		1.51	0.61	*
DFGT 1/2-mi.	1.65	0.69	*		1.41	0.71	*		1.95	0.72	**
DFGT 3/4-mi.	0.92	0.88			0.83	0.90			1.15	0.91	
DFGT 1-mi.	0.97	0.87			0.65	0.87			1.08	0.88	
McF.R^2	0.29	LnLik.	-105	McF.R^2	0.30	LnLik.	-103.8	McF.R^2	0.32	LnLik.	-101.9
AIC	238.9	-2LnLik	210.9	AIC	235.6	-2LnLik	207.6	AIC	231.8	-2LnLik	203.8
BIC	309.4	Con	0.88	BIC	306.2	Con	0.9	BIC	302.3	Con	1.0
Df.diff	-13.0	Wald	***	Df.diff	-13.0	Wald	***	Df.diff	-13.0	Wald	***
LogLik.diff	-44.0	n.obs	1141	LogLik.diff	-45.6	n.obs	1141	LogLik.diff	-47.6	n.obs	1141
Chisq	88.0			Chisq	91.3			Chisq	95.1		
p.value	0.0			p.value	0.0			p.value	0.0		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Diagnostic codes: McF.R^2 = McFadden's pseudo R-squared,; Con = concordance, Df.diff = degrees of freedom difference , LogLikdiff = log likelihood difference , Chisq = chi squared value for likelihood ratio test. LnLik = log likelihood, -2LnLik. = -2 log likelihood.

Table 7 (cont.). Cleveland Logistic Regressions by Wage Category – Employment and Land Use Variables for 2013

Cleveland 2013											
Low Wage				**Mid Wage**				**Upper Wage**			
	Est.	SE	Pr.		Est.	SE	Pr.		Est.	SE	Pr.
(Intercept)	-5.25	0.50	***		-5.31	0.51	***		-5.20	0.49	***
JobsAc	0.67	0.18	***		0.62	0.18	***		0.71	0.18	***
D3b	-0.37	0.20	.		-0.43	0.21	*		-0.38	0.21	.
MSUB	0.25	0.43			0.34	0.44			0.38	0.44	
DSDR	1.28	0.29	***		1.33	0.29	***		1.28	0.29	***
Prp3_4legs	-0.32	0.20			-0.34	0.17	.		-0.35	0.20	.
PrpRetArts	0.05	0.26			-0.01	0.14			-0.14	0.21	
PctLwr	-0.36	0.25		PctMid	0.28	0.20		PctUpper	0.00	0.18	
PctLwrR	-0.45	0.14	**	PctMidR	-0.44	0.22	**	PctUpperR	-0.45	0.18	*
Xcoord	-0.17	0.35			-0.08	0.35			-0.21	0.35	
Ycoord	0.34	0.40			0.35	0.40			0.36	0.40	
DFGT 1/4-mi.	1.63	0.61	**		1.75	0.63	**		1.66	0.61	**
DFGT 1/2-mi.	2.03	0.65	**		2.05	0.66	**		1.98	0.65	**
DFGT 3/4-mi.	1.56	0.74	*		1.61	0.75	*		1.55	0.73	*
DFGT 1-mi.	0.82	0.83			1.04	0.81			0.72	0.82	
McF.R^2	0.45	LnLik.	-118	McF.R^2	0.45	LnLik.	-118	McF.R^2	0.43	LnLik.	-121
AIC	266.6	-2LnLik	236.6	AIC	266.4	-2LnLik	236.4	AIC	272.5	-2LnLik	242.5
BIC	341.6	Con	0.9	BIC	341.4	Con	0.9	BIC	347.4	Con	0.9
Df.diff	-14.0	Wald	***	Df.diff	-14.0	Wald	***	Df.diff	-14.0	Wald	***
LogLik.diff	-96.1	n.obs	1095	LogLik.diff	-96.2	n.obs	1095	LogLik.diff	-93.2	n.obs	1095
Chisq	192.3			Chisq	192.5			Chisq	186.4		
p.value	0.0			p.value	0.0			p.value	0.0		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Diagnostic codes: McF.R^2 = McFadden's pseudo R-squared, Con = concordance, Df.diff = degrees of freedom difference , LogLikdiff = log likelihood difference , Chisq = chi squared value for likelihood ratio test. LnLik = log likelihood, -2LnLik. = -2 log likelihood.

In 2013, distance to residential clusters (DSDR) became statistically significant and positively associated with job clustering. Also, positive and statistically significant were jobs per acre, and proximity to transit stations up to three-fourths of a mile from the station. Negatively associated with job clustering was intersection density and percentages of low, mid, and upper-wage residences. Indicators of human scale, such as 3 -4 leg intersections and proportion of jobs that are in retail and arts were not statistically significant.

Table 9. Cleveland Logistic Regressions by Wage Category – Employment, Land Use and Demographic Variables for 2009

Cleveland 2009											
Low Wage				**Mid Wage**				**Upper Wage**			
	Est.	SE	Pr.		Est.	SE	Pr.		Est.	SE	Pr.
(Intercept)	-5.76	0.55	***		-5.57	0.51	***		-5.77	0.54	***
JobsAc	0.46	0.14	***		0.54	0.15	***		0.52	0.14	***
D3b	-0.28	0.30			-0.44	0.32			-0.27	0.31	
MCBD	-0.31	0.34			-0.32	0.35			-0.24	0.34	
PrpRetArts	0.73	0.38	.		0.10	0.26			0.49	0.27	.
PctLwr	-0.71	0.42	.	PctMid	-0.36	0.27		PctUpper	0.59	0.23	**
PctLwrR	0.18	0.19		PctMidR	-0.41	0.20	*	PctUpperR	0.20	0.23	
Xcoord	0.47	0.36			0.38	0.37			0.42	0.36	
Ycoord	-0.07	0.39			0.03	0.40			-0.05	0.39	
OnePersHH	0.45	0.21	*		0.52	0.21	*		0.44	0.21	*
TtlHHAc	-1.39	0.40	***		-1.15	0.40	**		-1.29	0.41	**
PctWhite	0.45	0.35			0.46	0.35			0.23	0.36	
TrnstShare	0.04	0.21			-0.02	0.21			-0.03	0.21	
PctHHnoKids	0.02	0.22			-0.10	0.21			0.02	0.22	
PctOwnOcc	-0.48	0.31			-0.42	0.31			-0.47	0.31	
Prp3_4legs	-0.11	0.25			-0.07	0.25			-0.06	0.25	
DFGT 1/4-mi.	2.12	0.67	**		2.08	0.67	**		2.11	0.66	**
DFGT 1/2-mi.	2.88	0.77	***		2.29	0.76	**		2.82	0.78	***
DFGT 3/4-mi.	1.72	0.96	.		1.50	1.01			1.86	0.98	.
DFGT 1-mi.	2.03	0.94	*		1.50	0.93			1.82	0.95	.
McF.R^2	0.35	LnLik.	-96.7	McF.R^2	0.36	LnLik.	-95.8	mcf	0.36	LnLik.	-95
AIC	233.44	-2LnLik	193	AIC	231.6	-2LnLik.	192	AIC	230.0	-2LnLik	190
BIC	334.23	Con	0.92	BIC	332.39	Con	93	BIC	330.8	Con	0.93
Df.diff	-19	Wald	***	Df.diff	-19	Wald	***	Df.diff	-19	Wald	***
LogLik.diff	-52.7	n.obs	1141	LogLik.diff	-53.64	n.obs	1141	LogLik.diff	-54.4	n.obs	1141
Chisq	105.5			Chisq	107.29			Chisq	108.8		
p.value	0			p.value	0			p.value	0		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Diagnostic codes: McF.R^2 = McFadden's pseudo R-squared, Con = concordance, Df.diff = degrees of freedom difference , LogLikdiff = log likelihood difference , Chisq = chi squared value for likelihood ratio test. LnLik = log likelihood, -2LnLik. = -2 log likelihood.

The sensitivity analysis highlights an interesting pattern overall: that the demographic variables considered are not significantly associated with the job clustering patterns in Cleveland. This includes percent white population, households without children, and percent of housing that is owner-occupied. Moreover, the other candidate demographic variables from table 7 above were excluded due to collinearity. The region tested was small enough that clusters of jobs of 20 per acre or more could be found across the region, which reduced the statistical significance of the CBD in terms of job clustering. In 2009 the most salient features for explaining job clustering were jobs per acre, single person households, total households per acre, and proximity to transit stations, excluding express or regular bus routes. Percent lower wage and upper wage jobs were statistically significant explanations for job clustering. Mid-wage residential as a percentage of all households was another significant explainer of job cluster variance. The prominence of retail and arts had some significance in the 2009 sensitivity analysis, as well. In this analysis, percentages of both lower and upper wage jobs were significantly and positively associated with job clustering. This contrasts with the first regression, which only makes upper wage job percentages relevant.

In 2013 approximately half of the variance in job clustering could be explained by the study variables. Jobs per acre was positively associated with job clustering. So too was distance to subcenter residential clusters. Distance to residential clusters was significant and positively associated with job clusters. Intersections with 3 or 4 legs were negatively associated with job clustering. Distance to subcenters was sufficiently noncollinear to include in the analysis, but still not significantly associated with job clustering. This begs the question of whether there are different kinds of centers. Measuring subcenters as a function of distance from the CBD is sensible given the central role in the theory of subcenters being subsidiary to the main center of the region in the CBD. Further research ought to measure the presence of job clusters in this fashion, as functions of their distance from the CBD. As with the trend in 2009, the significant demographic variables are limited to single-person households and households per acre. Proximity to transit was a positive significant association up to three-fourths of a mile from the stations. This is a longer distance than most studies have found for transit's influence. This is likely because the pattern under study is the drivers of job concentrations. While transit was influential, it still appears to be interconnected with autocentric development patterns. This makes sense, given the small spatial footprint of TOD neighborhoods.

Table 8 (cont.) Cleveland Logistic Regressions by Wage Category – Employment, Land Use and Demographic Variables for 2013

Cleveland 2013											
Low Wage				**Mid Wage**				**Upper Wage**			
	Est.	SE	Pr.		Est.	SE	Pr.		Est.	SE	Pr.
(Intercept)	-7.66	3.04	*		-8.10	3.04	**		-7.82	2.95	**
JobsAc	0.59	0.21	**		0.50	0.21	*		0.59	0.21	**
D3b	-0.27	0.23			-0.34	0.24			-0.29	0.23	
DSDR	1.20	0.31	***		1.31	0.31	***		1.26	0.31	***
MSUB	0.28	0.46			0.33	0.46			0.33	0.46	
PrpRetArts	0.03	0.28			0.01	0.24			-0.18	0.22	
PctLwr	-0.34	0.27		PctMid	0.35	0.20	.	PctUpper	-0.07	0.20	
PctLwrR	-0.43	0.16	**	PctMidR	-0.43	0.15	**	PctUpperR	-0.42	0.19	*
Xcoord	-0.36	0.39			-0.25	0.39			-0.39	0.40	
Ycoord	0.22	0.41			0.25	0.41			0.24	0.41	
OnePersHH	0.62	0.22	**		0.62	0.23	**		0.63	0.23	**
TtlHHAc	-0.57	0.28	*		-0.67	0.29	*		-0.65	0.29	*
PctWhite	-0.60	0.37			-0.46	0.38			-0.47	0.36	
MedHHinc	0.36	0.27			0.35	0.28			0.35	0.27	
TrnstShare	0.02	0.16			0.01	0.16			-0.01	0.15	
PctHHnoKids	-0.04	0.18			-0.04	0.18			-0.03	0.17	
PctOwnOcc	-36.61	49.57			-42.65	49.44			-40.38	48.13	
Prp3_4legs	-0.41	0.22	.		-0.43	0.22	.		-0.42	0.22	.
DFGT 1/4-mi.	1.52	0.67	*		1.57	0.68	*		1.49	0.67	*
DFGT 1/2-mi.	2.11	0.69	**		2.08	0.70	**		2.03	0.69	**
DFGT 3/4-mi.	1.87	0.82	*		1.83	0.82	*		1.78	0.80	*
DFGT 1-mi.	1.22	0.85			1.39	0.84	.		1.05	0.85	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1											
McF.R^2	0.48	LnLik.	-111	McF.R^2	0.49	LnLik.	-110	McF.R^2	0.47	LnLik.	-113
AIC	265.63	-2LnLik	222	AIC	263.75	-2LnLik	220	AIC	270.47	-2LnLik	226
BIC	375.6	Con	0.93	BIC	373.71	Con	0.93	BIC	380.44	Con	0.92
Df.diff	-21	Wald	***	Df.diff	-21	Wald	***	Df.diff	-21	Wald	***
LogLik.diff	-103.6	n.obs	1095	LogLik.diff	-104.6	n.obs	1095	LogLik.diff	-101.2	n.obs	1095
Chisq	207.22			Chisq	209.1			Chisq	202.38		
p.value	0			p.value	0			p.value	0		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Diagnostic codes: McF.R^2 = McFadden's pseudo R-squared,; Con = concordance, Df.diff = degrees of freedom difference , LogLikdiff = log likelihood difference , Chisq = chi squared value for likelihood ratio test. LnLik = log likelihood, -2LnLik. = -2 log likelihood.

This article analyses the dynamics of clustering of workers and jobs near transit stations by distance from the station across the time frames from 2009 to 2013. Logistic regression indicated that clustering of workers and jobs had a negligible influence in the beginning of the time period, with the variable being highly correlated with regional accessibility metrics. This association grew and became distinct over the time frame of the study. This occurred in concert with the ongoing negative association between job clustering and residential areas by wage levels, which started thus in 2006 and stayed thus to the year 2013.

Distance bands measure the influence of proximity to the station with the remainder of the region being a referent. Transit stations exerted a positive association throughout the years of the study, with steady to slightly declining influence in 2009 from pre-recession years, and with a strong surge by 2013, as measured by the degree of significance of the distance bands, as well as the increased distance from half to three-fourths of a mile. Additionally, the influence of stations extended to one mile for the mid-wage job analysis.

Place type variables taken separately revealed which were most relevant to this novel study. Tenure, presence of children, and densities of population, households, and intersections, all play a prominent role in other studies of urban development. These phenomena exert so much influence on each other that a full consideration of them must take them together, such as done in studies referenced above. However, taken separately, households per acre and intersection density had the greatest influence among place type variables.

Addressing the hypotheses, the first is partially fulfilled, as upper-wage jobs are joined by the other wage levels in being attracted to the stations across the time periods. When considering both versions of the model, it appears that the significance levels increased at distances further from the station over time. In 2009 there was a positive association between job clustering and the percentage of jobs that were upper wage. This did not remain consistent to 2013. In most cases, percentages of upper-wage residences were negatively associated with job clustering.

The second hypothesis, regarding polycentric development intensifying, was obscured by collinearity with job accessibility and distance to the CBD. This may be due to the relatively small scale of the study region. This does not leave use without any clues, however, regarding subcenters, since the dependent variable itself captures variance related to subcenters. The distance to residential clusters variable is positive, which means that proximity between residential and job clusters has a negative relationship. However, the importance of proximity to transit as an explanatory variable on which job clustering can be predicted cannot be ignored, as the analyses show a consistent and growing association between the former and the latter.

The third hypothesis, related to the second, suggests that transit stations may act as a catalyst for greater concentrations of jobs and residences near each other. The analysis indicates that residential clustering actually had a negative association with job clustering by 2013. Jobs and workers are not clustering together enough to show a strong attraction. However, the expected pattern of positive association between jobs and transit proximity was confirmed, and at an increased distance from the stations over the years of study.

Implications for Land Use & Transportation Policy

This study demonstrates that the clustering of jobs is influenced in part by a unique set of variables, distinct from other areas of research. The demographic profiles that are so oft used had little impact on the outcomes of the studied phenomenon. More influential were variables that fit in the hybrid transit/auto places that have been created through partial implementation of TOD policies. This appears to be due to the ongoing relative sparsity of compact TOD-style development.

Findings show that over the time period, residential clustering did not grow significantly near concentrations of jobs, which indicates that the market responded to the shock of recession by clustering firms but not residential land uses near transit to increase resiliency.

Renne (Renne et al., 2016) revealed the low-hanging fruit for increasing the optimality of land use and transportation policy, which relates to the existing trend of large shares of jobs inhabiting the first half-mile distance from transit stations while a very small share of housing units inhabits that space across the country. This is borne out in this study, as the results show that while transit proximity grows in influence on job clusters, the residential opportunities for TODs has yet to be significantly realized. In *Reshaping Metropolitan America*, Nelson (A. C. Nelson, 2013b) found that there are seas of vacant asphalt parking lots across the country that could serve as new spaces for LE development; moreover, these lots are usually sited at or near streets that, with only partial redevelopment, could provide transportation network access to these lots, including provision of stations along fixed transit systems. Many historically redlined neighborhoods could benefit from such new connections to the regional transportation network, and likely without any gentrification pressures to displace current residents; rather, these neighborhoods suffer more from disinvestment and face the much greater probability that their aging, decline and spatial isolation will go unremedied (Florida, 2017; A. C. Nelson & Hibberd, 2022a).

Accessibility studies via spatial dependence measures have merit, as seen in this study. However, further work should be done to identify variables to instrument and ways to answer directly for spatial nonstationarity in logistic regression, as in spatial autoregressive modeling or geographically-weighted regression. Further studies could be done to expand the regional contexts to include more cities, which would further test the relationship between polycentricity and job accessibility metrics that measure both regional and local accessibility.

Chapter 5: A Jobs-Worker Balance Index and Demographic Trends around TODs

Abstract

Spatial mismatch, the geographic isolation of workers from job centers, can be alleviated by balancing the ratio between jobs and workers within a given commute shed, i.e., the range of typical commuting distance for a region. Theory proposes that this balance increases employment accessibility, which reduces transportation costs, a household budget constraint second only to housing in magnitude. Transit stations are a key location for improvement of regional accessibility of workers to job locations. They serve as a geographic locus of opportunities, and may provide multiple potential benefits, contingent upon optimal implementation: they increase neighborhoods' resiliency to economic shocks, increase ecological soundness and improve regional accessibility. One of their effects is to reduce urban congestion and thus strengthen the regional economy. The diseconomy effect of urban congestion counteracts the effectiveness of mobility as the main source of accessibility. Efforts to reduce spatial mismatch might therefore be profitably focused near transit stations. This article uses a quasi-experimental regression analysis to ascertain the effects of transit proximity to the JWB across many US regions, which is measured as internal capture of work trips within a specified commute shed distance of a worker's origin location. Observations are first taken from a spatially random sample. Redlining's historical effects on job accessibility are considered as a special case. Regionwide dynamics of demographic profiles are compared to those of transit station areas across the years from 2002 to 2017.

Keywords: Internal capture of work trips, accessibility, redlining, propensity score matching

Introduction

Transit-oriented development (TOD) policy concentrates development near transit stations, intending to increase both local and regional accessibility through increasing connectivity to a variety of land uses. How well have TODs addressed spatial mismatch, one of the biggest obstructions of regional accessibility, across the years of the 21st century, and for whom? Spatial mismatch is the isolation of workers from job centers, and jobs-worker balance is the balance of jobs and workers within a given commute shed, i.e., the range of typical commuting distance. Theory proposes that this balance increases employment accessibility, which reduces transportation costs, providing households more funds for housing (Benner & Karner, 2016b; Stoker & Ewing, 2014).

Empirical evidence shows that transit stations may provide multiple potential benefits, contingent upon optimal implementation: they increase neighborhoods' resiliency to economic shocks, increase ecological soundness (A. C. Nelson et al., 2019) and improve regional accessibility (Aston et al., 2021b; Haas et al., 2009). One of their effects is to reduce urban congestion and thus strengthen the regional economy (Anderson, 2013).

The diseconomy effect of urban congestion counteracts the effectiveness of mobility as the main source of accessibility. Efforts to reduce spatial mismatch might be profitably focused near transit stations, which capture about half of US jobs within a half-mile distance, but only about 4% of residences (Renne et al., 2016). In addition to its added transport capacity and network connectivity, transit provides station areas that can serve as sites of higher-intensity land uses. Proximity to transit stations can increase accessibility more effectively than attempting to increase accessibility through expanding infrastructure that is focused solely on mobility-based benefits.

The effectiveness of transit stations at providing accessibility is highly contingent upon multiple factors of land use and transportation policy for the station and its surroundings. The place type of the land proximate to a transit station captures many of the factors that have been shown to influence transit outcomes (A. C. Nelson et al., 2020).

Transit station place typology has an extensive literature, with multiple theoretical streams to consider. The main streams include regional context, connectivity with the surrounding neighborhoods, and the node-place tension. Regional context includes the mix of urban characteristics that create places across the urban hierarchy from urban to suburban to rural. The degree of connectivity and relevance of a transit station to its immediate neighborhood is coined the TOD versus TAD typology, in which transit-adjacent development is insufficiently interconnected to the local transportation network and land uses to be considered truly a transit-integrative neighborhood, or TOD. Finally, the Bertolini paradigm of node-place tension or balance seeks to draw people to the place through transportation network connectivity (the node element) or through the utility of the land use mix at the station (the place element). If either element is insufficiently developed, the other element is said to be "unsustained" (Bertolini, 1996; Renne et al., 2017).

The empirical literature is scant that relates job-worker balance with the demographic and economic dynamics of transit station areas. This study will extend the evidence and consider whether transit stations can be seen empirically to capture growing shares of internal capture of work trips across the years 2002, 2009, and 2017, which represent periods before, during, and after the Great Recession. The economy will be defined in terms of housing and jobs, and the study will test whether there is a better balance of them in these neighborhoods than in the rest of the region, whether jobs match the skill and wage level of residents, and whether housing costs match wages from available local jobs. This will provide new evidence that metropolitan areas investing in fixed route transit systems can become more resilient to economic downturns.

Redlining

One particular area of interest is the effects on historically redlined zones across the time periods. Did these inner-city disinvestment zones respond well between 2002 and 2017 to the nearby transit stations?

