Redefining the Value of Accessibility: Toward a Better Understanding of How Accessibility Shapes Household Residential Location and Travel Choices

by

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ABSTRACT

Accessible locations in a metropolitan region afford individuals who occupy them greater convenience to interact with activities distributed across the region. This convenience may translate into a range of economic benefits: reduced time-plus-money spending on travel to reach desirable destinations (termed here travel-cost savings), welfare gains resulting from enhanced social and economic interactions, consumer satisfaction due to a greater choice of activities to engage with, and so on. Yet many urban researchers have either implicitly or explicitly equated the benefits afforded by accessible locations to travel-cost savings (TCS), excluding other forms of benefits from their purview. An exclusive focus on TCS underestimates the value of accessibility and in many policy contexts constitutes a conceptual barrier that impedes the promotion of accessibility-based planning practice and policymaking. For instance, observations of excess commuting are frequently used as evidence refuting the merits of job-housing balance strategies.

This three-paper dissertation challenges this TCS-based view of accessibility benefits. In the first paper, I trace the origin of TCS-based view of accessibility to classic urban economic theories and review its application in residential location studies. In order to test the hypothesis that individuals value accessibility beyond the benefit of travel-cost savings, I develop residential location choice models for two U.S. regions (Puget Sound and Southeast Michigan) to examine if transit accessibility remains a significant predictor of residential location choice after controlling for all possible travel-cost savings associated with it. The results do not support a TCS-based view

of accessibility benefits. Considering that only a small fraction of Americans regularly use transit, I conclude that it is probably the option value of transit access that attracts people to transit-accessible neighborhoods.

Building on the idea that individuals value accessibility beyond the benefit of TCS, the second paper critiques the common practice of using VMT reduction as the main empirical measure to represent the transportation benefits of accessibility-enhancing compact-development strategies. I argue that VMT-reduction measures blur the impact that compact development has on the utility that people receive from their environment because compactness can shape personal VMT in opposite directions: a desire for TCS would make people reduce their VMT consumption, but people can end up traveling more if they make more trips and/or travel to more remote destinations in order to gain greater destination utility. I test these ideas by fitting trip-frequency models in the Puget Sound region and in the Southeast Michigan region. Empirical analysis supports my hypothesis by suggesting that compact development has countervailing effects on driving. I thus conclude that VMT-reduction measures underrepresent the transportation benefits of compact development.

To facilitate accessibility-based planning policy implementation, the third paper empirically evaluates the relative importance of walkability, transit accessibility, and auto accessibility in residential location choice across three U.S. regions (Puget Sound, Southeast Michigan, and Atlanta). I find that, in general, transit accessibility is a more important determinant of resident location choice than walkability and auto accessibility. The results further suggest that the preferred behavior of households can be different from their actual choice because of housing supply constraints. This implies that if the conditions of housing supply change, estimates of accessibility preferences may change accordingly. This finding challenges the standard practice of land-use and transportation modeling which forecasts future land-use patterns based on presumed stability of historical or present estimates of accessibility preferences.

CHAPTER I

Introduction

Caught in a built environment where housing is distant from jobs and other essential services, many people living in U.S. cities often find it challenging to conveniently get to the destinations they value. If lacking access to a car, individuals can only reach a very constrained set of destinations using alternative travel modes, which means that they would have a limited choice of employment opportunities, shopping places, and healthcare services. As a result, travelers living in U.S. cities are in general more car-dependent and consume more gasoline than their counterparts living in European and Australian cities (Newman and Kenworthy, 1989; Giuliano and Dargay, 2006). This is largely because the land-use and transportation planning policy and practice in the U.S. have traditionally focused on promoting mobility rather than accessibility. Mobility refers to the ease of travel whereas accessibility refers to the ease to reach destinations or the potential to interact with opportunities/activities distributed across space (Hansen, 1959). A focus on mobility fails to adequately consider the opportunities/activities that motivate individuals to travel in the first place, and as a result, mobility-based planning often makes people travel faster but makes them more disconnected from essential destinations such as jobs and shopping destinations (Levine et al., 2012).

In recent years, there has been a growing recognition within the academic community that planning policies and practices should be oriented toward accessibility instead of mobility (Cervero, 1997; Martens, 2016; Levine et al., 2019). On the policy and practice side, however, much less progress has been made to implement accessibility-based planning ideas (Handy, 2005; Boisjoly and El-Geneidy, 2017; Proffitt et al., 2019). Commonly recognized factors that inhibit implementation includes confusion on definitions and measurements, constraints due to governance structure, and institutional barriers due to legacy and professional norms. Levine et al. (2019) further discussed some conceptual impediments that have held back policymakers and practitioners from sharing the accessibility perspective and adopting accessibility-informed policy and practice. In brief, they refuted misconceptions on what accessibility is, ought to be, and what would count as evidence to evaluate accessibility.

Building on previous accessibility research and in particular the Levine et al. work, this dissertation aims to further clear the way for accessibility-based planning practice and policymaking. A main focus of the dissertation addresses a misconception that equates the benefits of accessibility to travel-cost savings (TCS), which is termed here a TCS-based view of accessibility benefits. A TCS-based view of accessibility benefits is present in a variety of policy contexts, as reflected by the use of empirical measures that represent the benefits resulting from accessibility-promoting land-use and transportation policies. For example, in the residential location choice context, scholars often view commuting-cost savings as the main benefit that households can gain from living at locations near job centers. When evaluating the desirability of transportation investments, analysts usually measure travel-time savings to represent the benefits associated with these projects. In built-environment and travel-behavior studies, researchers consider the amount of reduction in vehicle miles traveled (VMT) as the main criterion to determine the travel benefits of compact-development policies. Savings in commuting costs, savings in travel time, and reduction in VMT are all essentially measures of travel-cost savings.

A TCS-based view of accessibility benefits ignores the fact that accessibility gains often translate into non-TCS benefits. Locations of higher accessibility afford individuals who occupy them a greater convenience/potential to interact with activities (e.g., people and services) distributed across space. This convenience may translate into a range of economic benefits: reduced time-plus-money spending on travel to reach desirable destinations (termed here travel-cost savings), welfare gains resulting from more social and economic interactions (e.g., greater participation in out-of-home activities), welfare gains associated with the flexibility to change trip destinations (e.g., travelling to more remote but more desirable destinations), and consumer satisfaction due to a greater choice of activities to engage with. These non-TCS aspects of accessibility benefits are jointly termed here destination-utility gains for convenience, since they all arise from interacting with or the ability to choose from spatially-distributed destinations (more accurately, the people and activities located at these destinations).

Some recent urban trends have provided empirical support for the importance of destination-utility gains. First, there is a rise of reverse-commuting (individuals work at suburban locations but live in central cities) in recent decades (Glaeser et al., 2001), which means that many people bear longer commutes to enjoy the enhanced social and economic interactions available in central cities (Jacobs, 1970). Besides, the gap between home values (on a per-square-foot-basis) in urban and suburban areas of the U.S. has widened dramatically over the past two decades (Fuller, 2016). Related, property prices in areas surrounding transit-oriented development have increased significantly in many cities, often causing low-income households to be displaced (Dawkins and Moeckel, 2016; Chapple and Loukaitou-Sideris, 2019). All of these empirical observations indicate a growing consumer demand for places of higher accessibility, but they cannot be reasonably accounted for by a TCS-based view of accessibility benefits.

There are at least two reasons why these recent trends must not be driven solely by individual desires for travel-cost savings, but rather by individual preferences for other benefits such as destination-utility gains. First of all, the rent premium commanded by locations of higher accessibility is often so high that makes it unlikely to be completely compensated by travel-cost savings. For example, an analysis of the median sales prices for single-family homes in suburban areas along Metro-North Railroads New Haven line suggests that homeowners pay tens of thousands dollars more for each less minute of rail travel time to the Grand Central Station(Kolomatsky, 2016). It is hard to believe that this high price premium completely results from the potential time-plus-money savings associated with rail commuting or rail use in general. Second, researchers often find that higher-income households with good car access like to move into transit-rich areas, but good transit access does not lead to a significant impact on car ownership (Chapple and Loukaitou-Sideris, 2019) or mode switch (Chatman, 2013).