Franklin D. Roosevelt's New Deal era programs were responsible for redlining inner city neighborhoods for exclusion from amortizing mortgages and insurance (Rothstein 2019). There was an openly racist policy that mixed-race neighborhoods were investment risks. In 1933 the Home Owner's Loan Corporation was established to rescue mortgages nearly in default. They purchased them and restructured them as 15-year amortizing loans, which newly offered the prospect of gaining ownership equity to many in the working and middle class who had not had this option. The HOLC issued these mortgages with low interest rates to increase affordability, so they needed to take a risk assessment. For this reason, they hired local real estate agents, whose code of ethics *required* racial segregation. Lenders relied upon federal insurance that enforced segregation. Racially mixed neighborhoods were considered high-risk, and thus was born the practice of redlining "high-risk" zones on the HOLC risk assessment maps (Rothstein, 2017).

In 1934 the Federal Housing Administration, established by FDR's administration, set out to provide new opportunities for households to purchase their first mortgages. They did so with the guidance of the HOLC risk assessment maps, and issued guidance that the safest risks were neighborhoods that had little possibility of being "infiltrated" by lower classes or by "inharmonious racial groups." (Rothstein, 2017).

The language used in the descriptions for each zone in the maps makes clear and evident the racial and class divisions used a basis for risk assessment. Red zones, grade D, were labeled "hazardous" on the map; yellow zones, grade C, were "definitely declining;" blue zones, grade B, were "still desirable;" and green zones, grade A, were "best." For example, zone B14 in Oakland, California was graded a B, or blue, which indicated that the area was "still desirable" for investment. The "clarifying remarks" for the zone were as follows:

> Some parts of this area would be considered only High Yellow but for the rigid restrictions existing in Piedmont as to type of new construction and also the fact that there are no Negroes or Asiatics allowed in the city limits. This will help keep even the older areas in favor from residential standpoint.[20]

Zone C19 of Staten Island, NY, grade C, yellow, or "definitely declining," included the following remarks, "detrimental influences: Few negroes on Dewey Ave. 25 mins require for trip to NY ferry. 15 cent fare on bus, 20 cents on railroad. Clarifying remarks: The small percentage of negroes in the area has been there for many years but has not increased."[21] Zone D12 in Denver, Colorado was red, labeled "hazardous" for its "detrimental influences," as follows:

> Negro and foreign infiltration-commercial encroachments. Clarifying remarks: This section, bordering the heavy commercial district to the west and northwest, is an old area now occupied by a combination of Negroes, Mexicans, and a transient class of workers. Shacks, largely held by speculators, rent for as low as $5 per month. Negroes occupy the eastern and better part of the area.[22]

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[20] From Mapping Inequality website. See https://dsl.richmond.edu/panorama/redlining/areadescriptions/negro* . Accessed 12/26/2023.
[21] Ibid.
[22] Ibid.

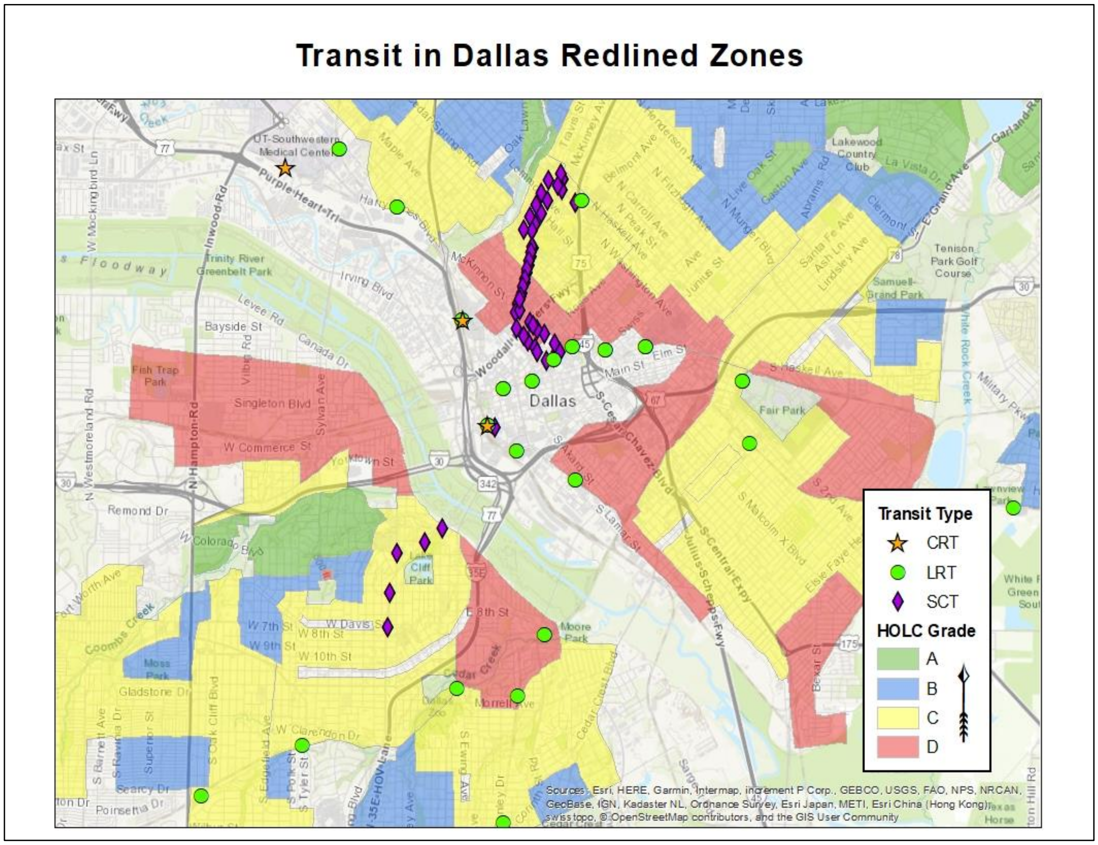

Figure 12. GIS map of HOLC risk assessment zones in Dallas, and currently existing transit stations by mode. Redlined zones (HOLC D) are shown, as well as other HOLC designations.

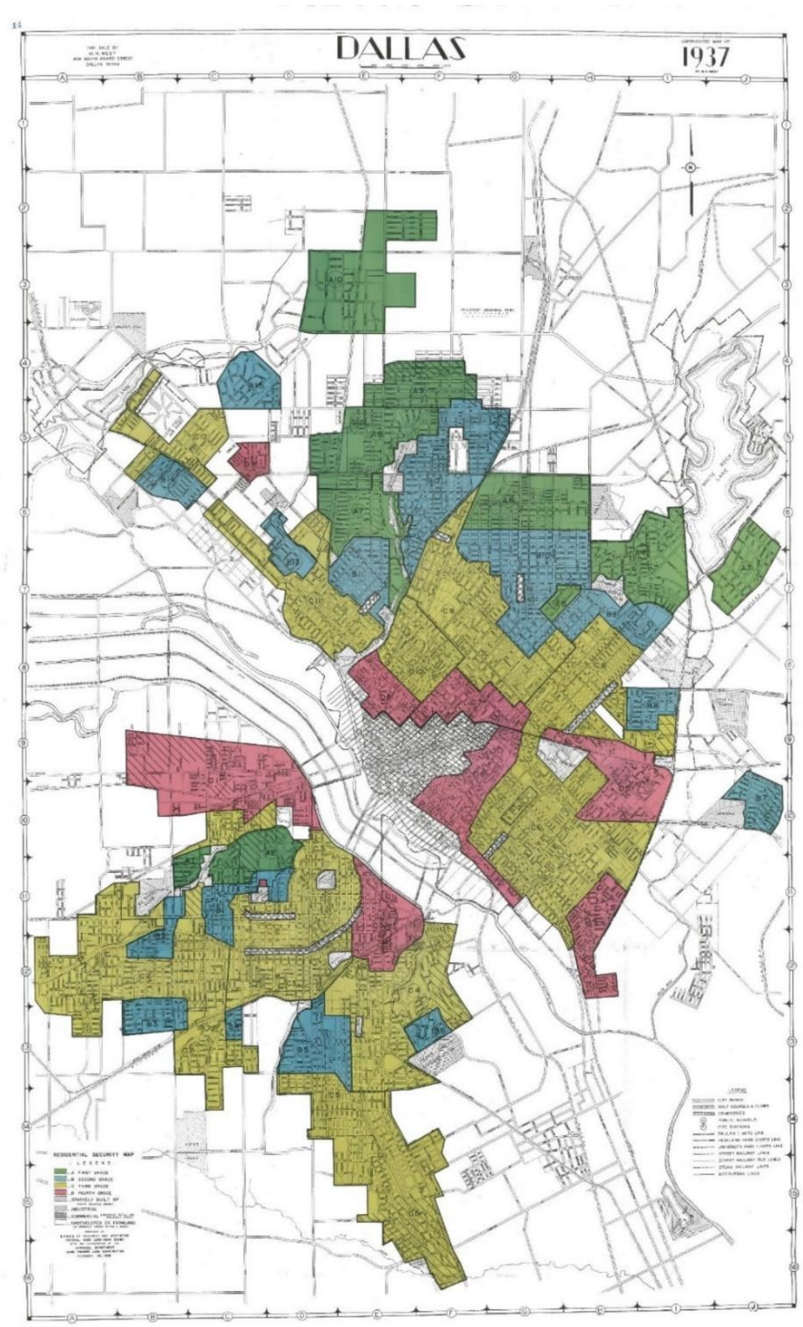

Figure 13. HOLC map of Dallas, Texas. Shows risk assessment for government loans or insurance.

Literature Review

Accessibility as a concept has been extensively utilized in the literature. Its definitions show its utility as a basis for the jobs-worker balance (JWB). It has been described as 'The potential of opportunities for interaction' (Hansen, 1959), or as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)" (Geurs & Wee, 2004). Four components, according to one study by Geurs and Wee (Geurs & Wee, 2004), comprise accessibility: land use, transportation, temporal, and individual. The land use component consists of a balance between the opportunities at each destination and the demand for such at origins of travel trips. The transportation component consists of the time and effort required to transport oneself and the desired goods between origin and destination using the available transportation infrastructure options. The temporal component includes the time available to travelers, and the constraints placed upon them in terms of the time of day in which opportunities are available, e.g., when shops or parks are open for use. The individual component includes the characteristics of individual travelers, such as their needs and abilities for travel. These may include income and budget constraints upon money spent on transportation (Geurs & Wee, 2004). For the purposes of this article, Hansen's elaboration is most cogent: "accessibility is a measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation" (Hansen, 1959). Proximity thus becomes as important as mobility in ascertaining employment access opportunities.

The literature suggests that reducing spatial mismatch is only one necessary step to relieving congestion and vehicle miles traveled in the city and must be combined with other design elements to attain the greatest effect (Bartholomew & Ewing, 2011). Moreover, while spatial mismatch is shown to be an important factor in the labor market, it is less important than neighborhood effects to employment outcomes of youth (Chetty et al., 2018). This suggests that while adults need to live near jobs, youth need to live near many employed adults. While this is an area of study needing much more attention, the findings thus far seem to support rather than contradict advocacy for jobs-worker balance, but also point to the importance of considering other elements of the built environment. Accessibility and design or amenity characteristics work together and are mutually dependent. Supportive approaches may include increasing the characteristics of the built environment that support non-automobile travel, such as increasing density and land use mix for greater local accessibility (Bartholomew & Ewing, 2011; Ewing & Cervero, 2010; Stoker & Ewing, 2014).

The literature further suggests that strong linkages between job and housing sites depend upon a proper match between them, in the form of jobs in sectors that match the income level of the nearby housing. The "workforce housing balance" or "jobs-housing fit" theorized by the literature denotes the degree to which middle- and working-class employees such as teachers or first responders are able to live near their work locations (Benner & Karner, 2016a; Calthorpe & Fulton, 2001; R. Cervero, 1989; A. Nelson et al., 2015). Gordon, Kumar, and Richardson (Gordon et al., 1989) hypothesized, moreover, different spatial distributions and commuting patterns between commercial and industrial land uses.

In efforts to increase employment access to certain demographic segments of the population, the land bidding process must be considered. The Alonso-Muth-Mills model of urban economics posits, supported by decades of empirical evidence, that land uses will bid for land with the most valuable characteristics. These may include proximity to the Central Business District (CBD), access to the best transportation infrastructure, and the cost of land. The great expansion of available land as one travels away from the CBD makes it far cheaper per acre, which leads some land uses to desire a position further away than those that require less land for optimal operation. In economic terms, the income elasticity of demand for a central location is higher for some firms or households than it is for land (Alonso, 1964; Mills, 1972; Muth, 1969). Given power and income dynamics among firms and households, some minority groups will be subject to outbidding by other groups in efforts to gain the best possible location in the urban region (R. E. Park et al., 1925).

Many different methods have been used in the literature on the spatial mismatch theory. Kain started testing the theory with OLS regressions of minority housing segregation by regressing the neighborhood employment ratio of blacks to total neighborhood employment on its residence ratio and the neighborhood's distance to the nearest local ghetto and the nearest major ghetto (Kain, 1968). Such further methods have been used as the transportation problem linear program (TPLP), linear and spatial regression, or multilevel analysis (R. Cervero, 1989; Horner et al., 2015; Schleith et al., 2016; Stoker & Ewing, 2014). Schleith et al. (Schleith et al., 2016) used the TPLP to devise an expected value, or optimal commute, against which to measure "excess commute" from the actual data.

Multiple heuristics have been devised for ascertaining the appropriate jobs-housing ratio. Two major studies propose a range of 0.75 to 1.25 (Margolis, 1957), or 1.5 (R. Cervero, 1989). Also being estimated by multiple heuristics is the scale of the neighborhood which should represent the space needing to be balanced. Commute sheds (neighborhoods to balance) of 3 miles have been used recently by the seminal work of Stoker & Ewing (Stoker & Ewing, 2014) Nelson et al. (A. C. Nelson et al., 2015b) also advocated for the jobs-worker balance in order to account for the varying of household size and of workers per household. Travel time is an important alternative to distance in determining a commute shed (A. Nelson et al., 2015).

Transit modes have displayed differential market response, one mode attracting more intensive land uses than others, and each mode attracting a specific set of economic sectors (A. C. Nelson & Hibberd, 2019b). Real estate rents, for example, responded at different rates and at different distances from the station when considering each transit mode separately. The streetcar systems in the US have responded with the strongest increases, with light rail also eliciting positive responses; bus rapid transit has shown mixed responses, while commuter rail has been flat or negative (Arthur C Nelson 2017b). These rules hold only contingently across the (sparse) literature, with other studies showing commuter rail also eliciting positive results (A. C. Nelson & Hibberd, 2019b). This differential response to transit proximity is expected to extend into demographic trends around transit stations, and by transit station place typology. People will respond differently to transit proximity according to, among other characteristics, their age, job sector, race, ethnicity, educational attainment, and family profile. Also, transit stations will elicit market and demographic responses differently across the place typology of transit stations.

Theory

This article's analyses are based upon the following theories: first, JWB will improve employment outcomes for previously isolated communities by increasing their access to employment locations. The JWB, as measured by internal capture, explicitly places workers and employment centers into close proximity; close enough to allow mobility options beyond the automobile, including walking, bicycling, and transit use. Given the historical trend of land uses bidding for control of land most useful to them, it makes sense that many TOD areas are not as balanced in land uses as is necessary to implement the ideal in TOD theory. This would require more residential land uses in TOD neighborhoods than has been implemented so far. Moreover, these residential land uses must be geared toward the attainment of all segments and wage groups of the workforce.

Reducing distance between workers and employment centers will reduce the costs of access, and therefore allow reallocation of time and money to other needs. Further, if the cost of travel between home and work was too high before introduction of transit stations, the station's introduction will serve to reduce that cost, which will put employment in the realm of possibilities for the first time for some workers.

Further, transit access by reducing congestion increases access to employment opportunities. This benefit is joined by the greater intensity of land uses around transit stations, and their integration with local and regional land uses. These characteristics of transit stations are expected to increase access to employment and thereby reduce the spatial mismatch between urban workers and regionally located employment centers.

Question & Hypotheses

To what extent are transit stations and JWB related? Do FRT system neighborhoods improve in the internal capture of work trips across the study years? Does the presence of a mix of economic groups increase internal capture? Which transit station neighborhood characteristics influence the greatest increases of internal capture? What is the state of redlined neighborhoods regarding these questions?

- Hypothesis 1: FRT system presence will be related to an increase in job-worker balance for specific segments of the population, not necessarily all segments by demographic group, income or job sector, within a half-mile of transit stations.
- Hypothesis 2: Redlined neighborhoods will exhibit a negative association with internal capture of work trips compared with other urban zones.

Research Design

This section will describe the study areas, time frame, data and methods used in the analysis. Then it will outline the method of Propensity Score Matching (PSM) and how the study will use it. Next, it will outline the general model to be used in regression analyses.. The final section will detail the approach taken to translate the CBG data from the pre-2010 era to the post-2010 data, overcoming the problem of incommensurability.

Study Areas and Time Frame

The case study regions come from all parts of the US, with broadly differential contexts, and diverse types of the following: transit system modes, regional urban form, economic sectors, population size and density, gross domestic product, and land use mix. For example, Minneapolis has 2 light rail lines (LRT) that together cover 23 miles of service, 5 bus rapid transit lines (BRT) that provide 86 miles of service, and the 40-mile Northstar commuter rail line (CRT). Many of our sample metro areas have rapid transit lines that are of more recent stock and are shorter in length than Minneapolis. The economically exemplary Tucson SunLink streetcar (SCT) line is about 4 miles long. The Salt Lake S Line streetcar is only 2 miles long.

Table 10. Census Names of Metropolitan Areas in the Study & Their Transit Modes

Study MSAs	Modes	Robustness Check MSAs	Modes
Atlanta, GA	HRT, SCT	Albuquerque, NM	BRT, CRT
Cleveland, OH	HRT, LRT, BRT	Santa Fe, NM	CRT
Dallas-Fort Worth, TX	LRT, SCT, CRT	Austin, TX	CRT
Denver, CO	LRT, CRT	Buffalo, NY	LRT
Houston, TX	LRT	Eugene, OR	BRT
Miami, FL	CRT	San Antonio, TX	BRT
Minneapolis-St. Paul, MN-WI	LRT, BRT, CRT	Tampa, FL	SCT
Orlando, FL	CRT	Tucson, AZ	SCT
Phoenix, AZ	LRT, BRT		
Pittsburgh, PA	LRT, BRT		
Portland, OR-WA	LRT, SCT, CRT		
Sacramento, CA	LRT		
Salt Lake City, Ogden, Provo, UT	LRT, BRT, SCT, CRT		
San Diego, CA	LRT, BRT, SCT, CRT		
San Jose, CA	LRT, BRT, CRT		
Seattle-Tacoma, WA	LRT, BRT, SCT, CRT		
Stockton, CA	BRT, CRT		

Data & Methods

The study will use a quasi-experimental design utilizing propensity score matching to identify treatment and control groups. It will use spatial regression to analyze demographic variety in the JWBI in transit station neighborhoods and regions across three years of cross-sectional data: 2002, 2009 and 2017. The regression will measure the relationship between relative values of the JWBI as the dependent variable, and relative concentrations of various demographic groups within a metropolitan area. The analysis will evaluate whether transit station neighborhoods (as distance bands), the treatment, are more likely to capture these concentrations than the transit-served county as a whole, which is the control group. Transit modes will include light rail (LRT), bus rapid transit (BRT), commuter rail (CRT), and streetcar (SCT). The observations from all transit types will be grouped together for analysis.

The study will use LEHD worker residence and worker job location data aggregated to the census block group level to allow for use of additional variables available at that scale. It will also include GIS-based distance controls, as well as demographic controls and real estate rents from the US Decennial Census and the American Community Survey (ACS). Some counties, especially large ones, have multiple land use typologies that differ significantly in population density, infrastructure, and other land use characteristics that make them incommensurable. An example is Pima County, Arizona, which at over 9,000 square miles, most of which is rural, has only a few hundred square miles of urbanized land. Ratios measuring balance between land uses should compare places similar in typology. The paper will differentiate between metropolitan regions, and account for the categorical differences between urban and rural land by using the U.S. Census's Urbanized Area boundary as the spatial bounds within each metropolitan area. Rural lands will not be included in the analysis. Change in the Gross Domestic Product (GDP) in terms of change over time, as well as difference of the study region from the US GDP, will be drawn from the U.S. Department of Commerce's Bureau of Economic Analysis (BEA).[23]

To calculate internal capture, a Near Table from GIS, which is an origin-destination matrix, measures the distance between each origin census block group, *i*, and every other census block group destination, *j*. The LEHD Origin-Destination (OD) tables, joined with the distance data from the Near analysis, provide origin and destination block IDs and jobs numbers. These tables were aggregated to the block group level and combined with the Worker Area Characteristics (WAC) and Resident Area Characteristics (RAC) tables to gain data by economic sector for each origin-destination pair. Variable sums for each commute shed are determined by an iterative routine in R. ACS and LEHD data are joined at the block group scale. LEHD data are grouped by NAICS codes for general wage and sector groups. Table 3 explains the variables for the analysis.

[23] https://apps.bea.gov/regional/histdata/

Table 11. Place-Based Job Sectors in the Study by Wage Category

NAICS	Description	Mean Annual Wages, 2020	Wage Category
44	Retail Trade	$36,510	Lower
56	Administrative, Support, Waste Mgmt., Remediation	$43,940	Lower
71	Arts, Entertainment and Recreation	$41,530	Lower
72	Accommodation and Food Services	$28,830	Lower
81	Other Services (except Public Administration)	$47,140	Lower
	Weighted Mean Wages and National Share of Jobs		***~$40,000***
48	Transportation and Warehousing	$51,150	Middle
53	Real Estate and Rental and Leasing	$53,030	Middle
61	Educational Services	$60,090	Middle
62	Health Care and Social Assistance	$57,160	Middle
92	Public Administration	$62,140	Middle
	Weighted Mean Wages and National Share of Jobs		***~$55,000***
22	Utilities	$84,080	Upper
31	Manufacturing	$56,270	Upper
42	Wholesale Trade	$61,170	Upper
51	Information	$85,350	Upper
52	Finance and Insurance	$77,930	Upper
54	Professional, Scientific and Technical Services	$88,920	Upper
55	Management of Companies and Enterprises	$89,950	Upper
	Weighted Mean Wages and National Share of Jobs		***~$80,000***

Source: Adapted from US Bureau of Labor Statistics figures.[24]

[24] See bls.gov. Accessed 9-29-2021.