When applied for land-use and transportation policy evaluation, a TCS-based view of transportation benefits underestimates the value of accessibility and hence weakens the policy importance of accessibility-enhancing strategies such as job-housing balance, transit-oriented development, and smart growth. For example, in a standard cost-benefit analysis of transportation investments, the main benefits measured are travel-time savings; and the size of travel-time savings often becomes the most important factor shaping the decisions on whether or not and how much to invest (Bristow and Nellthorp, 2000). If a transit investment project results in little travel-time savings but significant destination-utility gains, however, this TCS-based cost-benefit analysis would suggest this project to be much less cost-effective than it actually is. Moreover, viewing commuting-cost savings as the primary benefit of living close to employment centers, researchers often use observations of excess commuting (i.e., the difference between the observed amount of commuting and a theoretical minimum amount of commuting suggested by a given job-housing relationship) as evidence refuting the merits of job-housing balance strategies (Giuliano and Small, 1993; Yang, 2008). However, this interpretation would erroneously undermine the merits of job-housing balance policy, as long as excess commuting is at least partially driven by individual desire to get destination-utility gains from locations of higher accessibility.

In this dissertation, I focus on two major literature where a TCS-based view of accessibility benefits has largely taken hold. First is the residential location literature from which a TCS-based view of accessibility benefits originated. Robert Murray Haig (1929) first formulated the idea that accessible locations allow households to save travel costs and these savings would be consequently capitalized into land rents as a result of land competition, and this idea was later adopted by the classic urban economics model developed by Alonso (1964). In the Alonso model, households deciding where to live are assumed to make a trade-off between housing costs and commuting costs, as locations of higher accessibility allow households to reduce commuting costs but charges a higher land price. In recent decades, there have been many extensions to these classic models. In particular, researchers have incorporated more comprehensive accessibility measures that can account for both TCS and non-TCS benefits in residential location choice models; however, as I will discuss in detail in chapter two, these researchers rarely recognized that these measures pick up non-TCS forms of accessibility benefits. As a result, a TCS-based view of accessibility benefits still dominate the resident location choice literature and the related studies on excess commuting and location affordability.

The second literature that I focus on is the built-environment and travel-behavior studies. These studies usually apply measures of vehicle-miles-traveled (VMT) reduction (e.g., decreases in VMT, in car ownership, in the probability of driving, and in car-trip frequency) to evaluate the travel benefits of accessibility-promoting compact-development strategies. The estimated amount of VMT reduction resulting from compact development, usually based on a statistical analysis of the association between built-environment variables and travel outcomes, subsequently becomes the main criterion to judge the transportation merits of compact-development strategies. Since VMT reduction can be considered as a type of TCS measure, these studies have essentially adopted an implicit TCS-based view of accessibility benefits. However, these studies have largely failed to consider that compact-development policies also lead to destination-utility gains as individuals react to these policies by making more trips and by traveling to more remote destinations.

Besides advancing the theoretical understanding of accessibility's economic benefits, this dissertation aims to facilitate accessibility-based planning policy implementation. Although existing accessibility research is extensive, with contributors from a variety of disciplines such as urban planning, geography, and transportation engineering, the existing knowledge on the relative importance of different types of accessibility (walkability, transit accessibility, and auto accessibility) is very limited. The absence of such knowledge leads to confusions among transportation professionals as to which different type of accessibility to prioritize when the funding for transportation improvement is constrained. In addition, walkability, transit accessibility, and auto accessibility are often highly correlated at a given location; therefore, when accessibility shapes an outcome, policymakers often cannot discern the effect comes from which type of accessibility, which inhibits the design of clear and targeted policies. To address these problems requires empirical studies that distinguish the independent effect of walkability, transit accessibility, and auto accessibility on individual residential-location and/or travel outcomes.