Table 12. NAICS Place-Based Job Sectors by Economic Category

Manufacturing	
	Manufacturing
Industrial	
	Utilities
	Wholesale Trade
	Transportation and Warehousing
Retail-Accomodation-Food Services	
	Retail Trade
	Accommodation and Food Services
Knowledge	
	Information
	Professional, Scientific, and Technical Services
Office	
	Finance and Insurance
	Real Estate and Rental and Leasing
	Management of Companies and Enterprises
	Administrative and Support and Waste Management and Remediation Services
	Other Services (except Public Administration)
	Public Administration
Education	
	Educational Services
Health Care	
	Health Care and Social Assistance
Art-Entertainment-Recreation	
	Arts, Entertainment, and Recreation

Source: Nelson & Ganning (A. C. Nelson & Ganning, 2015).

To reduce the calculation burden, as well as the effects of spatial dependency, a spatial stratified random sampling will identify employment neighborhoods in 25 US metropolitan areas in treatment and control groups. The sampling is done by creating a random point sample in GIS across all of the study metro areas, confining the samples to the Urbanized Area boundaries, which serve as the strata for the sample. This confinement decreases spatial dependency in the sample by reducing spatial heterogeneity (Wang et al. 2012). All points receive data about the study variables from the underlying census block groups. To ensure sufficient sample size in each metropolitan area, the sampling algorithm assigns a minimum sample size for each metropolitan area. The final step in preparing the random sample for subsequent analysis is to remove duplicates, leaving only one sample from each census block group.

Propensity Score Matching (PSM) is used as a control group generator for use in quasi-experimental design. Treatment neighborhoods will be within 1 mile of transit, chosen as a short distance to travel by car or bike as a segment of a typical commute. These treatment observations are further classified by quarter-mile distance bands from the station. A Propensity Score-matched control group of employment is defined as zones outside of transit-served neighborhoods within the study metropolitan areas' Urbanized Area boundaries.

The purpose of PSM is to identify treatment and control groups that are statistically exchangeable; to avoid confounding effects there can be no significant differences in attributes between treatment and control groups. Each control group is matched to the treatment group by a series of variables that have statistically similar distributions in the control as found in the treatment. The control lacks the treatment, making it applicable as a control. To be more precise, each control group is matched to the treatment group using a propensity score, which is an indicator based on the distributions of the covariates shown to lead to a propensity towards the treatment. A propensity score is a balancing score. A balancing score, b(x), is one at which the distribution of a set of covariates, x, is balanced (i.e., approximately equivalent) for treated (z=1) and control (z=0) units. The distribution is conditioned upon b(x), or the balancing score of x. Therefore, the conditional distribution is x given b(x) (Rosenbaum & Rubin, 1983).

For this study, control group observations will be pulled from each of the transit-served metropolitan areas outside of the "treatment" areas, which are distances up to a half-mile away from transit stations. PSM analysis will ascertain which observations in the control group can be profitably compared to the treatment group observations. Unmatched observations are removed from the sample.

Steps include 1) propensity score estimation, 2) matching quality evaluation, 3) outcome analysis. In step 1, a logistic regression analysis produces the propensity scores for the purpose of matching treatment and control groups. The characteristics leading to the propensity score are averaged for both the control and treatment groups, and similar scores provide the match. One common matching algorithm pairs a treatment observation with the nearest-neighbor matching control observation, or the mean of some number of nearby control observations. Caliper matching allows a caliper band of matching tolerance around the propensity score. This would allow a pair of treatment and control units to be paired together based on propensity scores that differ by up to some tolerance level, such as 0.03 (Kim et al., 2021; Pan & Bai, 2015). The best matching method provides the lowest mean difference between treatment and control groups (Randolph et al., 2014). The sample size of control group observations will be much larger than that of the treatment group (Katchova 2013). This facilitates a proper match between each treatment and the control group. Observations in the control group must have a propensity score as high as the lowest score in the treatment group to be retained for analysis; likewise, the treatment-group propensity scores will only go as high as the highest score in the control group, thus creating observation sets within a "region of common support." Once the two groups are checked for similarity in the distributions of the covariates, the variance in the dependent variable between the two groups is attributable to the treatment. Finally, an impact estimate indicates the difference in the average outcome between treatment and control groups.

For step 2, matching quality evaluation, one measures the "quality of covariate balance." The "percent reduction in bias" is calculated, with a heuristic cutoff value of 80% reduction (Pan & Bai, 2015). The "average treatment effect" (ATE) is the difference between the expected value of the treatment and the control for all units in each group. This approach is justified upon the assumption of "no unobserved confounders," or endogenous effects from unmeasured variables. One limitation of the method is the possible effects from unobservable characteristics between groups, which would be caught within the error term of a regression-based approach (White & Sabarwal, 2014). Goodness-of-fit or statistical significance of the covariates are not the measured or relevant outcomes of the propensity score estimation. The important outcome is, rather, the degree of balance of the covariates for the observations in the treatment and control groups. The "average treatment effect for the treated" (ATT) produces an average treatment effect on the condition that a specified subset of treated observations and their matches in the control group are the only ones measured. As using ATE is essentially the same approach as performing a t-test, ATT is the preferred method. It eliminates control group observations that are not withing the region of common support.

A robustness check will be made by performing the analysis on an additional set of observations from metropolitan areas that have limited coverage by Fixed-Route Transit systems. The second set of regressions from the robustness check will serve as an important foil to the primary model runs. The best candidates for this set include Austin, Buffalo, Cincinnati, Eugene, San Antonio, Tampa, and Tucson. This iteration of the model will allow an analysis of the treatment results, to further verify the models from the samples from the main metropolitan areas.

General Model

The general regression model will be specified as follows:

$$Y_i = \mathrm{f}(\mathrm{SEC}, \mathrm{Loc}, \mathrm{TZ}) \tag{8}$$

Where SEC is a vector of socioeconomic demographic variables, Loc is a vector of locational variables, such as distance to the CBD, and TZ is the vector of ¼-mile distance dummies around transit stations. The dependent variable is the JWBI, or internal capture of work trips for each observation.

The variables to be included in the model as potential covariates are listed in table 13. Continuous variables will be centered for analysis. Each variable is important theoretically to the hypothesis. Householder age, percent white, percent Hispanic, and median household income are included because of their frequent use in the empirical demographic literature as important controls. Given the article's focus on the segmentation of the worker population, number of vehicles, educational attainment and couples without children are also included. The typology of places across the metropolitan area can be measured and classified by degrees of land use mix and accessibility. The model uses population density and entropy (a metric that captures the continuum from land use concentration to mixture or dispersal) as indicators of place typology (A. Nelson et al. 2021b). Transit zone dummies identify whether an observation is found within the study's treatment distance of half a mile or less from a transit station. Job-labor balance and income match are shown to be important predictors of internal capture (Stoker and Ewing 2014b). Gross Domestic Product can be used as a metric to capture the larger economic context as a control for more localized modeling efforts. This measure indicates the worth of final goods and services. The U.S. Bureau of Economic Analysis (BEA) provides data on GDP trends over time at various scales, including national, state, metropolitan areas, counties, and U.S. territories, as well as by industry. These figures indicate the rate of growth for each geographic scale or industry. Annual and quarterly updates are available, as are "real GDP" figures that account for inflation.[25] The study will assess GDP for temporal change and regional delta from national figures. These variables will provide controls for the regional and national economic dynamics that may affect the outcome of the study.

[25] https://www.bea.gov/resources/learning-center/what-to-know-gdp. Accessed 2-25-2024.

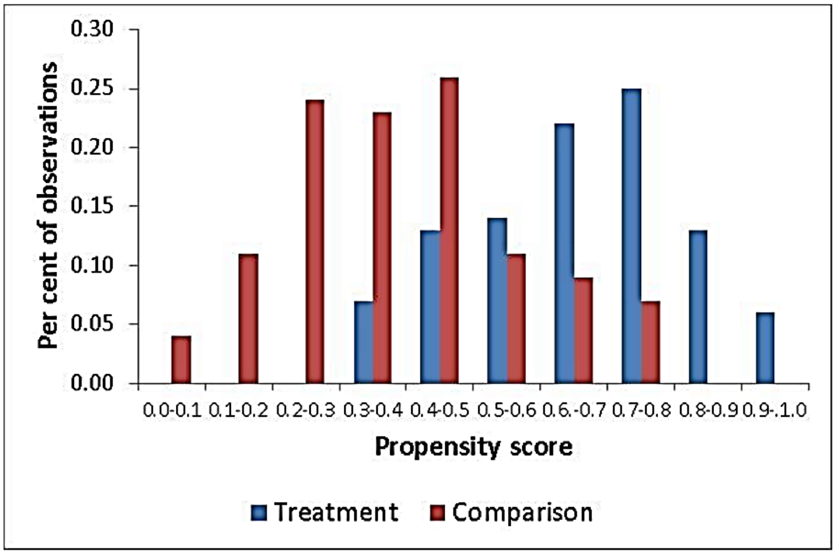

Figure 14. Propensity score distributions for hypothetical treatment and control groups. The "region of common support" is that region of propensity scores in which the groups overlap, denoting that observations in each group are sufficiently similar in characteristics to produce unbiased estimates in experimental analyses. Data only for illustrative purposes. Source: (White & Sabarwal, 2014).

Table 13. Spatial Mismatch Model, Functional Forms

Variables	**Expected Sign**	**Functional Form**	**Source**
Socioeconomic / Neighborhood			
Householder Age		Ln	ACS CBG
Under 25, 25-44 (45+ is referent)	+		
Percent White	+	Ln	ACS CBG
Percent Hispanic	-	Ln	ACS CBG
Percent Attained 4-year degree B15003e22/total pop	+	Ln	ACS Tract
Percent couples without kids	+	Ln	ACS CBG
Redlined zone dummy (Green zone is referent)	-	Categorical	Mapping Inequality
Vacancy rate B25004e1/B25001e1	-	Linear or Ln	ACS CBG
Number of vehicles per HH by tenure: No Vehicle	+	Linear	ACS CBG
Locational			
Regional Real GDP change between time periods	+	Linear	US BEA
Regional Delta from US Real GDP (single year)	+	Linear	US BEA
Transit Zone ¼-mile (>half-mile is referent)	+	Categorical	GIS
Population density (pop / square km)	+	Linear or Ln	ACS CBG, GIS
Entropy (land use mix)	+	Linear or Ln	LEHD, GIS
Job-Labor Balance	+	Linear	LEHD, GIS
Income Match	+	Linear	LEHD, GIS
Dependent			
Job-Worker Balance Index (Internal Capture at 3-mile distance from each origin)		Linear	GIS

A normalized entropy measure is adapted as follows from Ewing & Hamidi (2014),

$$\sum_{i=1}^{n} \sum_{j} \left(\left(P_j * LN(P_j) \right) / LN(j) \right) \tag{5}$$

where:

i is the enumeration unit, *n* equals the number of units per county, *j* equals the number of employment sectors, and *Pj* = proportion of jobs in sector *j*. This measure denotes the degree of land use similarity or dissimilarity in each enumeration unit. The normalizing weight is the natural log of the number of sectors. The entropy index is interpreted as follows: the higher the number, which is between 0 and 1, the more evenly mixed the land uses are by employment sector.

Mining, construction, and agriculture sector jobs are excluded from the classification, as the study of transit effects requires measures of jobs that have a permanent location. Controls will include local socioeconomic variables, local built environment variables, and geographic characteristics.

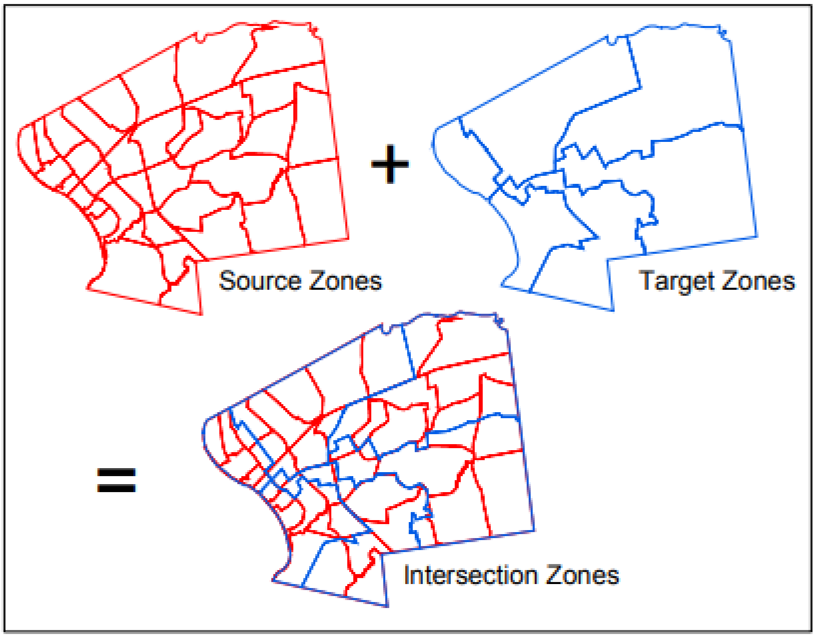

Figure 15. Areal interpolation of areal enumeration units facilitates translation between units with different zonal configurations. Source: (Garb et al., 2007).

The enumeration units released by the US Census Bureau have different zonal configurations each decade. This creates a problem of incommensurability between these time periods. As this study uses data across different zonal configurations, it is necessary to translate between the enumeration units. Areal interpolation provides a solution. As seen in figure 15, source and target zones are intersected. This creates a series of new shapes in the source zones, each one a subsection of the original source zones. Each portion of a source zone is assigned a proportional attribute value, based on the subsection's percentage of the original shape. These subsections are reassembled to match the boundaries of the new target zones, and the attribute values are summed to the new target zones. The interpolation process provides the most accurate results when using the smallest enumeration units possible. Drawbacks to the approach include some degree of error due to the assumption of even distribution of attributes across the enumeration units. More robust methods are available in the literature, e.g., dasymmetric mapping and other weighting schemes.[26] Data required for those methods, e.g., digital elevation models and other natural boundaries, are beyond the scope of this paper.

Results and Discussion

The analyses for this study include calculation of internal capture of work trips for 3-mile commute sheds around each census block group of 25 US metropolitan areas using an R routine to analyze LEHD data about workers, firms, and origin-destination pairs in commuting trips. It calculates locational and economic variables. These include entropy, which is a measure land of use mix; population per square kilometer, a density metric; income match (DIwages, a dissimilarity index), which is a measure of the degree of colocation of various groups of workers and their firms by wage level; and jobs-labor balance, which describes whether an area has more workers or more firms, or a balance in numbers of the two. It measures economic dynamics using GDP regional and national change variables. It includes demographic variables that are shown by the literature to be key variables of interest. The study therefore analyzes the explanatory power of various demographic, economic, and locational variables on the prevalence of internal capture. It includes a spatial stratified sample of the data within the Urbanized Area boundary of each city. It identifies appropriate treatment and control groups for a quasi-experimental regression of the study variables.

Variables of interest for the study provide an interesting picture of commuting and demographic dynamics, but gaps in available data caused some obstructions in the study. The internal capture results indicate that the study's metropolitan areas have an overall mean of about 15% internal capture of work trips within 3 miles of workers' residences. Interestingly, this trend holds steady over the study years, and is not greatly increasing as a percentage of trips. Some metropolitan areas with important potential as study areas did not have the needed years available in the LEHD data. US Census ACS and Decennial Census data sets had variables of interest for the study that contained many null values for the study areas. For this reason, vacancy rates and median household income were not considered for this study.

The PSM tables report the statistics of the analyses. They include values for the treatment group mean and the control group mean before and after matching, which the PSM algorithm calculates as part of the process. They also report t-test p-values for the comparison between treatment and control groups for each variable. Finally, the key statistic reported is the mean difference between treatment and control groups, which is reported both before and after matching analysis. PSM identifies the "region of common support," in which the treatment and control variables' distributions overlap and removes those observations that lie outside of this distribution region. The results show that the PSM algorithm removed many observations from the original random samples.

Results of the PSM show an improvement in mean difference after matching. There are still some statistically significant differences between treatment and control groups for some of the covariates, as seen in the p-values of the "after matching" section of the table; however, many are not significantly different. Overall, there is a marked improvement in bias removal after the PSM. Some research on PSM significance testing, moreover, indicates that p values

[26] See the NHGIS website, https://www.nhgis.org/. Accessed 4/28/2024.

may be misleading or simply inappropriate to use, and other diagnostics, especially the variance ratio, which shows balance when the ratio is close to 1, are more relevant (Z. Zhang et al. 2019).

OLS and diagnostics indicate useful model results. Most assumptions for coefficient signs held. Adjusted R-squared values indicate relatively good explanatory power for the models, with some unexplained variance. These are 0.4, 0.5, and 0.4 for the years 2002, 2009, and 2017, respectively. VIF scores for all regressions indicate that there is no collinearity bias in the results. Breusch-Pagan tests indicate that there is a need to correct heteroskedasticity in the error terms, which is handled in the study models by providing robust standard errors and p-values. The Wald test provides a heteroskedasticity-robust comparison of overall model goodness-of-fit, similar to the F-test.

Demographic patterns across the years tell an interesting story, with recognizable trends as well as some surprises. Race and ethnicity affected internal capture. White and Hispanic households positively influenced internal capture, and both were statistically significant across the study years. The age of the householder had a negative effect for younger householders, or those 25 to 45, compared to the referent of age 45 or greater. Very young householders, less than age 25, had little effect. Household size had an influence. Couples without children had a positive association with internal capture. Educational attainment had a negative influence on internal capture. As one gains education, and presumably income as well, commutes get longer. This effect went down over the study years. The coefficient in 2002 was -0.23 but was -0.13 in 2017. Having no vehicle was positively associated in two of the three years, including the most recent, 2017. This indicates that some of the internal capture of trips is due to active modes of transportation, as well as transit use.

The trend in income match is surprising. While it has the expected positive influence in 2002 and 2007, it has a slightly negative influence in 2017. This may indicate some pattern in land development that is obstructing the building of workforce housing in certain areas. The study areas are all in the urbanized portions of the metropolitan areas, many of which have struggled in recent years to build such housing. It calls for further research to ascertain the underlying cause.

GDP variables presented some surprises, as well. In all cases, the regional and national dynamics of the economy had a major impact on internal capture. Surprisingly, the regional GDP had the opposite effect as hypothesized. As regional GDP increased, it had a considerable downward influence on internal capture. This may be simply due to the overall trend in economic growth that tends to increase commute distances. Our regional economies seem to be to geared toward longer commutes during growth periods.

While land use mix is known widely in the literature to increase positive outcomes of property values and other desired outcomes, it is not significant in our study. This may indicate that density and local and regional economic characteristics play a larger part in commuting patterns than small-scale land use mix.

The results indicate that redlined zones are still affected in terms of internal capture of work trips. This may indicate that the built environment and economic health of a neighborhood influences commuting patterns and modes. There are some temporal patterns that indicate further study may be useful. In 2002, for example, the redlined zones (HOLC D) were negatively associated with internal capture, but not statistically significant. HOLC C zones were not a factor, while HOLC B zones were statistically significant and moderately negative influences on internal capture, compared with HOLC A and the rest of the metro area. In 2009, none of the zones were statistically significant. This changed again in 2017, when the redlined zones (HOLC D) were again statistically significant and negatively associated with internal capture. People in these neighborhoods are still making longer commutes to work.

Robustness check results indicate, as hoped, that the model works best in areas where transit has been established. Internal capture of work trips is therefore positively influenced by transit stations, particularly those in higher-density neighborhoods. Only in 2017 do the transit distance bands show statistical significance, and that at a 7% p-value. Some of the studied metro areas do have some established transit lines by 2017, such as Tucson's streetcar line, which opened in 2014. However, the lack of statistical significance in the other study years indicates that the same influence of transit in the main sample metros does not hold in the robustness check metros. Therefore, the transit effects in the main sample metros are more plausible.

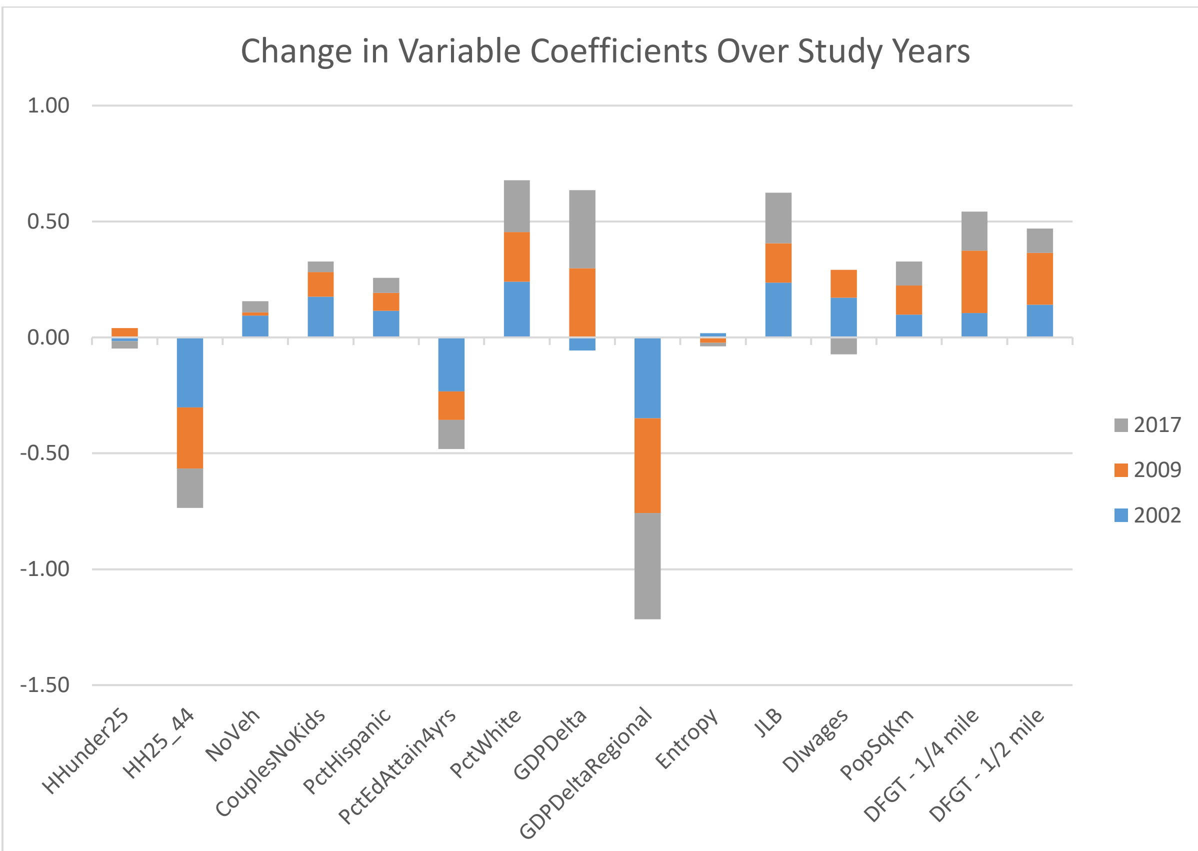

Figure 16. Regression Scaled Coefficient Dynamics

Table 14. Propensity Score Matching for Redlining Sample

	Redlining PSM									
2017	Before Match					After Match				
	transit before	no transit before	mean diff before	p.val	Var Ratio	transit after	no transit after	mean diff after	p.val	Var Ratio
HHunder25	0.2	-0.06	23.64	0	1.8	0.2	0.11	7.23	0	1.2
HH25_44	0.05	-0.01	6.71	0.14	1.02	0.05	-0.01	6.26	0.01	1.36
NoVeh	0.34	-0.1	40.05	0	2.06	0.34	0.03	24.83	0	2.01
CouplesNoKids	-0.08	0.02	-10.35	0.02	0.77	-0.08	-0.03	-5.19	0.08	1.21
PctHispanic	0.07	-0.02	9.26	0.04	0.9	0.07	0.04	3.34	0.13	1.02
PctEdAttain4yrs	-0.04	0.01	-4.62	0.35	1.91	-0.04	-0.08	3.54	0.04	1.68
PctWhite	-0.13	0.04	-16.95	0	0.89	-0.13	-0.06	-7.02	0	0.99
GDPDelta2017	-0.08	0.02	-9.66	0.04	1.08	-0.08	-0.06	-1.29	0.34	1.11
GDPDeltaRegional2017	-0.22	0.06	-31.41	0	0.54	-0.22	-0.22	-0.59	0.81	0.95
Entropy	0.12	-0.03	15.58	0	1.04	0.12	0.12	0.5	0.8	1.13
JLB	0.02	-0.01	2.46	0.58	0.9	0.02	0.05	-3.67	0.09	1.18
DIwages	-0.14	0.04	-18.84	0	0.74	-0.14	-0.12	-2.69	0.2	1.1
DIsectors	-0.09	0.02	-11.39	0.01	0.75	-0.09	-0.1	2.06	0.37	0.94
PopSqKm	0.12	-0.03	14.99	0	1.3	0.12	0.06	5.12	0.01	1.21
2009										
HHunder25	0.12	-0.04	15.11	0.01	1.35	0.12	0.05	6.46	0	1.36
HH25_44	0	0	0.29	0.96	0.94	0	0.01	-0.71	0.77	1.34
NoVeh	0.24	-0.07	29.41	0	1.7	0.24	0.16	7.32	0	1.12
CouplesNoKids	-0.16	0.05	-20.79	0	0.82	-0.16	-0.09	-7.02	0.01	1.1
PctHispanic	0.19	-0.06	24.86	0	1.06	0.19	0.15	4.64	0.09	1
PctEdAttain4yrs	-0.07	0.02	-9.24	0.07	0.66	-0.07	-0.13	6.92	0.07	1.77
PctWhite	-0.22	0.06	-28.56	0	0.94	-0.22	-0.14	-8.42	0	1.08
GDPDelta2009	0.11	-0.03	14.6	0.01	0.84	0.11	0.09	2.38	0.33	0.98
GDPDeltaRegional2009	-0.17	0.05	-23.83	0	0.54	-0.17	-0.15	-2.56	0.54	0.81
Entropy	0.05	-0.02	6.79	0.21	1.09	0.05	0.04	1.12	0.76	1.14
JLB	-0.06	0.02	-7.16	0.18	0.98	-0.06	0.12	-17.69	0	1.46
DIwages	-0.12	0.04	-16.4	0	0.75	-0.12	-0.11	-0.96	0.7	1.09
DIsectors	-0.1	0.03	-13.97	0.01	0.67	-0.1	-0.07	-3.97	0.15	1.03
PopSqKm	0.15	-0.04	19.19	0	1.16	0.15	0.11	4.25	0.03	1.28

Table 16. (Continued). Propensity Score Matching for Redlining Sample

	Redlining PSM									
2000	Before Match					After Match				
	transit before	no transit before	mean diff before	p.val	Var Ratio	transit after	no transit after	mean diff after	p.val	Var Ratio
HHunder25	0.12	-0.04	15.37	0	1.05	0.12	0.06	5.47	0	1.26
HH25_44	-0.07	0.02	-9.62	0.06	0.68	-0.07	-0.03	-4.85	0.02	1.09
NoVeh	0.29	-0.09	34.98	0	1.97	0.29	0.22	5.37	0	1.15
CouplesNoKids	-0.15	0.05	-20.61	0	0.82	-0.15	-0.1	-6.17	0.06	1.36
PctHispanic	0.18	-0.05	22.47	0	1.17	0.18	0.12	4.75	0.01	0.98
PctEdAttain4yrs	-0.06	0.02	-8.12	0.13	0.9	-0.06	-0.15	8.79	0.02	2.69
PctWhite	-0.19	0.06	-25.02	0	0.99	-0.19	-0.13	-5.73	0	0.96
GDPDelta2002	0.01	0	0.98	0.86	1.59	0.01	0.04	-2.57	0.61	1.85
GDPDeltaRegional2002	-0.18	0.06	-26.02	0	0.54	-0.18	-0.12	-7.83	0.1	0.77
Entropy	0.08	-0.02	9.76	0.08	1.11	0.08	0.04	3.56	0.15	1.25
JLB	-0.06	0.02	-7.6	0.17	1.1	-0.06	0.08	-13.32	0	1.64
DIwages	-0.16	0.05	-21.71	0	0.63	-0.16	-0.15	-1.35	0.76	0.98
DIsectors	-0.15	0.05	-21.72	0	0.57	-0.15	-0.14	-1.97	0.35	1.14
PopSqKm	0.16	-0.05	20.07	0	1.53	0.16	0.05	9.47	0.02	1.93

Table 15. OLS Regression Results for Redlining Sample

Redlining Sample 2000									
	Residuals:								
	Min 1Q Median 3Q Max								
	-1.8046 -0.4598 -0.0374 0.3648 3.5991								
Coefficients:	Standard				Robust				
	Est	Std. Error	t value	Pr(>|t|)	Est	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.07	0.03	-2.19	0.03	-0.07	0.03	-2.26	0.02	*
HHunder25	-0.05	0.03	-1.71	0.09	-0.05	0.04	-1.47	0.14	
HH25_44	-0.22	0.04	-5.19	0.00	-0.22	0.04	-4.98	0.00	***
NoVeh	0.11	0.02	4.57	0.00	0.11	0.03	4.17	0.00	***
CouplesNoKids	0.11	0.04	2.82	0.00	0.11	0.05	2.36	0.02	*
PctHispanic	0.07	0.03	2.11	0.04	0.07	0.03	2.2298	0.03	*
PctEdAttain4yrs	-0.11	0.03	-3.48	0.00	-0.11	0.03	-4.38	0.00	***
PctWhite	0.15	0.04	3.92	0.00	0.15	0.04	4.38	0.00	***
GDPDelta2002	0.06	0.02	2.42	0.02	0.06	0.04	1.51	0.13	
GDPDeltaRegional2002	-0.38	0.03	-12.03	0.00	-0.38	0.03	-13.50	0.00	***
Entropy	0.05	0.03	1.84	0.07	0.05	0.03	1.83	0.07	.
JLB	0.25	0.03	9.54	0.00	0.25	0.02	10.85	0.00	***
DIwages	0.09	0.03	2.78	0.01	0.09	0.03	2.85	0.00	**
PopSqKm	0.12	0.03	4.43	0.00	0.12	0.03	4.28	0.00	***
DFGTE_B0250_1	0.16	0.05	2.94	0.00	0.16	0.06	2.88	0.00	**
DFGTE_B0500_1	0.13	0.07	1.79	0.07	0.13	0.08	1.69	0.09	.
HOLC_D	-0.16	0.15	-1.12	0.26	-0.16	0.13	-1.31	0.19	
HOLC_C	0.03	0.15	0.23	0.81	0.03	0.13	0.27	0.79	
HOLC_B	-0.26	0.17	-1.55	0.12	-0.26	0.12	-2.09	0.04	*
Residual standard error: 0.69 on 869 degrees of freedom									
Multiple R-squared: 0.3948, Adjusted R-squared: 0.3823									
F-statistic: 31.5 on 18 and 869 DF, p-value: 0.00									
Breusch-Pagan test: BP = 71.094, df = 18, p-value = 0.00									
Wald test									
Res.Df Df F	Pr(>F)	nobs	log Lik.	AIC	BIC				
1 869		888	-920.95	1881.9	1977.7				
2 887 -18 31.498 pval: 0.00 ***									

Table 17 (Continued). OLS Regression Results for Redlining Sample

Redlining 2009									
	Residuals:								
	Min 1Q Median 3Q Max								
	-1.9529 -0.4543 -0.0262 0.3833 3.3348								
Coefficients:	Standard				Robust				
	Est	Std. Error	t value	Pr(>|t|)	Est	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.06	0.03	-1.78	0.08	-0.06	0.03	-1.89	0.06	.
HHunder25	0.09	0.03	3.28	0.00	0.09	0.03	3.10	0.00	**
HH25_44	-0.36	0.05	-7.69	0.00	-0.36	0.05	-7.58	0.00	***
NoVeh	0.09	0.02	3.83	0.00	0.09	0.03	3.27	0.00	**
CouplesNoKids	0.12	0.05	2.73	0.01	0.12	0.04	2.84	0.00	**
PctHispanic	0.04	0.04	1.06	0.29	0.04	0.04	1.11	0.27	
PctEdAttain4yrs	-0.16	0.04	-4.27	0.00	-0.16	0.03	-4.47	0.00	***
PctWhite	0.24	0.04	5.71	0.00	0.24	0.04	5.73	0.00	***
GDPDelta2009	-0.05	0.03	-1.69	0.09	-0.05	0.04	-1.10	0.27	
GDPDeltaRegional2009	-0.45	0.03	-13.36	0.00	-0.45	0.04	-11.70	0.00	***
Entropy	0.03	0.03	1.13	0.26	0.03	0.03	1.15	0.25	
JLB	0.20	0.03	7.05	0.00	0.20	0.03	7.66	0.00	***
DIwages	0.01	0.03	0.25	0.80	0.01	0.03	0.25	0.80	
PopSqKm	0.10	0.03	3.71	0.00	0.10	0.03	3.99	0.00	***
DFGTE_B0250_1	0.30	0.06	5.32	0.00	0.30	0.05	5.50	0.00	***
DFGTE_B0500_1	0.21	0.08	2.66	0.01	0.21	0.08	2.54	0.01	*
HOLC_D	-0.17	0.14	-1.23	0.22	-0.17	0.13	-1.34	0.18	
HOLC_C	0.02	0.14	0.12	0.90	0.02	0.12	0.15	0.88	
HOLC_B	0.08	0.15	0.49	0.62	0.08	0.13	0.57	0.57	
Residual standard error: 0.7418 on 891 degrees of freedom									
Multiple R-squared: 0.4055, Adjusted R-squared: 0.3935									
F-statistic: 33.76 on 18 and 891 DF, p-value: 0.00									
Breusch-Pagan test: BP = 128.7, df = 18, p-value 0.00									
Wald test									
Res.Df Df F	Pr(>F)	nobs	log Lik.	AIC	BIC				
1 891		910	-1009.8	2059.6	2155.9				
2 909 -18 33.759 pval: 0.00 ***									

Table 17 (Continued). OLS Regression Results for Redlining Sample

Redlining Sample 2017									
	Residuals:								
	Min 1Q Median 3Q Max								
	-1.77 -0.52 -0.08 0.38 5.53								
Coefficients:	Standard				Robust				
	Est	Std. Error	t value	Pr(>|t|)	Est	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.03	0.03	0.79	0.43	0.03	0.03	0.84	0.40	
HHunder25	0.02	0.02	0.96	0.34	0.02	0.03	0.84	0.40	
HH25_44	-0.33	0.05	-7.37	0.00	-0.33	0.05	-6.36	0.00	***
NoVeh	0.07	0.02	2.96	0.00	0.07	0.03	2.69	0.01	**
CouplesNoKids	0.13	0.05	2.59	0.01	0.13	0.05	2.43	0.02	*
PctHispanic	0.02	0.04	0.47	0.64	0.02	0.03	0.60	0.55	
PctEdAttain4yrs	-0.07	0.02	-2.78	0.01	-0.07	0.02	-2.72	0.01	**
PctWhite	0.18	0.04	4.48	0.00	0.18	0.03	5.39	0.00	***
GDPDelta2017	0.13	0.03	4.58	0.00	0.13	0.03	4.85	0.00	***
GDPDeltaRegional2017	-0.53	0.04	-14.52	0.00	-0.53	0.04	-12.85	0.00	***
Entropy	0.04	0.03	1.46	0.14	0.04	0.03	1.49	0.14	
JLB	0.19	0.03	6.81	0.00	0.19	0.03	7.24	0.00	***
DIwages	-0.11	0.03	-3.76	0.00	-0.11	0.03	-4.03	0.00	***
PopSqKm	0.11	0.03	3.90	0.00	0.11	0.03	4.11	0.00	***
DFGTE_B0250_1	0.16	0.06	2.70	0.01	0.16	0.05	2.97	0.00	**
DFGTE_B0500_1	0.13	0.08	1.69	0.09	0.13	0.08	1.71	0.09	.
HOLC_D	-0.21	0.15	-1.43	0.15	-0.21	0.12	-1.75	0.08	.
HOLC_C	-0.08	0.18	-0.45	0.65	-0.08	0.16	-0.50	0.62	
HOLC_B	-0.07	0.18	-0.41	0.68	-0.07	0.11	-0.68	0.49	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.855 on 1223 degrees of freedom
Multiple R-squared: 0.3221, Adjusted R-squared: 0.3122
F-statistic: 32.29 on 18 and 1223 DF, p-value: 0.00
Breusch-Pagan test: BP = 88.877, df = 18, p-value = 0.00
Wald test

Res.Df	Df	F	Pr(>F)	nobs	log Lik.	AIC	BIC
1 1223				1242	-1558.2	3156.3	3258.8
2 1241	-18	32.288	pval: 0.00 ***		(df=20)		

Table 16. Propensity Score Matching Results for Main Sample and Robustness Check

	Main Sample PSM										Robustness Check PSM									
2017	Before Match					After Match					Before Match					After Match				
	transit before	no transit before	mean diff before	p.val	Var Ratio	transit after	no transit after	mean diff after	p.val	Var Ratio	transit before	no transit before	mean diff before	p.val	Var Ratio	transit after	no transit after	mean diff after	p.val	Var Ratio
HHunder25	0.3	-0.1	29.8	0.0	2.1	0.3	0.1	9.9	0.0	1.3	0.0	0.0	4.5	0.6	1.1	0.0	0.0	4.7	0.2	1.4
HH25_44	0.1	0.0	6.9	0.2	1.0	0.1	0.0	7.5	0.0	1.3	0.1	0.0	7.2	0.4	1.4	0.1	0.1	-4.1	0.2	1.3
NoVeh	0.4	-0.1	47.2	0.0	2.4	0.4	0.2	14.7	0.0	1.3	0.2	-0.1	20.9	0.0	1.1	0.2	0.0	18.6	0.0	1.2
CouplesNoKids	-0.1	0.0	-13.0	0.0	0.7	-0.1	-0.1	-5.9	0.1	1.2	0.0	0.0	-0.8	0.9	1.4	0.0	0.0	-3.8	0.3	1.3
PctHispanic	0.1	0.0	17.2	0.0	1.1	0.1	0.1	7.3	0.0	1.1	-0.2	0.1	-30.9	0.0	0.7	-0.2	-0.2	-5.7	0.2	1.0
PctEdAttain4yrs	-0.1	0.0	-10.3	0.1	0.9	-0.1	-0.2	7.1	0.0	1.3	0.0	0.0	5.4	0.6	5.0	0.0	0.0	1.0	0.9	4.1
PctWhite	-0.2	0.1	-24.7	0.0	1.0	-0.2	-0.1	-5.7	0.0	1.0	0.1	0.0	14.0	0.1	0.8	0.1	0.2	-10.6	0.0	1.1
GDPDelta2017	0.2	-0.1	25.4	0.0	1.2	0.2	0.1	10.9	0.0	1.1	-0.5	0.2	-77.9	0.0	0.5	-0.5	0.5	-140.9	0.0	0.4
GDPDeltaRegional2017	-0.3	0.1	-36.2	0.0	0.6	-0.3	-0.2	-4.6	0.1	1.0	0.3	-0.1	49.9	0.0	0.9	0.3	0.3	9.9	0.0	0.9
Entropy	0.2	0.0	20.3	0.0	1.1	0.2	0.2	1.7	0.5	1.3	0.1	0.0	7.7	0.4	0.9	0.1	0.2	-14.0	0.0	1.6
JLB	0.1	0.0	6.3	0.3	1.0	0.1	0.1	-4.7	0.1	1.4	0.0	0.0	1.7	0.8	0.7	0.0	0.0	1.2	0.9	1.1
DIwages	-0.2	0.1	-25.7	0.0	0.7	-0.2	-0.1	-7.8	0.0	1.1	0.0	0.0	-0.3	1.0	0.8	0.0	-0.1	9.8	0.1	1.6
DIsectors	0.0	0.0	-5.2	0.3	0.8	0.0	0.0	-1.4	0.6	1.0	-0.1	0.1	-20.4	0.0	0.5	-0.1	-0.2	12.7	0.0	1.1
PopSqKm	0.2	-0.1	21.7	0.0	1.4	0.2	0.1	6.3	0.0	1.1	0.0	0.0	3.1	0.7	1.1	0.0	-0.1	14.0	0.0	1.9
2009																				
HHunder25	0.1	0.0	15.3	0.0	0.9	0.1	0.1	6.6	0.3	1.4	0.1	0.0	14.6	0.2	3.3	0.1	0.0	6.9	0.1	1.9
HH25_44	0.0	0.0	1.7	0.8	1.0	0.0	0.0	0.5	0.8	1.3	0.0	0.0	-4.0	0.7	0.9	0.0	0.0	0.1	1.0	1.3
NoVeh	0.3	-0.1	35.8	0.0	1.8	0.3	0.3	3.7	0.0	1.1	0.1	0.0	7.9	0.5	1.2	0.1	-0.1	10.8	0.1	1.2
CouplesNoKids	-0.1	0.0	-18.2	0.0	0.8	-0.1	-0.1	-9.5	0.0	1.2	-0.2	0.1	-30.4	0.0	1.1	-0.2	-0.1	-10.7	0.0	1.4
PctHispanic	0.2	-0.1	27.5	0.0	1.2	0.2	0.1	12.4	0.0	1.1	0.1	0.0	18.5	0.1	0.9	0.1	0.0	10.7	0.0	1.0
PctEdAttain4yrs	-0.1	0.0	-13.6	0.0	0.4	-0.1	-0.1	2.9	0.6	1.6	0.0	0.0	2.4	0.8	1.7	0.0	0.1	-4.0	0.3	0.9
PctWhite	-0.2	0.1	-28.6	0.0	1.0	-0.2	-0.1	-16.0	0.0	1.0	-0.2	0.1	-28.0	0.0	0.7	-0.2	-0.1	-17.6	0.0	0.9
GDPDelta2009	0.2	-0.1	26.0	0.0	0.9	0.2	0.2	-0.9	0.5	1.0	-0.1	0.0	-18.3	0.1	0.6	-0.1	-0.1	-2.1	0.8	1.0
GDPDeltaRegional2009	-0.3	0.1	-40.2	0.0	0.6	-0.3	-0.2	-9.9	0.1	0.7	0.7	-0.2	79.5	0.0	2.7	0.7	0.1	43.0	0.0	2.0
Entropy	0.1	0.0	18.1	0.0	1.1	0.1	0.2	-3.2	0.1	1.2	-0.2	0.1	-26.2	0.0	1.0	-0.2	0.0	-20.3	0.0	1.1
JLB	0.0	0.0	-1.0	0.9	1.1	0.0	0.1	-8.8	0.0	1.4	-0.2	0.1	-22.4	0.0	0.7	-0.2	0.1	-23.9	0.0	0.9
DIwages	-0.1	0.0	-14.6	0.0	0.8	-0.1	0.0	-11.9	0.0	1.2	-0.2	0.1	-20.8	0.0	0.7	-0.2	-0.3	14.2	0.0	1.2
DIsectors	-0.1	0.0	-9.1	0.1	0.8	-0.1	0.0	-8.2	0.2	0.8	-0.2	0.1	-26.6	0.0	0.5	-0.2	-0.3	8.8	0.1	0.8
PopSqKm	0.2	0.0	19.6	0.0	1.1	0.2	0.1	4.9	0.1	1.6	0.2	-0.1	21.8	0.1	1.7	0.2	0.1	8.7	0.2	1.4