Furthermore, the current practice of land-use and transportation modeling may impede accessibility promotion as a result of methodological limitations. For example, the standard practice of land-use and transportation planning relies on analyzing current or historic data on household behavior to first estimate their preferences and then to apply these preference estimates for forecasting future land-use patterns (often 20-40 years). A presumption made in the process is that household preferences for accessibility and other goods or services (e.g., school quality) will remain constant over the forecasting period. This assumption will only be true if the market conditions (e.g., demand for and supply of accessible neighborhoods) of the study region remain unchanged. In reality, however, driven by rising demand for accessible neighborhoods (especially among the millennials and empty nesters), there is a growing call to reverse the exclusionary single-family zoning practice that has led to an undersupply of walkable and transit-accessible neighborhoods in most U.S. metropolitan regions (Levine, 2006). As a result, the assumption that household preferences for accessibility will remain stable over a 20-40 years period of time is not likely to hold true.

This three-paper dissertation addresses the issues raised above that are impeding the promotion of accessibility-based planning practice and policymaking. These papers examine a misconception on the concept of accessibility and its economic benefits, a fallacy in the use of vehicle-miles-traveled as the main criterion for accessibility evaluation, and the problematic practice of extrapolating current accessibility-preference estimates into the future. In each paper, I raise theoretical arguments and subsequently design an empirical test to verify them. The empirical analysis not only serves the purpose of hypothesis testing but also seeks to generate novel empirical evidence that can guide the design and implementation of accessibility-based planning strategies. Toward this goal, I fit statistical models for multiple U.S. regions rather than a single region to enhance the robustness of study findings and their transferability to other places. Besides, the differences in model outputs across regions can shed light on the importance of local context in shaping statistical results.

My empirical analysis examines three U.S. regions, including Atlanta, Puget Sound, and Southeast Michigan. These regions are selected not only because of my familiarity with them but also because they have distinctive metropolitan forms which result in great variations in the supply of accessible neighborhoods. Atlanta region has long been regarded as a sprawling region dominated by low-density, and auto-dependent development, and only in recent years, it has started to promote more mixed-use, transit-oriented development. With the city of Seattle serving as a strong urban core, Puget Sound excels Atlanta and Southeast Michigan in walkability and transit accessibility. Consequently, the use of non-driving travel modes is much more popular in Puget Sound than the other two regions.[1] Finally, the Southeast Michigan region is a slowly growing Midwest region with a declining central city (the city of Detroit). While it is less sprawled out than the Atlanta region and some parts of it (e.g., downtown Detroit and downtown Ann Arbor) are well served by public transit, most neighborhoods are not walkable. The existence of these variations allows me to fully explore how transferable the study findings are how regional differences shape model outputs.

The three papers are summarized as follows. In the first paper, I trace the origin of a TCS-based view of accessibility to early location theory formulated by Robert Murray Haig (1926) and the classic urban economic models developed by Alonso (1964), Muth (1969), and Mills (1972). I review the use of different accessibility measures in residential location studies and the explicit or implicit TCS-based view of accessibility benefits adopted by these studies. In order to test the hypothesis that individuals value accessibility beyond the benefit of travel-cost savings, I develop residential location choice models in the Puget Sound region and the Southeast Michigan region to examine if transit accessibility remains a significant predictor of residential location choice once all possible travel-cost savings are controlled for. Results of the residential location choice models refute a TCS-based view of accessibility benefits. Considering that only a small fraction of Americans regularly use transit, I conclude

[1] The conclusion is reached by examining the most recent regional household travel survey data of these regions. For example, the proportion of trips made by walking and transit in Puget Sound is 10% and 5.5% respectively. These numbers are 7% and 3.1% in the Atlanta region, and 7% and 3% in Southeast Michigan.

that it is probably the option value of transit access that attracts people to live at places of high transit accessibility.