Table 18 (Continued). Propensity Score Matching Results for Main Sample and Robustness Check

	Main Sample PSM										**Robustness Check PSM**									
2000	**Before Match**					**After Match**					**Before Match**					**After Match**				
	transit before	no transit before	mean diff before	p.val	Var Ratio	transit after	no transit after	mean diff after	p.val	Var Ratio	transit before	no transit before	mean diff before	p.val	Var Ratio	transit after	no transit after	mean diff after	p.val	Var Ratio
HHunder25	0.1	0.0	13.9	0.0	0.9	0.1	0.0	7.8	0.0	1.2	0.2	-0.1	20.1	0.1	1.7	0.2	0.0	13.7	0.0	1.1
HH25_44	-0.1	0.0	-6.2	0.3	0.7	-0.1	0.0	-3.6	0.4	1.1	-0.2	0.1	-21.7	0.0	0.8	-0.2	-0.2	-1.7	0.7	1.0
NoVeh	0.3	-0.1	40.8	0.0	1.9	0.3	0.1	16.3	0.0	1.6	0.1	0.0	17.0	0.1	2.0	0.1	0.1	5.4	0.4	1.3
CouplesNoKids	-0.1	0.0	-14.5	0.0	0.9	-0.1	-0.1	-3.4	0.2	1.4	-0.3	0.1	-42.7	0.0	0.6	-0.3	-0.2	-9.0	0.2	1.1
PctHispanic	0.2	-0.1	30.1	0.0	1.5	0.2	0.2	1.3	0.5	1.0	0.1	0.0	8.1	0.4	0.9	0.1	0.1	1.3	0.8	0.8
PctEdAttain4yrs	-0.1	0.0	-15.7	0.0	0.4	-0.1	-0.2	9.2	0.0	1.4	0.1	0.0	7.8	0.5	3.9	0.1	0.1	-0.8	0.8	1.4
PctWhite	-0.2	0.1	-27.2	0.0	1.1	-0.2	-0.1	-7.5	0.0	1.0	-0.1	0.0	-18.3	0.1	0.7	-0.1	-0.1	-8.5	0.2	0.7
GDPDelta2002	-0.2	0.1	-21.0	0.0	1.7	-0.2	0.1	-25.4	0.0	1.4	0.4	-0.1	52.4	0.0	0.9	0.4	0.1	28.0	0.0	1.0
GDPDeltaRegional2002	-0.3	0.1	-45.9	0.0	0.6	-0.3	-0.3	-5.6	0.1	0.9	0.7	-0.2	83.7	0.0	3.4	0.7	0.1	46.1	0.0	3.0
Entropy	0.2	-0.1	19.6	0.0	1.1	0.2	0.1	3.7	0.2	1.3	-0.1	0.0	-17.6	0.1	1.1	-0.1	-0.1	-5.7	0.2	1.1
JLB	0.0	0.0	0.7	0.9	1.1	0.0	0.1	-6.7	0.0	1.2	-0.2	0.1	-27.5	0.0	1.1	-0.2	-0.1	-15.8	0.0	1.3
DIwages	-0.1	0.0	-16.9	0.0	0.7	-0.1	-0.1	-2.7	0.6	1.1	-0.2	0.1	-33.2	0.0	0.5	-0.2	-0.3	1.9	0.9	0.8
DIsectors	-0.1	0.0	-19.5	0.0	0.7	-0.1	-0.1	-10.2	0.0	1.1	-0.2	0.1	-27.0	0.0	0.4	-0.2	-0.3	20.4	0.0	1.5
PopSqKm	0.2	-0.1	21.5	0.0	1.5	0.2	0.1	6.0	0.0	1.3	0.1	0.0	17.0	0.1	1.7	0.1	0.1	5.1	0.5	1.6

Table 17. OLS Regression Results for Main Sample and Robustness Check

Main Sample 2000

Residuals:	Min	1Q	Median	3Q	Max
	-2.065	-0.475	-0.083	0.3883	3.1093

Robustness Check 2000

Residuals:	Min	1Q	Median	3Q	Max
	-2.03	-0.35	0.0125	0.382	1.596

Coefficients:	Standard				Robust					Standard				Robust				
	Est	Std. Error	t val	Pr>|t|	Est	Std. Error	t val	Pr>|t|		Est	Std. Error	t val	Pr>|t|	Est	Std. Error	t val	Pr>|t|	
(Intercept)	0.02	0.04	0.37	0.71	0.02	0.05	0.35	0.72		-0.12	0.06	-2.00	0.05	-0.12	0.07	-1.72	0.09	.
HHunder25	-0.02	0.04	-0.41	0.68	-0.02	0.04	-0.41	0.68		0.04	0.04	0.87	0.39	0.04	0.04	0.93	0.35	
HH25_44	-0.30	0.05	-5.55	0.00	-0.30	0.05	-5.61	0.00	***	-0.06	0.07	-0.90	0.37	-0.06	0.07	-0.90	0.37	
NoVeh	0.09	0.03	2.99	0.00	0.09	0.03	3.08	0.00	**	0.08	0.04	2.05	0.04	0.08	0.04	1.96	0.05	.
CouplesNoKids	0.18	0.05	3.58	0.00	0.18	0.05	3.50	0.00	***	0.05	0.08	0.65	0.51	0.05	0.08	0.62	0.54	
PctHispanic	0.11	0.04	3.00	0.00	0.11	0.04	3.18	0.00	**	0.09	0.10	0.98	0.33	0.09	0.08	1.24	0.22	
PctEdAttain4yrs	-0.23	0.06	-4.07	0.00	-0.23	0.06	-3.83	0.00	***	-0.01	0.03	-0.23	0.82	-0.01	0.02	-0.30	0.77	
PctWhite	0.24	0.05	5.09	0.00	0.24	0.05	5.23	0.00	***	0.14	0.10	1.32	0.19	0.14	0.08	1.70	0.09	.
GDPDelta2002	-0.06	0.03	-1.99	0.05	-0.06	0.02	-2.35	0.02	*	0.43	0.04	9.88	0.00	0.43	0.06	7.00	0.00	***
GDPDeltaRegional2002	-0.35	0.04	-8.89	0.00	-0.35	0.03	-10.2	0.00	***	-0.33	0.04	-7.70	0.00	-0.33	0.04	-7.78	0.00	***
Entropy	0.02	0.03	0.56	0.57	0.02	0.03	0.58	0.56		0.12	0.04	2.71	0.01	0.12	0.04	2.72	0.01	**
JLB	0.24	0.03	7.36	0.00	0.24	0.03	8.04	0.00	***	0.27	0.04	6.14	0.00	0.27	0.04	6.28	0.00	***
DIwages	0.17	0.04	4.67	0.00	0.17	0.03	4.98	0.00	***	-0.19	0.06	-3.33	0.00	-0.19	0.06	-3.18	0.00	**
PopSqKm	0.10	0.03	2.95	0.00	0.10	0.03	3.02	0.00	**	0.12	0.04	2.79	0.01	0.12	0.04	3.01	0.00	**
DFGTE_B0250_1	0.10	0.06	1.61	0.11	0.10	0.06	1.73	0.08	.	-0.15	0.12	-1.23	0.22	-0.15	0.14	-1.12	0.27	
DFGTE_B0500_1	0.14	0.09	1.60	0.11	0.14	0.09	1.66	0.10	.	-0.12	0.16	-0.73	0.47	-0.12	0.17	-0.70	0.49	

Main Sample 2000

Residual standard error: 0.7352 on 636 degrees of freedom

Multiple R-squared: 0.3967, Adjusted R-squared: 0.3825

F-statistic: 27.88 on 15 and 636 DF, p-value: 0.00

Breusch-Pagan test: BP = 38.493, df = 15, p-value = 0.00

Wald test

Res.Df Df F Pr(>F)	nobs	log Lik.	AIC	BIC
1 636	652	-716.5	1467	1543.1
2 651 -15 27.882 pval: 0.00 ***		(df=17)		

Robustness Check 2000

Residual standard error: 0.6041 on 220 degrees of freedom

Multiple R-squared: 0.6428, Adjusted R-squared: 0.6184

F-statistic: 26.39 on 15 and 220 DF, p-value: 0.00

Breusch-Pagan test: BP = 43.715, df = 15, p-value = 0.00

Wald test

Res.Df Df F Pr(>F)	nobs	log Lik.	AIC	BIC
1 220	236	-207.63	449.3	508.15
2 235 -15 26.393 pval: 0.00 ***		(df=17)		

Table 18. OLS Regression Results for Main Sample and Robustness Check

Main Sample 2009

Residuals:	Min	1Q	Median	3Q	Max
	-1.89	-0.46	-0.06	0.42	2.77

Coefficients:	Standard Est.	Std. Error	t val	Pr(>|t|)	Robust Est.	Std. Error	t val	Pr(>|t|)	
(Intercept)	-0.05	0.04	-1.25	0.21	-0.05	0.04	-1.31	0.19	
HHunder25	0.04	0.03	1.15	0.25	0.04	0.03	1.22	0.22	
HH25_44	-0.26	0.05	-5.25	0.00	-0.26	0.05	-5.37	0.00	***
NoVeh	0.01	0.03	0.58	0.56	0.01	0.02	0.66	0.51	
CouplesNoKids	0.11	0.05	2.04	0.04	0.11	0.05	2.06	0.04	*
PctHispanic	0.08	0.04	2.07	0.04	0.08	0.04	2.03	0.04	*
PctEdAttain4yrs	-0.12	0.05	-2.52	0.01	-0.12	0.06	-2.07	0.04	*
PctWhite	0.21	0.04	5.11	0.00	0.21	0.04	5.27	0.00	***
GDPDelta2009	0.30	0.03	9.64	0.00	0.30	0.03	9.92	0.00	***
GDPDeltaRegional2009	-0.41	0.04	-11.45	0.00	-0.41	0.03	-13.0	0.00	***
Entropy	-0.02	0.03	-0.76	0.45	-0.02	0.03	-0.79	0.43	
JLB	0.17	0.03	5.46	0.00	0.17	0.03	5.40	0.00	***
DIwages	0.12	0.03	3.56	0.00	0.12	0.03	3.97	0.00	***
PopSqKm	0.13	0.03	3.85	0.00	0.13	0.03	3.64	0.00	***
DFGTE_B0250_1	0.27	0.06	4.49	0.00	0.27	0.06	4.50	0.00	***
DFGTE_B0500_1	0.22	0.08	2.71	0.01	0.22	0.08	2.74	0.01	**

Residual standard error: 0.7029 on 658 degrees of freedom
Multiple R-squared: 0.5427, Adjusted R-squared: 0.5322
F-statistic: 52.05 on 15 and 658 DF, p-value: 0.00
Breusch-Pagan test: BP = 35.525, df = 15, p-value = 0.002069
Wald test

	Res.Df Df F Pr(>F)	nobs	log Lik.	AIC	BIC
1	658	674	-710.7	1455.4	1532.1
2	673 -15 52.049 p.val: 0.00***		(df=17)		

Robustness Check 2009

Residuals:	Min	1Q	Median	3Q	Max
	-1.85	-0.35	0.005	0.36	1.89

Coefficients:	Standard Est.	Std. Error	t val	Pr(>|t|)	Robust Est.	Std. Error	t val	Pr(>|t|)	
(Intercept)	0.09	0.06	1.52	0.13	0.09	0.06	1.46	0.14	
HHunder25	0.03	0.04	0.80	0.43	0.03	0.03	1.19	0.23	
HH25_44	-0.25	0.08	-3.04	0.00	-0.25	0.08	-3.29	0.00	**
NoVeh	0.22	0.05	4.49	0.00	0.22	0.04	5.13	0.00	***
CouplesNoKids	-0.02	0.08	-0.26	0.79	-0.02	0.08	-0.26	0.80	
PctHispanic	-0.04	0.09	-0.42	0.67	-0.04	0.07	-0.59	0.55	
PctEdAttain4yrs	-0.07	0.04	-1.83	0.07	-0.07	0.04	-1.85	0.07	.
PctWhite	0.13	0.10	1.23	0.22	0.13	0.08	1.58	0.12	
GDPDelta2009	-0.35	0.06	-5.99	0.00	-0.35	0.07	-4.93	0.00	***
GDPDeltaRegional2009	-0.36	0.05	-7.28	0.00	-0.36	0.05	-7.20	0.00	***
Entropy	0.07	0.05	1.34	0.18	0.06	0.05	1.34	0.18	
JLB	0.11	0.05	2.05	0.04	0.11	0.05	1.97	0.05	.
DIwages	-0.14	0.06	-2.52	0.01	-0.14	0.06	-2.32	0.02	*
PopSqKm	0.08	0.05	1.68	0.10	0.08	0.05	1.79	0.08	.
DFGTE_B0250_1	-0.04	0.13	-0.34	0.73	-0.04	0.14	-0.33	0.74	
DFGTE_B0500_1	-0.06	0.18	-0.36	0.72	-0.06	0.19	-0.33	0.74	

Residual standard error: 0.6406 on 220 degrees of freedom
Multiple R-squared: 0.6334, Adjusted R-squared: 0.6084
F-statistic: 25.34 on 15 and 220 DF, p-value: 0.00
Breusch-Pagan test: BP = 26.59, df = 15, p-value = 0.03226
Wald test

	Res.Df Df F Pr(>F)	nobs	log Lik.	AIC	BIC
1	220	236	-221.48	477	535.85
2	235 -15 25.335 p.val: 0.00 ***		(df=17)		

Table 20 (Continued). OLS Regression Results for Main Sample and Robustness Check

Main Sample 2017

Residuals:	Min	1Q	Median	3Q	Max
	-2.03	-0.48	0.002	0.44	2.63

Coefficients:	Standard				Robust				
	Est	Std. Error	t val	Pr >|t|	Est	Std. Error	t val	Pr(>|t|)	
(Intercept)	0.05	0.04	1.30	0.20	0.05	0.04	1.34	0.18	
HHunder25	-0.03	0.02	-1.31	0.19	-0.03	0.02	-1.25	0.21	
HH25_44	-0.17	0.05	-3.53	0.00	-0.17	0.05	-3.38	0.00	***
NoVeh	0.05	0.02	2.17	0.03	0.05	0.02	2.31	0.02	*
CouplesNoKids	0.05	0.05	0.86	0.39	0.05	0.06	0.78	0.44	
PctHispanic	0.07	0.03	1.92	0.06	0.07	0.03	2.04	0.04	*
PctEdAttain4yrs	-0.13	0.03	-3.91	0.00	-0.13	0.03	-3.83	0.00	***
PctWhite	0.22	0.04	5.98	0.00	0.22	0.04	5.63	0.00	***
GDPDelta2017	0.34	0.03	12.64	0.00	0.34	0.03	13.39	0.00	***
GDPDeltaRegional2017	-0.46	0.04	-13.00	0.00	-0.46	0.03	-13.2	0.00	***
Entropy	-0.02	0.03	-0.59	0.56	-0.02	0.03	-0.58	0.56	
JLB	0.22	0.03	7.51	0.00	0.22	0.03	7.08	0.00	***
DIwages	-0.07	0.03	-2.29	0.02	-0.07	0.03	-2.21	0.03	*
PopSqKm	0.10	0.03	4.00	0.00	0.10	0.03	3.67	0.00	***
DFGTE_B0250_1	0.17	0.05	3.09	0.00	0.17	0.05	3.06	0.00	**
DFGTE_B0500_1	0.11	0.08	1.38	0.17	0.11	0.08	1.36	0.17	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.7185 on 848 degrees of freedom

Multiple R-squared: 0.4168, Adjusted R-squared: 0.4065

F-statistic: 40.41 on 15 and 848 DF, p-value: 0.00

Breusch-Pagan test: BP = 56.752, df = 15, p-value = 0.00

Wald test

Res.Df Df F Pr(>F)	nobs	log Lik.	AIC	BIC
1 848	864	-932.3	1898.6	1979.5
2 863 -15 40.406 pval: 0.00 ***		(df=17)		

Robustness Check 2017

Residuals:	Min	1Q	Median	3Q	Max
	-1.64	-0.382	-0.037	0.31	2.825

	Standard				Robust				
	Est	Std. Error		t val	Est	Std. Error	t val	Pr(>|t|)	
(Intercept)	0.16	0.04	3.63	0.00	0.16	0.06	2.74	0.01	**
HHunder25	0.00	0.04	-0.01	0.99	0.00	0.05	-0.01	1.00	
HH25_44	-0.06	0.06	-1.00	0.32	-0.06	0.05	-1.17	0.24	
NoVeh	0.20	0.04	5.48	0.00	0.20	0.04	4.89	0.00	***
CouplesNoKids	-0.06	0.05	-1.05	0.29	-0.06	0.05	-1.06	0.29	
PctHispanic	-0.13	0.09	-1.40	0.16	-0.13	0.08	-1.57	0.12	
PctEdAttain4yrs	-0.06	0.03	-1.95	0.05	-0.06	0.03	-1.63	0.10	
PctWhite	0.07	0.09	0.69	0.49	0.07	0.08	0.84	0.40	
GDPDelta2017	-0.02	0.04	-0.57	0.57	-0.02	0.04	-0.62	0.53	
GDPDeltaRegional2017	-0.71	0.05	-13.7	0.00	-0.71	0.07	-10.6	0.00	***
Entropy	-0.04	0.04	-0.98	0.33	-0.04	0.04	-0.89	0.37	
JLB	0.03	0.04	0.74	0.46	0.03	0.04	0.83	0.41	
DIwages	-0.16	0.04	-3.89	0.00	-0.16	0.04	-4.54	0.00	***
PopSqKm	-0.01	0.04	-0.27	0.79	-0.01	0.04	-0.28	0.78	
DFGTE_B0250_1	-0.22	0.10	-2.09	0.04	-0.22	0.12	-1.82	0.07	.
DFGTE_B0500_1	-0.29	0.14	-2.09	0.04	-0.29	0.16	-1.80	0.07	.

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6188 on 362 degrees of freedom

Multiple R-squared: 0.6233, Adjusted R-squared: 0.6077

F-statistic: 39.93 on 15 and 362 DF, p-value: 0.00

Breusch-Pagan test: BP = 78.458, df = 15, p-value = 0.00

Wald test

Res.Df Df F Pr(>F)	nobs	log Lik.	AIC	BIC
1 362	378	-346.74	727.49	794.4
2 377 -15 39.932 pval: 0.00 ***		(df=17)		

Implications for Planning & Policy

Internal capture, based in the theory of accessibility, should replace raw jobs-housing balance figures for policy decisions about how to improve development patterns for reductions in vehicle miles traveled. Internal capture has not seen a great deal of increase in percentage in our metropolitan areas overall in the years of this study. Housing may be the key to internal capture in the areas studied in this article. The increase in internal capture of work trips may just be waiting for increases in attainable housing in the urban heart of our metropolitan areas, such as those studied in this article. The overwhelming majority of residential building permits issued nationally are in large-lot single-family housing (Hibberd, n.d.). While this is partly due to the market demand for such, there is a whole "missing middle" typology of housing that has a profoundly unmet demand, such as townhouses and triplexes (Parolek 2020a). The positive association between internal capture and population density, as well as jobs-labor balance, suggests that more density of workforce housing in our urban centers will increase internal capture. TODs are uniquely designed, geographically situated, and interconnected with regional transportation networks to provide areas to make these increases and currently are mostly comprised of non-residential land uses (Renne et al. 2016b). This leaves residential land uses a vital area for development in TODs that aspire to be complete communities, even microcosms of our metropolitan areas where people of all walks of life can enjoy greater access to needed land uses of all types within short distances and at prices of entry attainable to most who wish to live there.

For example, this study highlighted the positive association between couples with no children and internal capture. Other studies, however, have pinpointed households with children as parties interested in living in compact highly accessible urban places (A. Nelson et al. 2021b). The missing middle housing types are needed in and near TOD neighborhoods to give these younger households a foothold into these desirable places, in housing that is priced toward being attainable to young households, both as places to live and as investments that will help them accrue equity as owners. This can have implications for the creation of more such households among the Gen Z and younger generations.

This article also highlighted the ongoing phenomenon of the positive association between people getting greater educational attainment and a pattern of longer commutes. Regional GDP growth was also negatively associated with internal capture, which means that regional economic vitality seems to be positively associated with longer commutes. What this tells us about economic development needs further study, however.

Value capture policies have been used to intensify development around transit stations, including funds to create affordable housing options in some of these places. The success of many early transit lines in the US, China, and Japan greatly depended upon this development approach. Indeed, many transit systems, both early and current, have been funded using the value granted land uses by these transportation network connections. This has applicability to local small business development, such as live-work spaces that will certainly increase internal capture. Recent studies by Nelson et al. (A. Nelson et al. 2021b) have shown that transit station areas across the country, even within a half-mile of the station, have a great deal of potential for development intensification that would aid this effort. This does not have to entail profound changes, but rather "gentle density" increases can maintain the character of our urban places.

This article also highlights the ongoing effects of disinvestment in redlined neighborhoods (Mallach 2018b). Gentle density with an eye to incremental development and simple design is needed in order to make funding available to many places that are usually outside the purview of major development projects. This approach could make it more feasible to increase the supply of residential land uses in TOD areas, which will also increase the affordability. People worried about gentrification in these neighborhoods can turn to local residents for a list of potential improvements that are most needed. They can also insist on developments that aim at greater affordability through missing middle housing designed for the workforce and greater accessibility through the creation of local small businesses.

There is still much to learn about what makes a metropolitan area successful at reducing commutes. Larger trends in the economy and housing markets play major roles that require further study. The redlining outcomes indicate the role of the neighborhood scale of urban health in commuting patterns. This requires further investigation. Further research could also look at specific sectors of workers and firms to evaluate patterns of land use succession dynamics. Many transit systems have been developed in recent years, and these should also be evaluated for their contribution to internal capture and accessibility.

Chapter 6: Conclusion - Relative Effectiveness of TOD policies for JWB and Implications

The automobile-focused urban life comes with some unintended consequences, including isolating some workers from jobs. Kain's spatial mismatch theory links suburbanization with an increase of joblessness for urban populations because of a lack of access to suburbanization of jobs (Kain, 1968). Disinvestment in urban redlined districts, for example, ruined the urban cores of cities across the country and left these aging urban centers without the necessary revitalization (Rothstein, 2017).

The oft used job-housing balance (JHB), which is a raw magnitude approximating balance in a specified enumeration unit but should be conceptualized and analyzed as an accessibility problem. Accessibility should be considered both mobility and proximity, but ever since the Fordist era began the "mobility turn" has dominated culture, economics, and urban policies. The dependency on the automobile has wildly changed our urban structure, replacing the human-scaled proximity paradigm of land development with a seemingly random pattern driven by mobilities and their overwhelmingly disruptive (and costly) infrastructures (Sheller & Urry, 2006). While many and profound are the positive results of the automobility revolution, urban sprawl, colossal debt at all levels of government, and spatial mismatch are some of the noteworthy negatives.

Transit-Oriented Development (TOD) planning and policy has the normative goal to maximize internal trips within the TOD zone, largely through the design of human-scaled places connected by a network of multimodal transportation systems that include transit and active transportation as much as automobility (Gulden et al., 2013). This leads to increased efficiency in travel patterns, measured as trip generation reductions, which are sometimes substantial in nature (Clifton et al., 2015; Ewing et al., 2011) as much as 40% reduction (or more) from the estimates provided by the ITE handbook (R. Cervero & Arrington, 2008).

This study focuses on the spatial association between employment and worker locations and the impact this association has on accessibility, or the ease with which households and firms can access the need linkages to the situs requirements of their unique location and land use. The JWB Index reveals latent processes of multiple dimensions that shape the balance of employment and workers in any location. The resulting patterns seem to reveal a series of different varieties of urban patterns leading to short commutes. The second paper of the study tests the JWB in the context of polycentric development dynamics over a 7-year period before, during and after Great Recession, measuring how well local employment clusters are predicted by the location of local residential clusters of workers, with the distance to transit station as an additional predictor. The third paper determines how well the presence of various demographic groups and related spatial domains predict the JWBI, with several locational controls and the special case of redlined urban districts.

This study provides empirical evidence regarding the relative effectiveness of TOD at increasing workforce and workplace accessibility through greater job-worker balance. Further study would include adding clustering effects of zoning, to ascertain how significant clustering of jobs or housing coincide with various zones. Additionally, the proximity of many modes of FRT in downtown neighborhoods suggest plausibility of major interaction effects between transit modes. Further work on this phenomenon would be of great worth. Further work could place the transit stops at the center of commuter sheds based on commute time data to determine whether internal capture grew over time in those locations. The model should also be extended to include the ever-expanding portions of our metropolitan areas outside the most highly urbanized areas.

This study highlights several useful research insights:

Findings indicate that there is a need for more emphasis on accessibility in the commuting literature, with jobs-worker balance (JWB) as an innovative approach to the issue that draws upon the structure of the region for analysis. Further research on balancing workers and firms should more fully emphasize, moreover, the ongoing need for proximity between land uses in the post-Ford era.

Analysis of the optimal JWB requires local knowledge and analysis custom fit to the individual region. Each region has multiple spatial regimes and unique historical development patterns. Further efforts to refine the JWB approach might include greater use of the gravity model. A gravity-based conceptualization of origin-destination attraction might provide a useful enhancement of internal capture measurement.

Spatial analysis adds a great deal of understanding to urban questions. Spatial dependence can be measured and used as a modeling tool. Measuring and correcting for spatial nonstationarity in model parameters increases the accuracy of models that have this bias. As stated above, there is no actual case when spatial dependence does not play a role in a cross-sectional data set. The assumptions of OLS regression include spatially independent observations that are i.i.d. and uncorrelated with the error term. When study variables break these assumptions, corrections are needed, just as is the case with the problems in data space so widely researched in OLS diagnostics. The next steps in research should include finding ways to model the spatial effects of highly variegated landscapes, such as in Seattle, Washington. Ways to optimize the commute shed in the JWB internal capture analysis. Coding an algorithm that can apply a range of commute shed definitions. Applying the correctives of SAR modeling to the logistic regression model would be likewise helpful. The multiple scales at which urban processes operate over time require fitting models for multiple times and places, and logistic regression also needs to be extended, if possible, with methods to directly correct spatial biases.

Research Goals and Results

This dissertation sought to obtain new insights on how effectively TOD policies and design improve accessibility for firms and workers to neighborhoods where Fixed-Route Transit (FRT) has been introduced. Using new theories, data sets, and methodologies, the research provides further evidence regarding transit's effects on employment accessibility. It introduces the JWBI. As hypothesized, the study uncovered nuance in the grouping of workers and their urban context. It also gives new guidance towards transit-driven reductions in spatial mismatch, which will help increase the economic resilience of cities' firms and labor forces. It also emphasizes the transportation industry's desired focus on the transportation-land use connection.

Urban economics is still determined by the spatial structure of the region. Distance to the CBD is one of the most salient variables in nearly every model in the study. The tradeoff between land area and accessibility to intensely concentrated land uses and human networks lives on in the internet era. Agglomeration economies remain a vital key to the economic health of an urban area.

Centering across the region can increase efficiency, agglomeration, and resilience to economic shocks. This study highlights the situation in recent years across many metropolitan areas: while much has been done to increase centering and thereby improve land use and transportation efficiencies, the polycentric land development approach remains more of a goal for the future of the city than a present reality. Florida (Florida 2017b) emphasized: "make clustering work for us and not against us" by developing the most sought-after land more efficiently and intensively. We need to "liberalize and modernize" our zoning and building codes. Gentle density will avoid the overheated land markets of the "superstar cities," and "pedestrian scale" mid-rise mixed-use areas enable the interaction among people that creates a growth environment (Florida, 2017; Parolek, 2020).

Many Americans want compact mixed-use land uses and access to transit; all development to 2030 could be done in transit-served corridors without meeting current unmet demand; the optimal use of urban land supports job-worker balance, and vice-versa. That optimal use includes such features as higher-density clustering of activities in infill locations, with mixed uses and human scale. It includes smaller local shops, schools and parks accessible by walking, biking and transit as well as by automobile, using more highly connected roads and sidewalks designed to safely and comfortably accommodate all modes of travel. It also includes a public realm for every community, planned and coordinated by a broad range of community stakeholders (A. C. Nelson, 2013b).

Solutions for affordable housing in LE neighborhoods are needed. Our current ever-widening gap between need and supply indicates that new designs and policies are needed. To make an obvious point, housing for most workers is not clustering near jobs because attainable "missing middle" housing is not being built in those locations.

Research Papers

The first of the research articles in the study focuses on the question of jobs-worker balance, asking the question,

> *To what extent can balance between workers and their jobs be modeled as internal capture of work trips within a commute shed, taking into consideration the labor force, income match, and BE characteristics?*

The article's hypothesis is that internal capture will be positively associated in each commute shed with income match, employment of the labor force, centering, intensity of land use mix and accessibility, and proximity to transit. The Denver Metro Area will serve as a case study region, given its relative geographic uniformity.

The hypothesis was confirmed in this study, showing the efficacy of using an accessibility-based metric. A major implication for policy includes the need to tailor jobs and housing to a classification of workers, each distinguishable in income, economic sector and multiple demographic characteristics. Further, accessibility policies must emphasize proximity rather than just mobility; accessibility has decreased to the degree that mobility has increased while proximity has decreased. That is, despite the absolute dominance of the automobile as a travel mode, commuting costs in time or distance have dramatically expanded in recent decades.

However, a removal of present transit systems would also lead to a dramatic increase in traffic congestion. Policies should advance efforts to increase proximity between residences and work locations, particularly through modes of transportation alternative to the automobile, which overwhelmingly dominates current land use and transportation funding and policy.

This study also highlights a need to increase gentle density and "missing middle" housing on the local scale, and polycentrism across each region. Each of these approaches will improve the level of attainability of housing near TODs. The former increases the housing supply, while the latter increases in number the locations across each region that benefit from agglomeration economies through greater proximity to localized assets, along with access to a range of networked assets of the regional economy and community, particularly jobs and housing.

The second research article in chapter 4 focuses on the dynamics in concentrations of workers' jobs and residences and their proximity to transit stations. The hypotheses are as follows:

> *What impact did the presence of FRT have upon the job-worker balance before, during, and after the Great Recession? How did this vary across income groups, economic sectors and station-area place type? How did this correlate with dynamics in polycentric development between time periods?*

The article's hypotheses include the following:

- Hypothesis 1: jobs will continue to be attracted to transit throughout the time period, with higher-income jobs that require less space outbidding other sectors for station area space.
- Hypothesis 2: Polycentric development will intensify, particularly near transit stations, across the years, as a market response to economic shocks.
- Hypothesis 3: Clustering of both jobs and residences will be stronger over time at transit stations, demonstrating that JWB is easier to achieve in partnership with transit network connectivity.

Addressing the hypotheses, the article finds that jobs at all wage levels were attracted to the station areas of the study region and the time frame. The association between transit proximity and job clustering was clear across the years of the study. In 2009 the association did exist but did not remain consistent to 2013. In most cases, percentages of upper-wage residences, indeed all wage levels of residences were negatively associated with job clustering. The second hypothesis, regarding polycentric development intensifying, was somewhat difficult to conclude, given the collinearity of subcenters with job accessibility and distance to the CBD. The statistical tests of spatial dependency revealed clear levels of significant clustering of both worker and residential land uses, but the centering metric acted as a function of distance to the CBD, and therefore was highly correlated with other regional accessibility metrics in the study. However, the importance of proximity to transit as an explanatory variable on which job clustering can be predicted cannot be ignored, as the analyses show a consistent and growing association between the former and the latter. The third hypothesis, related to the second, suggests that transit stations may precipitate greater concentrations of jobs nearby, but residential clusters, while occurring, are not collocating with clusters of jobs. The analysis indicates that residential clustering actually had a negative association with job clustering by 2013. Further research could test the issue of scale and determine if using different neighborhood sizes would change the results. However, the expected pattern of positive association between jobs and transit proximity came through.

In chapter 5, we discussed the extent to which transit stations are associated with job-worker balance. Using propensity score matching to remove bias from treatment and control comparisons, the study compared cities with more robust transit systems to those with little or no transit development at the time of study. The questions and hypotheses are as follows:

To what extent are transit stations and JWB related? Do FRT system neighborhoods improve in the internal capture of work trips across the study years? Does the presence of a mix of economic groups increase internal capture? Which transit station neighborhood characteristics influence the greatest increases of internal capture? What is the state of redlined neighborhoods regarding these questions?

- Hypothesis 1: FRT system presence will be related to an increase in job-worker balance for specific segments of the population, not necessarily all segments by demographic group, income or job sector.
- Hypothesis 2: Based on the literature, it is expected that most stations will have increased in balance by adding some housing, while overall employment will dominate TOD neighborhoods.

The effect of transit proximity held in the cities with developed transit systems, while being not significantly or weakly associated with transit proximity in the cities with little or no transit. This determined that in the sampled cities, proximity to transit did lead to larger percentages of internal capture of work trips.

Demographic temporal patterns show recognizable trends as well as some surprises. White and Hispanic households were positively associated with internal capture, and both were statistically significant across the time frame. Younger working-age householders were less likely than the referent, above age 45, to commute within an internal capture commute shed of 3 miles. Couples without children were more likely to commute within the 3-mile internal capture distance. Educational attainment led to weaker association with internal capture. Commutes got longer with education attainment. This effect went down over the study years. Having no vehicle was usually positively associated with internal capture. This indicates that active modes of transportation, as well as transit use, contribute to internal capture.

There remains much to be learned about what makes a city able to provide its workers with a short commute. However, more tools, theories, and data sources are coming available. Accessibility is an important paradigm for refining our measurement of jobs-worker balance. Internal capture seems to thrive best in locations with density and jobs-labor balance, near transit. This is counteracted by the sprawling nature of our metros and the ongoing development of autocentric land uses. TOD neighborhoods remain a source of low-hanging fruit when it comes to places where the “missing middle’ housing can be developed in an effort to increase the affordable housing stock. The missing townhouses and garden apartments and triplexes can become a source of investment as well as attainable housing for people who may otherwise be unable to start their own household. In a TOD neighborhood, these missing housing types can be further made affordable by cutting the cost of transportation to work and many other land uses, as many of the needed places will be close at hand.

The available range of choices for every community is quite broad, but contingent upon how each community desires to grow. Many people have stood in the way of appropriate growth that could benefit their communities. There is further effort needed to tailor the options mentioned in this study to the many and varied communities across the country. Many people advocate for top-down expert-driven decisions or seek grandiose mega-projects when local knowledge and incremental approaches would be of most benefit. Opening up the areas most benefitted by gentle density and more options in commuting and housing types to greater public and political involvement in growth choices is critical to the success of our efforts to increase location efficiency and resilience in the workforce.

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References Cited

Acevedo-Garcia, Dolores, Nancy McArdle, Erin Hardy, Keri-Nicole Dillman, Jason Reece, Unda Ioana Crisan, David Norris, and Theresa L. Osypuk. 2016. "Neighborhood Opportunity and Location Affordability for Low-Income Renter Families." *Housing Policy Debate* 26 (4–5): 607–45. https://doi.org/10.1080/10511482.2016.1198410.

Adkins, Arlie, Carrie Makarewicz, Michele Scanze, Maia Ingram, Arlie Adkins, Carrie Makarewicz, Michele Scanze, et al. 2017. "Walking Vary by Socioeconomic Context ?" 4363 (September). https://doi.org/10.1080/01944363.2017.1322527.

Adkins, Arlie, Andrew Sanderford, and Gary Pivo. 2017. "How Location Efficient Is LIHTC? Measuring and Explaining State-Level Achievement." *Housing Policy Debate* 1482 (January): 1–21. https://doi.org/10.1080/10511482.2016.1245208.

Alonso, William. 1964. *Location and Land Use*. Cambridge, MA: Harvard University Press.

Anas, Alex, Richard Arnott, and Kenneth A. Small. 1998a. "American Economic Association." *Journal of Economic Literature* 36 (3): 1426–64. https://doi.org/10.1057/978-1-349-95189-5_340.

———. 1998b. "American Economic Association." *Journal of Economic Literature* 36 (3): 1426–64. https://doi.org/10.1057/978-1-349-95189-5_340.

Anderson, Michael L. 2013. "Subways, Strikes, and Slowdowns: The Impacts of Public Transit on Traffic Congestion." 18757. NBER Working Paper.

Andrews, Richard Bruce. 1971. *Urban Land Economics and Public Policy*. Free Press.

Anguelovski, I. 2015. "From Toxic Sites to Parks as (Green) LULUs? New Challenges of Inequity, Privilege, Gentrification, and Exclusion for Urban Environmental Justice." *Journal of Planning Literature* 31 (1): 0885412215610491-. https://doi.org/10.1177/0885412215610491.

Anselin, Luc. 1988. *Spatial Econometrics: Methods and Models*. Springer + Science + Business Media, B.V.

Appleyard, Bruce S, Alexander R Frost, and Christopher Allen. 2019. "Are All Transit Stations Equal and Equitable ? Calculating Sustainability , Livability , Health , & Equity Performance of Smart." *Journal of Transport & Health* 14 (100584): 1–15. https://doi.org/10.1016/j.jth.2019.100584.

Arribas-Bel, Daniel, and Fernando Sanz-Gracia. 2014. "The Validity of the Monocentric City Model in a Polycentric Age: US Metropolitan Areas in 1990, 2000 and 2010." *Urban Geography* 35 (7): 980–97. https://doi.org/10.1080/02723638.2014.940693.

Aston, Laura, Graham Currie, Alexa Delbosc, Md Kamruzzaman, and David Teller. 2021a. "Exploring Built Environment Impacts on Transit Use–an Updated Meta-Analysis." *Transport Reviews* 41 (1): 73–96. https://doi.org/10.1080/01441647.2020.1806941.

———. 2021b. "Exploring Built Environment Impacts on Transit Use–an Updated Meta-Analysis." *Transport Reviews* 41 (1): 73–96. https://doi.org/10.1080/01441647.2020.1806941.

Aziz, H M Abdul, Nicholas N Nagle, April M Morton, Michael R Hilliard, A Devin, and Robert N Stewart. 2018. “Exploring the Impact of Walk-Bike Infrastructure , Safety Perception , and Built-Environment on Active Transportation Mode Choice : A Random Parameter Model Using New York City Commuter Data.” *Transportation* 45: 1207–29. https://doi.org/https://doi-org.ezproxy4.library.arizona.edu/10.1007/s11116-017-9760-8.

Bartholomew, K., and R. Ewing. 2011. “Hedonic Price Effects of Pedestrian- and Transit-Oriented Development.” *Journal of Planning Literature* 26 (1): 18–34. https://doi.org/10.1177/0885412210386540.

Batty, Michael. 2013. *The New Science of Cities*. Cambridge, MA: The MIT Press.

Benner, Chris, and Alex Karner. 2016a. “Low-Wage Jobs-Housing Fit : Identifying Locations of Affordable Housing Shortages.” *Urban Geography* 37 (6): 883–903. https://doi.org/10.1080/02723638.2015.1112565.

———. 2016b. “Low-Wage Jobs-Housing Fit: Identifying Locations of Affordable Housing Shortages.” *Urban Geography* 37 (6): 883–903. https://doi.org/10.1080/02723638.2015.1112565.

Bertolini, Luca. 1996. “Nodes and Places: Complexities of Railway Station Redevelopment.” *European Planning Studies* 4 (3): 331–45. https://doi.org/10.1080/09654319608720349.

Bhatta, Bharat P, and Odd I Larsen. 2011. “Are Intrazonal Trips Ignorable ?” 18: 13–22. https://doi.org/10.1016/j.tranpol.2010.04.004.

Blumenberg, Evelyn, and Hannah King. 2021. “Jobs–Housing Balance Re-Re-Visited.” *Journal of the American Planning Association* 87 (4): 484–96. https://doi.org/10.1080/01944363.2021.1880961.

Blumenberg, Evelyn, and Michael Manville. 2004. “Beyond the Spatial Mismatch : Welfare Recipients And.” *Journal OfPlanning Literature* 19 (2). https://doi.org/10.1177/0885412204269103.

Blumenberg, Evelyn, and Fariba Siddiq. 2023. “Commute Distance and Jobs-Housing Fit.” *Transportation* 50 (3): 869–91. https://doi.org/10.1007/s11116-022-10264-1.

Brenda Scheer, Reid Ewing, Keunhyun Park, and Shabnam Sifat Ara Khan. 2017. “How Does Transportation Affordability Vary between TODs, TADs, and Other Areas?”

Browne, Irene. 2000. “Opportunities Lost? Race, Industrial Restructuring, and Employment among Young Women Heading Households.” *Social Forces* 78 (3): 907–29. https://doi.org/10.1093/sf/78.3.907.

Bullard, Robert D. 2007. *Growing Smarter : Achieving Livable Communities, Environmental Justice, and Regional Equity*. Cambridge, Mass.: MIT Press.

Cadwallader, Martin T. 1975. “A Behavioral Model of Consumer Spatial Decision Making Author.” *Economic Geography* 51 (4): 339–49.

Calthorpe, Peter. 2011. *Urbanism in the Age of Climate Change*. Washington, DC: Island Press.

Calthorpe, Peter., and William B. Fulton. 2001. *The Regional City : Planning for the End of Sprawl*. Island Press.

Can, Ayse. 1992. “Specification and Estimation of Hedonic Housing Price Models.” *Regional Science and Urban Economics* 22 (3): 453–74. https://doi.org/10.1016/0166-0462(92)90039-4.

Canepa, Brian. 2007. “Bursting the Bubble: Determining the Transit-Oriented Development’s Walkable Limits.” *Transportation Research Record* 1992: 28–34. https://doi.org/10.3141/1992-04.

Cao, Xinyu, Patricia L. Mokhtarian, and Susan L Handy. 2009. “Examining the Impacts of Residential Self-Selection on Travel Behaviour: A Focus on Empirical Findings.” *Transport Reviews* 29 (3): 359–95. https://doi.org/10.1080/01441640802539195.

Carrillo, Laura, Mary Pattillo, Erin Hardy, and Dolores Acevedo-garcia. 2016. “Housing Decisions Among Low-Income Hispanic Households in Chicago.” *Cityscape: A Journal of Policy Development and Research* 18 (2): 109–50.

Center for Neighborhood Technology. 2015. “H + T Index Methods,” no. March.

Cervero, R., and K. Kockelman. 1997. “Travel Ridership and the 3Ds: Density, Diversity and Design.” *Transportation Research D* 2 (3): 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6.

Cervero, R., and K. L. Wu. 1997. “Polycentrism, Commuting, and Residential Location in the San Francisco Bay Area.” *Environment and Planning A* 29 (5): 865–86. https://doi.org/10.1068/a290865.

Cervero, Robert. 1989. “Jobs-Housing Balancing and Regional Mobility.” *Journal of the American Planning Association* 55 (2): 136–50. https://doi.org/10.1080/01944368908976014.

———. 1996. “Jobs-Housing Balance Revisited: Trends and Impacts in the San Francisco Bay Area.” *Journal of the American Planning Association* 62 (4): 492–511. https://doi.org/10.1080/01944369608975714.

———. 2001. “Efficient Urbanisation: Economic Performance and the Shape of the Metropolis.” *Urban Studies* 38 (10): 1651–71.

———. 2002. “Built Environments and Mode Choice: Toward a Normative Framework.” *Transportation Research Part D* 7: 265–84.

———. 2004. “Effects of Light and Commuter Rail Transit on Land Prices: Experiences in San Diego County.” *Journal of the Transportation Research Forum* 43 (1): 121–38. https://doi.org/http://dx.doi.org/10.5399/osu/jtrf.43.1.741.

Cervero, Robert, and G B Arrington. 2008. “Vehicle Trip Reduction Impacts of Transit-Oriented Housing.” *Journal of Public Transportation* 11 (3): 1–17. https://doi.org/10.5038/2375-0901.11.3.1.

Cervero, Robert B., Erick Guerra, and Stefan Al. 2017. *Beyond Mobility: Planning Cities for People and Places*. Washington, DC: Island Press.

Cervero, Robert, and Michael Duncan. 2006. “Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?” *Journal of the American Planning Association* 72 (4): 475–90.

———. 2008. “Jobs-Housing Balauce or Retail-Housing Mixing ?” *Journal of the American Planning Association* 74 (2): 475–90.

Chapple, Karen, and Anastasia Loukaitou-Sideris. 2019. *Transit-Oriented Displacement or Community Dividends? Understanding the Effects of Smarter Growth on Communities*. Cambridge, MA: The MIT Press.

Chetty, Raj, John N. Friedman, Nathaniel Hendren, Maggie R. Jones, and Sonya R. Porter. 2018. “The Opportunity Atlas: Mapping the Childhood Roots of Social Mobility.” *Working Papers* No. 25147 (October). https://doi.org/10.3386/w25147.

Christaller, Walter. 1941. *Ostgebieten Und Ihre Kultur- Und Marktbereiche [Central Places in the Eastern Territories and Their Cultural and Market Segments].* Leipzig, Germany: Verlag Koehler.

Christaller, Walter, Germany Christaller, Central Place, and Central Place. 1933. “Christaller ’ s Central Place Theory Assumptions :,” 1–9.

Clark, William A. V. (William A. V.), and Frans M. Dieleman. 1996. *Households and Housing: Choice and Outcomes in the Housing Market*. *Center for Urban Policy Research*. New Brunswick: Center for Urban Policy Research.

Cliff, Andrew David, and J K Ord. 1973. *Spatial Autocorrelation*. London: Pion.

Clifton, Kelly J, Kristina Marie Currans, and Christopher D Muhs. 2015. “Adjusting ITE ’ s Trip Generation Handbook for Urban Context.” *Journal of Transport and Land Use* 8 (1): 5–29.

Cutsinger, Jackie, and George Galster. 2006. “There Is No Sprawl Syndrome: A New Typology of Metropolitan Land Use Patterns.” *Urban Geography* 27 (3): 228–52. https://doi.org/10.2747/0272-3638.27.3.228.

Dawkins, Casey, and Rolf Moeckel. 2016. “Transit-Induced Gentrification : Who Will Stay, and Who Will Go?” *Housing Policy Debate* 26 (4–5): 801–18. https://doi.org/10.1080/10511482.2016.1138986.

Delmelle, Elizabeth C., Isabelle Nilsson, and Alexander Bryant. 2021. “Investigating Transit-Induced Displacement Using Eviction Data.” *Housing Policy Debate* 31 (2): 326–41. https://doi.org/10.1080/10511482.2020.1815071.

Delmelle, Elizabeth, and Isabelle Nilsson. 2020. “New Rail Transit Stations and the Out-Migration of Low-Income Residents.” *Urban Studies* 57 (1): 134–51. https://doi.org/10.1177/0042098019836631.

Dittmar, Hank, and Gloria Ohland. 2004. *The New Transit Town: Best Practices In Transit-Oriented Development*. Washington, DC: Island Press.

Downs, Anthony. 2004. *Still Stuck in Traffic*. Washington, D.C.: The Brookings Institution.

———. 2005. “Smart Growth: Why We Discuss It More than We Do It.” *Journal of the American Planning Association* 71 (4): 367–78. https://doi.org/10.1080/01944360508976707.

Duany, Andrés, Elizabeth Plater-Zyberk, and Jeff Speck. 2010. *Suburban Nation: The Rise of Sprawl and the Decline of the American Dream*. New York: North Point Press.

Dunham-Jones, Ellen, and June Williamson. 2011. *Retrofitting Suburbia: Urban Design Solutions for Redesigning Suburbs*. Hoboken, NJ: John Wiley & Sons.

Duque, J. C., R. Ramos, and J. Surinach. 2007. "Supervised Regionalization Methods: A Survey." *International Regional Science Review* 30 (3): 195–220. https://doi.org/10.1177/0160017607301605.

Duque, Juan C., Richard L. Church, and Richard S. Middleton. 2011. "The P-Regions Problem." *Geographical Analysis* 43 (1): 104–26. https://doi.org/10.1111/j.1538-4632.2010.00810.x.

Easterlin, R. 1995. "Will Raising the Income of All Increase the Happiness of All?" *Journal of Economic Behaviour and Organization* 27 (27): 35–47. https://doi.org/10.1016/0167-2681(95)00003-B.

Ewing, Reid. 1997. "Is Los Angeles-Style Sprawl Desirable?" *Journal of the American Planning Association* 63 (1): 107–26. https://doi.org/10.1080/01944369708975728.

Ewing, Reid, and Hamidi, Shima. 2014. "Measuring Urban Sprawl and Validating Sprawl Measures." Washington, D.C.

Ewing, Reid, and Robert Cervero. 2001. "Travel and the Built Environment: A Synthesis." *Transportation Research Record* 1780 (Paper No. 01-3515): 87–114. https://doi.org/10.3141/1780-10.

———. 2010. "Travel and the Built Environment: A Meta-Analysis." *Journal of the American Planning Association* 76 (3): 265–94. https://doi.org/10.1080/01944361003766766.

———. 2017. "' Does Compact Development Make People Drive Less ?' The Answer Is Yes." *Journal of the American Planning Association* 83 (1): 19–25. https://doi.org/10.1080/01944363.2016.1245112.

Ewing, Reid, Michael Greenwald, Ming Zhang, Jerry Walters, Mark Feldman, Robert Cervero, Lawrence Frank, and John Thomas. 2011. "Traffic Generated by Mixed-Use Developments—Six-Region Study Using Consistent Built Environmental Measures." *Journal of Urban Planning and Development* 137 (3): 248–61. https://doi.org/10.1061/(asce)up.1943-5444.0000068.

Ewing, Reid, Shima Hamidi, Guang Tian, David Proffitt, Stefania Tonin, and Laura Fregolent. 2018. "Testing Newman and Kenworthy ' s Theory of Density and Automobile Dependence." *Journal of Planning Education and Research* 38 (2): 167–82. https://doi.org/10.1177/0739456X16688767.

Florida, Richard. 2017a. *The New Urban Crisis: How Our Cities Are Increasing Inequality, Deepening Segregation, and Failing the Middle Class-and What We Can Do about It*. New York: Basic Books.

———. 2017b. *The New Urban Crisis: How Our Cities Are Increasing Inequality, Deepening Segregation, and Failing the Middle Class-and What We Can Do about It*. New York: Basic Books.

Freeman, Lance. 2019a. *A Haven and a Hell: The Ghetto in Black America*. New York: Columbia University Press.

———. 2019b. *A Haven and a Hell: The Ghetto in Black America*. New York: Columbia University Press.

Fujita, Masahisa, and Jacques-Francois Thisse. 2002. *Economics of Agglomeration : Cities, Industrial Location, and Regional Growth*. New York, UNITED STATES: Cambridge University Press.

Gabe, Jeremy, Spenser Robinson, and Andrew R. Sanderford. 2018. "How Urban Form Reveals the Heterogeneous Nature of Walkability." *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3264837.

Galster, George C, and Sean P Killen. 1995. "The Geography of Opportunity: A Reconnaissance and Conceptual Framework." *Housing Policy Debate* 6 (1): 7–43. https://doi.org/10.1080/10511482.1995.9521180.

Galster, George, and Jackie Cutsinger. 2007. *Racial Settlement and Metropolitan Land-Use Patterns: Does Sprawl Abet Black-White Segregation? Urban Geography*. Vol. 28. https://doi.org/10.2747/0272-3638.28.6.516.

Galster, George, Royce Hanson, Michael R. Ratcliffe, Harold Wolman, Stephen Coleman, and Jason Freihage. 2001. "Wrestling Sprawl to the Ground: Defining and Measuring an Elusive Concept." *Housing Policy Debate* 12 (4): 681–717. https://doi.org/10.1080/10511482.2001.9521426.

Garb, Jane L., Robert G. Cromley, and Richard B. Wait. 2007. "Estimating Populations at Risk for Disaster Preparedness and Response." *Journal of Homeland Security and Emergency Management* 4 (1). https://doi.org/10.2202/1547-7355.1280.

Getis, Arthur, and J K Ord. 1992. "The Analysis of Spatial Association." *Geographical Analysis* 24 (3): 189–206. https://doi.org/10.1111/j.1538-4632.1992.tb00261.x.

Geurs, Karst T, and Bert Van Wee. 2004. "Accessibility Evaluation of Land-Use and Transport Strategies : Review and Research Directions." *Journal of Transport Geography* 12: 127–40. https://doi.org/10.1016/j.jtrangeo.2003.10.005.

Giuliano, Genevieve. 1995. "The Weakening Transportation-Land Use Connection." *ACCESS*, 1995.

Giuliano, Genevieve, and Kenneth A. Small. 1993. "Is the Journey to Work Explained by Urban Structure?" *Urban Studies* 30 (9): 1485–1500. https://doi.org/10.1080/00420989320081461.

Glaeser, Edward L. 2011. *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier*. New York: Penguin Books.

Glaeser, Edward L. & Kahn, Matthew E. 2000. "Why Do the Poor Live in Cities?" 7636. *Ariel*. NBER Working Paper Series.

Glaeser, Edward L, and Matthew E Kahn. 2004. "Sprawl and Urban Growth." In *Handbook of Regional and Urban Economics*, edited by J. V Henderson and J.E Thisse, 4:2481–2527. Elsevier B.V. https://doi.org/10.1016/S0169-7218(04)07056-X.

Glaeser, Edward L., Matthew E. Kahn, and Jordan Rappaport. 2008. "Why Do the Poor Live in Cities? The Role of Public Transportation." *Journal of Urban Economics* 63 (1): 1–24. https://doi.org/10.1016/j.jue.2006.12.004.

Gordon, Peter, Ajay Kumar, and Harry W Richardson. 1989. “The Influence of Metropolitan Spatial Structure on Commuting Time *” 151: 138–51.

Gordon, Peter, and Harry W Richardson. 1997. “Cities a Desirable Planning Goal ?” *Journal of the American Planning Association* 63 (1): 95–106. https://doi.org/10.1080/01944369708975727.

Graaskamp, James A. 1981. “Fundamentals of Real Estate Development.” *ULI-The Urban Land Institute*. Washington, DC. https://doi.org/10.1108/14635789210031253.

Guerra, Erick, Robert Cervero, and Daniel Tischler. 2012. “Half-Mile Circle.” *Transportation Research Record*, no. 2276: 101–9. https://doi.org/10.3141/2276-12.

Gulden, Jeff, J. P. Goates, and Reid Ewing. 2013. “Mixed-Use Development Trip Generation Model.” *Transportation Research Record*, no. 2344: 98–106. https://doi.org/10.3141/2344-11.

Guo, Yuntao, Srinivas Peeta, and Sekhar Somenahalli. 2017. “The Impact of Walkable Environment on Single-Family Residential Property Values.” *Journal of Transport and Land Use* 10 (1): 241–61. https://doi.org/10.5198/jtlu.2017.824.

Haas, Peter M, Carrie Makarewicz, Albert Benedict, and Scott Bernstein. 2009. “Estimating Transportation Costs by Characteristics of Neighborhood and Household.” *Transportation Research Record: Journal of the Transportation Research Board* 2077 (1): 62–70. https://doi.org/10.3141/2077-09.

Hagerstrand, Torsten. 1970. “What about People in Regional Science?” *Papers of the Regional Science Association* 24: 7–21.

Hajrasouliha, Amir H., and Shima Hamidi. 2017. “The Typology of the American Metropolis: Monocentricity, Polycentricity, or Generalized Dispersion?” *Urban Geography* 3638 (April): 1–25. https://doi.org/10.1080/02723638.2016.1165386.

Hamidi, Shima, Ahmad Bonakdar, Golnaz Keshavarzi, and Reid Ewing. 2020. “Do Urban Design Qualities Add to Property Values ? An Empirical Analysis of the Relationship between Urban Design Qualities and Property Values.” *Cities* 98 (June 2018): 102564. https://doi.org/10.1016/j.cities.2019.102564.

Hamidi, Shima, Reid Ewing, and John Renne. 2016. “How Affordable Is HUD Affordable Housing?” *Housing Policy Debate* 26 (3): 437–55. https://doi.org/10.1080/10511482.2015.1123753.

Hamidi, Shima, Reid Ewing, and Sadegh Sabouri. 2020. “Longitudinal Analyses of the Relationship between Development Density and the COVID-19 Morbidity and Mortality Rates: Early Evidence from 1,165 Metropolitan Counties in the United States.” *Health and Place* 64 (April): 102378. https://doi.org/10.1016/j.healthplace.2020.102378.

Handy, Susan. 2005. “Smart Growth and the Transportation-Land Use Connection: What Does the Research Tell Us?” *International Regional Science Review* 28 (2): 146–67. https://doi.org/10.1177/0160017604273626.

Hansen, Walter G. 1959. “How Accessibility Shapes Land Use.” *Journal of the American Institute of Planners* 25 (2): 73–76. https://doi.org/10.1080/01944365908978307.

Hejazi, Seyed Jafar, Mahmoud Arvin, Ayyoob Sharifi, and Azadeh Lak. 2023. “Measuring the Effects of Compactness/Sprawl on COVID 19 Spread Patterns at the Neighborhood Level.” *Cities* 132 (November 2022): 104075. https://doi.org/10.1016/j.cities.2022.104075.

Hibberd, Robert. n.d. “Market Demand-Based Planning and Permitting : Special Case of Affordable Housing” 5 (1): 245–73.

Hibberd, Robert, and Arthur C Nelson. 2018. “Nationwide Worker Database to Analyze Transit Outcomes Using an Economic and Demographic Lens DATA PROJECT Nationwide Worker Database to Analyze Transit Outcomes Using an Economic and Demographic Lens Description of Database Content & Methodology Cont.”

Higgins, Christopher D., and Pavlos S. Kanaroglou. 2016. “Forty Years of Modelling Rapid Transit’s Land Value Uplift in North America: Moving beyond the Tip of the Iceberg.” *Transport Reviews* 36 (5): 610–34. https://doi.org/10.1080/01441647.2016.1174748.

Hill, Linda L. 2006. *Georeferencing : The Geographic Associations of Information*. Cambridge Mass. ;;London: MIT.

Horner, Mark W., Daniel K. Schleith, and Michael J. Widener. 2015. “An Analysis of the Commuting and Jobs–Housing Patterns of Older Adult Workers.” *The Professional Geographer* 0124 (July 2015): 1–11. https://doi.org/10.1080/00330124.2015.1054018.

Hoyt, M. 1939. *The Structure and Growth of Residential Neighborhoods in American Cities*. Washington, DC: Federal Housing Administration.

Hu, Lingqian. 2019. “Racial/Ethnic Differences in Job Accessibility Effects: Explaining Employment and Commutes in the Los Angeles Region.” *Transportation Research Part D: Transport and Environment* 76 (September): 56–71. https://doi.org/10.1016/j.trd.2019.09.007.

Ihlanfeldt, Keith R. 2020. “Vehicle Miles Traveled and the Built Environment: New Evidence from Panel Data.” *Journal of Transport and Land Use* 13 (1): 23–48. https://doi.org/10.5198/jtlu.2020.1647.

Ihlanfeldt, Keith R, and David L Sjoquist. 1998. “The Spatial Mismatch Hypothesis : A Review of Recent Studies and Their Implications for Welfare Reform.” *Housing Policy Debate* 9 (4): 849–92. https://doi.org/10.1080/10511482.1998.9521321.

Immergluck, Daniel. 1998. “Job Proximity and the Urban Employment Problem: Do Suitable Nearby Jobs Improve Neighbourhood Employment Rates?” *Urban Studies* 35 (1): 7–23.

Jackson, Monica C, Lan Huang, Qian Xie, and Ram C Tiwari. 2010. “A Modified Version of Moran’s I.” *International Journal of Health Geographics* 9: 33. https://doi.org/10.1186/1476-072X-9-33.

Jadhav, Anil, Dhanya Pramod, and Krishnan Ramanathan. 2019. “Comparison of Performance of Data Imputation Methods for Numeric Dataset.” *Applied Artificial Intelligence* 33 (10): 913–33. https://doi.org/10.1080/08839514.2019.1637138.

Jones, Bryan D. 2017a. “Behavioral Rationality as a Foundation for Public Policy Studies.” *Cognitive Systems Research* 43: 63–75. https://doi.org/10.1016/j.cogsys.2017.01.003.

———. 2017b. “Behavioral Rationality as a Foundation for Public Policy Studies.” *Cognitive Systems Research* 43: 63–75. https://doi.org/10.1016/j.cogsys.2017.01.003.

Kain, John F. 1968. “Housing Segregation, Negro Employment, and Metropolitan Decentralization.” *The Quarterly Journal of Economics* 82 (2): 175–97.

———. 1992. “The Spatial Mismatch Hypothesis : Three Decades Later.” *Housing Policy Debate* 3 (2): 371–460. https://doi.org/10.1080/10511482.1992.9521100.

Kain, John F., Gary R. Fauth, and Jeffrey Zax. 1977. “Forecasting Auto Owner- Ship and Mode Choice for U.S. Metropolitan Areas.”

Kamruzzaman, Md, Farjana Mostafiz Shatu, Julian Hine, and Gavin Turrell. 2015. “Commuting Mode Choice in Transit Oriented Development: Disentangling the Effects of Competitive Neighbourhoods, Travel Attitudes, and Self-Selection.” *Transport Policy* 42: 187–96. https://doi.org/10.1016/j.tranpol.2015.06.003.

Kasarda, John. 1988. “Jobs, Migrations and Emerging Urban Mismatches.” In *Urban Change and Poverty*, edited by Michael McGreary and Lawrence Lynn, 148–98. Washington, DC: National Academy Press.

Katchova, Ani. 2013. “Probit and Logit Models.” Econometrics Academy. 2013. https://sites.google.com/site/econometricsacademy/econometrics-models/probit-and-logit-models.

Kelejian, Harry H., and Ingmar R. Prucha. 2007. “HAC Estimation in a Spatial Framework.” *Journal of Econometrics* 140 (1): 131–54. https://doi.org/10.1016/j.jeconom.2006.09.005.

Kim, Keuntae, Keunhyun Park, and Arthur C Nelson. 2021. “Impacts of Light Rail Transit on Labor Participation and Housing Affordability in the U . S .: Longitudinal Analysis Using Propensity Score Matching.” *Transportation Research Record* 00 (0): 1–13. https://doi.org/10.1177/03611981211029650.

Kloosterman, Robert, and Sako Musterd. 2001. “The Polycentric Urban Region: Towards a Research Agenda.” *Urban Studies* 38 (4): 623–33. https://doi.org/10.1080/00420980120035259.

Kneebone, Elizabeth. 2017. “The Changing Geography of US Poverty.” Brookings. 2017. https://www.brookings.edu/articles/the-changing-geography-of-us-poverty/.

Lancaster, Kelvin. 1966. “A New Approach to Consumer Theory.” *The Journal of Political Economy* 74 (2): 132–57.

Lang, Robert E., and Jennifer LeFurgy. 2003. “Edgeless Cities: Examining the Noncentered Metropolis.” *Housing Policy Debate* 14 (3): 427–60. https://doi.org/10.1080/10511482.2003.9521482.

Lees, Loretta, Tom Slater, and Elvin Wyly. 2008. *Gentrification*. New York: Routledge/Taylor & Francis Group.

Levine, Jonathan. 1998. “Rethinking Accessibility and Jobs-Housing Balance.” *Journal of the American Planning Association* 64 (2): 133–49. https://doi.org/10.1080/01944369808975972.

Liu, Liwen, Ming Zhang, and Tao Xu. 2020. “A Conceptual Framework and Implementation Tool for Land Use Planning for Corridor Transit Oriented Development.” *Cities* 107 (September): 102939. https://doi.org/10.1016/j.cities.2020.102939.

“Location Affordability Index (LAI).” 2018. Washington, D.C.

Logan, John R., Zengwang Xu, and Brian J. Stults. 2014. “Interpolating U.S. Decennial Census Tract Data from as Early as 1970 to 2010: A Longitudinal Tract Database.” *Professional Geographer* 66 (3): 412–20. https://doi.org/10.1080/00330124.2014.905156.

Lopez, Natalie, and Chris Lukinbeal. 2010. “Comparing Police and Residents ’ Perceptions of Crime in a Phoenix Neighborhood Using Mental Maps in GIS Comparing Police and Residents ’ Perceptions of Crime in a Phoenix Neighborhood Using Mental Maps in GIS.” In *Yearbook of the Association of Pacific Coast Geographers*, 33–55. https://doi.org/10.1353/pcg.2010.0013.

Lösch, August. 1954. *The Economics of Loction*. New Haven: Yale University Press.

Lynch, Kevin. 1960. “Ch. 1-3, App A+B.” *Image of the City*. https://doi.org/10.2307/427643.

Mahmood, Md Sohel. 2024. *Statistics in R Series: Logistic Regression*. Md Sohel Mahmood.

Mallach, Alan. 2018a. *The Divided City: Poverty and Prosperity in Urban America*. Washington, DC: Island Press.

———. 2018b. *The Divided City: Poverty and Prosperity in Urban America*. Washington, DC: Island Press.

Margolis, Julius. 1957. “Municipal Fiscal Structure in a Metropolitan Region.” *Journal of Political Economy* 65 (3): 225–36.

Massey, Douglas S, and Nancy A Denton. 1988. “The Dimensions of Residential Segregation on JSTOR.” *Social Forces* 67 (2): 281–315. https://doi.org/10.1093/sf/67.2.281.

Massey, Douglas S., and Nancy A Denton. 1993. *American Apartheid: Segregation and the Making of the Underclass*. Cambridge, MA: Harvard University Press.

Meijers, Evert. 2005. “Polycentric Urban Regions and the Quest for Synergy: Is a Network of Cities More than the Sum of the Parts?” *Urban Studies* 42 (4): 765–81. https://doi.org/10.1080/00420980500060384.

———. 2008. “Measuring Polycentricity and Its Promises.” *European Planning Studies* 16 (9): 1313–23. https://doi.org/10.1080/09654310802401805.

Meijers, Evert J. 2007. “From Central Place To Network Model: Theory and Evidence of a Paradigm Change.” *Tijdschrift Voor Economische En Sociale Geografie* 98 (2): 245–59.

Meijers, Evert J., and Martijn J. Burger. 2010. “Spatial Structure and Productivity in US Metropolitan Areas.” *Environment and Planning A* 42 (6): 1383–1402. https://doi.org/10.1068/a42151.

Mills, Edwin S. 1972. “Markets and Efficient Resource Allocation in Urban Areas.” *The Swedish Journal of Economics* 74 (1): 100–113.

Mondschein, Andrew, and Brian D. Taylor. 2017. “Is Traffic Congestion Overrated? Examining the Highly Variable Effects of Congestion on Travel and Accessibility.” *Journal of Transport Geography* 64 (October 2016): 65–76. https://doi.org/10.1016/j.jtrangeo.2017.08.007.

Moore, Terry, Paul Thorsnes, and Bruce Appleyard. 2007. “The Transportation/ Land Use Connection.” Chicago.

Mouratidis, Kostas. 2022. “COVID-19 and the Compact City: Implications for Well-Being and Sustainable Urban Planning.” *Science of the Total Environment* 811: 152332. https://doi.org/10.1016/j.scitotenv.2021.152332.

Mu, Wangshu, and Daoqin Tong. 2020. “Distance in Spatial Analysis: Measurement, Bias, and Alternatives.” *Geographical Analysis*, 1–26. https://doi.org/10.1111/gean.12254.

Mulligan, Gordon F., Mark D. Partridge, and John I. Carruthers. 2012. “Central Place Theory and Its Reemergence in Regional Science.” *The Annals of Regional Science* 48 (2): 405–31. https://doi.org/10.1007/s00168-011-0496-7.

Muth, Richard F. 1969. *Cities and Housing: The Spatial Pattern of Urban Residential Land Use*. Chicago: University of Chicago Press.

National Academies of Sciences, Engineering, and Medicine. 2024. *Critical Issues in Transportation for 2024 and Beyond*. Washington, D.C.: The National Academies Press. https://doi.org/10.17226/27432.

Nelson, A.C., D. Eskic, S. Hamidi, S.J. Petheram, R. Ewing, and J.H. Liu. 2015. *Office Rent Premiums with Respect to Light Rail Transit Stations: Case Study of Dallas, Texas, with Implications for Planning of Transit-Oriented Development*. *Transportation Research Record*. https://doi.org/10.3141/2500-13.

Nelson, Arthur C. 2013. “FOUNDATIONS OF REAL ESTATE FINANCE FOR PUBLIC-PRIVATE PARTNERSHIPS PLG/RED 402A/502A.” *Journal of Economic Behavior & Organization* 89: 143–44.

Nelson, Arthur C. 2013. *Reshaping Metropolitan America: Development Trends and Opportunities to 2030*. Washington, DC: Island Press.

———. 2014. *Foundations of Real Estate Finance for Development: A Guide to Public-Private Partnerships*. Washington, DC: Island Press.

Nelson, Arthur C. 2017a. “Transit and Real Estate Rents.” Portland, OR.

———. 2017b. “Transit-Oriented Developments Make a Difference in Job Location.” *Fordham Urban Law Journal* 44 (4).

———. 2020. “The Great Senior Short-Sale or Why Policy Inertia Will Short Change Millions of America ’ s Seniors.” *Journal of Comparative Urban Law and Policy* 4 (1): 470–525.

Nelson, Arthur C, Dejan Eskic, Shima Hamidi, Susan J Petheram, Reid Ewing, and Jenny H Liu. 2015. “Office Rent Premiums with Respect to Light Rail Transit Stations.” *Transportation Research Record: Journal of the Transportation Research Board* 2500 (January): 110–15. https://doi.org/10.3141/2500-13.

Nelson, Arthur C, and Joanna Ganning. 2015. “National Study of BRT Development Outcomes.” Portland, OR.

Nelson, Arthur C., and Robert Hibberd. 2019a. “Express Busways and Economic Development: Case Study of the Miami-Dade South Express Busway.” *Research in Transportation Economics*, no. January: 100731. https://doi.org/10.1016/j.retrec.2019.05.004.

———. 2019b. “The Link between Transit Station Proximity and Real Estate Rents , Jobs , People and Housing with Transit and Land Use Planning Implications The Link between Transit Station Proximity and Real Estate Rents , Jobs , People and Housing with Transit and Land.” Portland, OR.

Nelson, Arthur C, and Robert Hibberd. 2021a. “Effect of Transit Station Proximity on Change in Jobs by Sector and Wages Between the Great Recession and Covid-19 with Implications for Transit and Land Use Planning After the Pandemic.” In *100th Annual Meeting of the Transportation Research Board*. Washington, D.C.: TRB Annual Meeting.

———. 2021b. “Influence of Rail Transit on Development Patterns in the Mountain Mega-Region with a Surprise and Implications for Rail Transit and Land-Use Planning.” *Transportation Research Record* 00 (0): 1–17. https://doi.org/10.1177/0361198120980439.

———. 2022a. “TRB Annual Meeting Influence of Transit Station Proximity on Demographic Change Including Displacement and Gentrification with Implications for Transit and Land Use Planning.” In *Transportation Research Board*.

———. 2022b. “TRB Annual Meeting Using Real Estate Markets to Evaluate Transit Station Area Outcomes.” In *Transportation Research Board*.

Nelson, Arthur C., Robert Hibberd, and Kristina M. Currans. 2020. “Transit Impacts on Jobs , People and Real Estate National Institute for Transportation and Communities.” Portland.

Nelson, Arthur C., and Robert E. Lang. 2011. *Megapolitan America: A New Vision for Understanding America’s Metropolitan Geography*. Chicago: APA Planners Press.

Nelson, Arthur C, John Travis Marshall, Julian Conrad Juergensmeyer, and James C Nicholas. 2017. *Market Demand-Based Planning and Permitting*. Chicago: American Bar Association Press.

Nelson, Arthur C., Michael D. Meyer, and Catherine B. Ross. 1997. “Parking Supply Policy and Transit Use: Case Study of Atlanta, Georgia.” *Transportation Research Record* 2 (1604): 60–66. https://doi.org/10.3141/1604-08.

Nelson, Arthur C., Philip Stoker, and Robert Hibberd. 2019. “Light Rail Transit and Economic Recovery: A Case of Resilience or Transformation?” *Research in Transportation Economics* 74 (November 2018): 2–9. https://doi.org/10.1016/j.retrec.2018.11.003.

Nelson, Arthur, Robert Hibberd, Kristina Currans, and Nicole Iroz-elardo. 2021a. “Transit Impacts on Jobs , People and Real Estate TRANSIT IMPACTS ON JOBS , PEOPLE AND REAL ESTATE Final Report.” Portland, OR.

———. 2021b. “Transit Impacts on Jobs , People and Real Estate TRANSIT IMPACTS ON JOBS , PEOPLE AND REAL ESTATE Final Report.” Portland, OR.

Nelson, Arthur, Matt Miller, Dejan Eskic, Keuntae Kim, Reid Ewing, Jenny Liu, Matt Berggren, and Zakari Mumuni. 2015. “Do TODs Make a Difference?”

Osborne, Jason W. 2015. “Best Practices in Logistic Regression.” 55 City Road: SAGE Publications, Ltd. https://doi.org/10.4135/9781483399041 NV - 0.

Ostrom, Elinor. 1998. “A Behavioral Approach to the Rational Choice Theory of Collective Action : Presidential Address , American Political Science Association , 1997 Author (s): Elinor Ostrom Source : The American Political Science Review , Vol . 92 , No . 1 (Mar ., 1998),.” *American Political Science Review* 92 (1): 1–22.

Pan, Wei, and Haiyan Bai. 2015. “Propensity Score Analysis: Concepts and Issues.” In *Propensity Score Analysis : Fundamentals and Developments*, edited by Wei Pan and Haiyan Bai, 3–19. New York: Guilford Publications.

Park, Keunhyun, Reid Ewing, Sadegh Sabouri, Dong-ah Choi, Shima Hamidi, and Guang Tian. 2020. “Guidelines for a Polycentric Region to Reduce Vehicle Use and Increase Walking and Transit Use.” *Journal of the American Planning Association* 0 (0): 1–14. https://doi.org/10.1080/01944363.2019.1692690.

Park, Robert E., E. W. Burgess, Roderick Duncan McKenzie, and Louis Wirth. 1925. *The City*. Chicago, Ill.: University of Chicago Press.

Parolek, Daniel. 2020a. *Missing Middle Housing. Thinking Big and Building Small to Respond to Today’s Housing Crisis.* Washington: Island Press.

———. 2020b. *Missing Middle Housing. Thinking Big and Building Small to Respond to Today’s Housing Crisis.* Washington: Island Press.

Pivo, Gary. 2013. “The Definition of Affordable Housing : Concerns and Related Evidence.” Washington, D.C.

Plane, David A. 1993. “Demographic Influences on Migration.” *Regional Studies* 27 (4): 375–83. https://doi.org/10.1080/00343409312331347635.

Plane, David A., and Peter A. Rogerson. 1994. *The Geographical Analysis of Population with Applications to Planning and Business*. New York: John Wiley & Sons.

Proffitt, David G., Keith Bartholomew, Reid Ewing, and Harvey J. Miller. 2019. “Accessibility Planning in American Metropolitan Areas: Are We There Yet?” *Urban Studies* 56 (1): 167–92. https://doi.org/10.1177/0042098017710122.

Putnam, R D. 2000. *Bowling Alone: The Collapse and Revival of American Democracy*. New York: Simon & Schuster.

Randolph, Justus J, Kristina Falbe, Austin Kureethara Manuel, and Joseph L Balloun. 2014. “A Step-by-Step Guide to Propensity Score Matching in R Information on the Dataset Used.” *Practical Assessment, Research & Evaluation* 19 (18): 1–6.

Read, Dustin C., Andrew R. Sanderford, and Thomas Skuzinski. 2019. “The Bounded and Pragmatic Consultant: Fiscal Impact Analysts as Rational Actors.” *Planning Practice and Research* 34 (4): 475–88. https://doi.org/10.1080/02697459.2019.1624427.

Read, Dustin, and Andrew Sanderford. 2017. “Examining Five Common Criticisms of Mixed-Income Housing Development Found in the Existing Real Estate, Public Policy and Urban Planning Literatures.” *Journal of Real Estate Literature* 25 (1): 31–48.

Renne, John L. 2017. “Make Rail (and Transit-Oriented Development) Great Again.” *Housing Policy Debate* 27 (3): 472–75. https://doi.org/10.1080/10511482.2017.1298213.

Renne, John L, D Ph, Shima Hamidi, D Ph, Reid Ewing, and D Ph. 2017. “Research in Transportation Economics Transit Commuting , the Network Accessibility Effect , and the Built Environment in Station Areas across the United States.” *Research in Transportation Economics* 60 (2016): 35–43. https://doi.org/10.1016/j.retrec.2017.02.003.

Renne, John L, Tara Tolford, Shima Hamidi, and Reid Ewing. 2016a. “The Cost and Affordability Paradox of Transit- Oriented Development : A Comparison of Housing and Transportation Costs Across Transit-Oriented Development , Hybrid and Transit-Adjacent Development Station Typologies.” *Housing Policy Debate* 26 (4–5): 819–34. https://doi.org/10.1080/10511482.2016.1193038.

———. 2016b. “The Cost and Affordability Paradox of Transit- Oriented Development : A Comparison of Housing and Transportation Costs Across Transit-Oriented Development , Hybrid and Transit-Adjacent Development Station Typologies.” *Housing Policy Debate* 26 (4–5): 819–34. https://doi.org/10.1080/10511482.2016.1193038.

Ribant, Michael, Xuwei Chen, Michael Ribant, and Xuwei Chen. 2020. “A Typology of U . S . Shrinking Cities.” *The Professional Geographer* 72 (1): 152–64. https://doi.org/10.1080/00330124.2019.1633366.

Rodriguez, Michael A, and Christopher B Leinberger. 2023. “Foot Traffic Ahead: Ranking America’s Largest Metros, 2023.” Washington, D.C.

Rose, Jonathan, U.S. EPA. 2011. “Location Efficiency and Housing Type,” no. March.

Rosen, Sherwin. 1974. “Hedonic Prices and Implicit Markets : Product Differentiation in Pure Competition.” *Journal of Political Economy* 82 (1): 34–55.

Rosenbaum, B Y Paul R, and Donald B Rubin. 1983. “The Central Role of the Propensity Score in Observational Studies for Causal Effects.” *Biometrika* 70 (1): 41–55.

Rothstein, Richard. 2017. *The Color of Law: A Forgotten History of How Our Government Segregated America*. New York: Liveright Publishing.

Sabouri, Sadegh, Amanda Dillon, David Proffitt, Megan Townsend, and Reid Ewing. 2019. "State-of-the-Practice in Connecting and Coordinating Transportation and Land Use Planning in the U.S.A." *Transportation Research Record* 2673 (9): 240–53. https://doi.org/10.1177/0361198119844762.

Sanchez, Thomas W, Qing Shen, and Zhong-ren Peng. 2004. "Transit Mobility , Jobs Access and Low-Income Labour Participation in US Metropolitan Areas" 41 (7): 1313–31. https://doi.org/10.1080/0042098042000214815.

Sardari, Reza, Shima Hamidi, and Raha Pouladi. 2018. "Effects of Traffic Congestion on Vehicle Miles Traveled." *Transportation Research Record*. https://doi.org/10.1177/0361198118791865.

Schleith, Daniel, Michael Widener, and Changjoo Kim. 2016. "An Examination of the Jobs-Housing Balance of Different Categories of Workers across 26 Metropolitan Regions." *Journal of Transport Geography* 57: 145–60. https://doi.org/10.1016/j.jtrangeo.2016.10.008.

Schwanen, Tim, Frans M. Dieleman, and Martin Dijst. 2003. "Car Use in Netherlands Daily Urban Systems: Does Polycentrism Result in Lower Commute Times?1." *Urban Geography* 24 (5): 410–30. https://doi.org/10.2747/0272-3638.24.5.410.

Selten, Reinhard. 1990. "Bounded Rationality." *Journal of Institutional and Theoretical Economics (JITE)* 146 (4): 649–58.

Sheller, Mimi, and John Urry. 2006. "The New Mobilities Paradigm." *Environment and Planning A* 38 (2): 207–26. https://doi.org/10.1068/a37268.

Shen, Qingyun, Jonathan Levine, Joe Grengs, and Qng Shen. 2012. "Does Accessibility Require Density or Speed?" *Journal of the American Planning Association* 78 (2): 157–72. https://doi.org/10.1080/01944363.2012.677119.

Silverman, Robert Mark. 2018. "Rethinking Shrinking Cities : Peripheral Dual Cities Have Arrived." *Journal of Urban Affairs* 00 (00): 1–18. https://doi.org/10.1080/07352166.2018.1448226.

Simon, H. A. 1956. "Rational Choice and the Structure of the Environment." *Psychological Review* 63 (2): 129–38. https://doi.org/10.1037/h0042769.

Simon, Herbert A. 1957. *Models of Man; Social and Rational. Models of Man; Social and Rational.* Oxford, England: Wiley.

Smith, Jeffery J., Thomas A. Gihring, and An Annotated Bibliography. 2017. "Financing Transit Systems through Value Capture: An Annotated Bibliography." *American Journal of Economics and Sociology*. Vol. 65. https://doi.org/10.1111/j.1536-7150.2006.00474.x.

Stoker, Philip. 2016. "Light Rail Transit and Economic Recovery: A Case of Resilience or Transformation?," no. November: 1–28.

Stoker, Philip, and Reid Ewing. 2014a. "Job – Worker Balance and Income Match in the United States." *Housing Policy Debate* 24 (2). https://doi.org/10.1080/10511482.2013.852604.

———. 2014b. "Job – Worker Balance and Income Match in the United States." *Housing Policy Debate* 24 (2). https://doi.org/10.1080/10511482.2013.852604.

Sultana, Selima. 2002. "Job/Housing Imbalance and Commuting Time in the Atlanta Metropolitan Area: Exploration of Causes of Longer Commuting Time." *Urban Geography* 23 (8): 728–49. https://doi.org/10.2747/0272-3638.23.8.728.

Sultana, Selima, and Joe Weber. 2007. "Journey-to-Work Patterns in the Age of Sprawl: Evidence from Two Midsize Southern Metropolitan Areas." *Professional Geographer* 59 (2): 193–208. https://doi.org/10.1111/j.1467-9272.2007.00607.x.

Thaler, Richard H. 2016. "Behavioral Economics: Past, Present, and Future." *Revista de Economia Institucional* 20 (38): 9–43. https://doi.org/10.18601/01245996.v20n38.02.

Thomas, Ren, and Luca Bertolini. 2020. *Transit-Oriented Development: Learning from International Case Studies*. Cham, Switzerland: Palgrave MacMillan. https://doi.org/10.1007/978-3-030-48470-5.

Thompson, Michael and Smart, Michael. 2017. "Bus Rapid Transit Proximity and Property Values in Cleveland, Ohio." In *Transportation Research Board 96th Annual Meeting*, 1–17.

Thünen, JH von, and C.M. Wartenberg. 1966. *Isolated State (An English Edition of Der Isolierte Staat ... Translated by C.M. Wartenberg.* Edited by P.G. Hall. Oxford: Pergamon Press.

Tobler, W R. 1970. "A Computer Movie Simulating Urban Growth in the Detroit Region." *Economic Geography* 46 (sup1): 234–40. https://doi.org/https://doi.org/10.2307/143141.

United States Environmental Protection Agency. 2023. "Smart Location Mapping." United States Environmental Protection Agency. 2023. https://www.epa.gov/smartgrowth/smart-location-mapping.

Wang, Jin Feng, A. Stein, Bin Bo Gao, and Yong Ge. 2012. "A Review of Spatial Sampling." *Spatial Statistics* 2 (1): 1–14. https://doi.org/10.1016/j.spasta.2012.08.001.

Warner, Sam Bass. 1978. *Streetcar Suburbs: The Process of Growth in Boston, 1870-1900.* Cambridge, MA: Harvard University Press.

Weitz, Jerry. 2003. "Jobs-Housing Balance." Chicago, Ill.

White, Howard, and Shagun Sabarwal. 2014. "Quasi-Experimental Design and Methods." Florence, Italy.

Wolch, Jennifer R., Jason Byrne, and Joshua P. Newell. 2014. "Urban Green Space, Public Health, and Environmental Justice: The Challenge of Making Cities 'Just Green Enough.'" *Landscape and Urban Planning* 125: 234–44. https://doi.org/10.1016/j.landurbplan.2014.01.017.

Wong, Grace K.M. 2002. "A Conceptual Model of the Household's Housing Decision-Making Process: The Economic Perspective." *Review of Urban and Regional Development Studies* 14 (3): 217–34. https://doi.org/10.1111/1467-940x.00055.

Yang, Liu, Michiyo Iwami, Yishan Chen, Mingbo Wu, and Koen H. van Dam. 2022. "Computational Decision-Support Tools for Urban Design to Improve Resilience against COVID-19 and Other Infectious Diseases: A Systematic Review." *Progress in Planning* 168 (March 2022): 100657. https://doi.org/10.1016/j.progress.2022.100657.

Yao, Jing, A Stewart Fotheringham, and A Stewart Fotheringham. 2017. "Local Spatiotemporal Modeling of House Prices : A Mixed Model Approach." *The Professional Geographer* 0124 (June). https://doi.org/10.1080/00330124.2015.1033671.

Zhang, Ming, and Lanlan Wang. 2013. "The Impacts of Mass Transit on Land Development in China : The Case of Beijing." *Research in Transportation Economics* 40 (1): 124–33. https://doi.org/10.1016/j.retrec.2012.06.039.

Zhang, Zhongheng, Hwa Jung Kim, Guillaume Lonjon, and Yibing Zhu. 2019. "Balance Diagnostics after Propensity Score Matching." *Annals of Translational Medicine* 7 (1): 16–16. https://doi.org/10.21037/atm.2018.12.10.

Zuk, Miriam, Ariel H. Bierbaum, Karen Chapple, Karolina Gorska, and Anastasia Loukaitou-Sideris. 2018. "Gentrification, Displacement, and the Role of Public Investment." *Journal of Planning Literature* 33 (1): 31–44. https://doi.org/10.1177/0885412217716439.

Zuk, Miriam, and Ian Carlton. 2015. "Equitable Transit Oriented Development: Examining the Progress and Continued Challenges of Developing Affordable Housing in Opportunity and Transit-Rich Neighborhoods." Washington, D.C.

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Other Citations to include

Leonard, Jonathan S. 1985. Space, Time, and Unemployment: Los Angeles 1980. Unpublished manuscript, University of California, Berkeley.

Ellwood, David T. 1986. The Spatial Mismatch Hypothesis: Are There Teen-Age Jobs Missing in the Ghetto? In The Black Youth Employment Crisis, edited by Richard B. Freeman and Harry J. Holzer. Chicago: University of Chicago Press.

Harrison, Bennet. 1972a. The Intrametropolitan Distribution of Minority Eco- nomic Welfare. Journal of Regional Science 12:23–43.

______. 1972b. Education, Training, and the Urban Ghetto. Baltimore and London: The Johns Hopkins University Press.

Jencks, Christopher, and Susan E. Mayer. 1990. Residential Segregation, Job Proximity, and Black Job Opportunities. In Inner-City Poverty in the United States, edited by Lawrence E. Lynn, Jr., and Michael G.H. McGeary. Washington, DC: National Academy Press.

Margolis, J. 1973. Municipal Fiscal Structure in a Metropolitan Region. Urban Economics: Readings and Analysis, edited by R.E. Grieson. Boston: Little Brown.

Masters, Stanley H. 1974. A Note on John Kain's 'Housing Segregation, Negro Employment, and Metropolitan Decentralization.' Quarterly Journal of Economics 88:505–19.

______ . 1975. Black-White Income Differentials: Empirical Studies and Policy Implications. New York: Academic Press.