Building on the idea that individuals value accessibility beyond the benefit of TCS, the second paper critiques the standard practice of applying measures of vehicle-miles-traveled (VMT) reduction as the main criterion to evaluate the travel benefits of compact-development strategies in built-environment and travel-behavior studies. I argue that compact development often induces additional car travel by generating more trips and by expanding individual activity space, which result in greater consumer welfare and can sometimes advance equity goals. I further fit trip frequency and car-trip frequency models in the Puget Sound region and Southeast Michigan region to test this hypothesis. Results show that transit accessibility (the main measure of compact development examined here) is positively associated with trip frequency (by all modes) in both regions. Besides, while the association between transit accessibility and car-trip frequency is negative in Puget Sound, this association is positive in Southeast Michigan. These results imply that compact-development strategies have countervailing effects on car use (a mode-switch effect that reduces car trips and a trip-generation effect that increases car trips), and whether or not these policies reduce car-trip frequency depends on if the mode-switch effect outweighs the trip-generation effect. It follows that a VMT-reduction-based land-use and transportation policy evaluation is problematic because measures of VMT reduction underrepresent the transportation benefits of compact development.

To facilitate accessibility-based planning policy implementation, the third paper empirically evaluates the relative importance of three types of accessibility (walkability, transit accessibility, and auto accessibility) in residential location choice. Two major findings can be inferred from the model outputs in three U.S. regions (Puget Sound, Southeast Michigan, and Atlanta). First, transit accessibility is a more important determinant of resident location choice than walkability and auto accessibility.

Second, location accessibility plays an important role in residential location choice, but its impact is modest compared to other factors such as commuting cost and housing affordability. In addition, comparing the results across the three study regions suggests that the preferred behavior of households can be different from their actual choice because of housing supply constraints. This implies that if the conditions of housing supply change, estimates of accessibility preferences may change accordingly. This finding challenges the standard practice of land-use and transportation modeling which forecasts future (often 20-40 years) land-use patterns based on presumed stability of historical or present estimates of accessibility preferences.

CHAPTER II

Is the Value of Accessibility Beyond Travel Cost Savings? An Empirical Examination in the Residential Location Context

2.1 Introduction

Accessibility describes the potential from a location to interact with opportunities (e.g., people and activities) distributed across space (Hansen, 1959). As an essential indicator of locational advantage, accessibility was considered as a major force shaping urban land value (Hurd, 1903), regional economy (Haig, 1926), and urban land-use patterns (Alonso, 1964) in the fundamental theories of urban and regional studies. Recognizing its importance, some scholars even argue that accessibility is the most important feature that cities or central areas of a region provide to location seekers (Haig, 1926; Webber, 1964; Lynch, 1981; Ewing, 1997; Glaeser and Gottlieb, 2009). [1] Recently, in a think piece commissioned by the Brookings Institution to inform

[1] The pioneer location theorist and regional economists Robert Haig asserted that "the essential quality which the [urban] center possesses is physical proximity, or accessibility, to all parts of the area (Haig, 1926, pp.420)." Similarly, urban theorist Melvin Webber (1964, pp.169) suggested that "the unique commodity that the city offers to location seekers is accessibility." Urban designer Kevin Lynch (1981, pp.187) wrote the following: "Cities may have first been built for symbolic reasons and later for defense, but it soon appeared that one of their special advantages was the improved access they afforded." In a debate on compact versus sprawled metropolitan form, Ewing (1997, pp.109) argued that "the most important indicator [of sprawl] is poor accessibility." Urban

metropolitan policy, Duranton and Guerra (2016) argue that accessibility should be placed at the center of the study of urban development.

The theoretical importance of accessibility is verified by numerous empirical studies. With contributors from a variety of disciplines such as urban planning, geography, engineering, and economics, decades of accessibility research have repeatedly verified the continuing influence that accessibility has on urban development and major socioeconomic outcomes. For example, a large number of empirical studies have shown that accessibility increases, especially gains in transit accessibility, would have a significant positive impact on property value (Adair et al., 2000; Bowes and Ihlanfeldt, 2001; Debrezion et al., 2007; Osland and Thorsen, 2008; Du et al., 2012; Li et al., 2015; Lin and Cheng, 2016). Besides, researchers have accumulated a vast amount of evidence linking accessibility to a diverse range of important socioeconomic benefits such as reduced car use (Ewing and Cervero, 2001), enhanced economic growth and labor productivity (Chatman and Noland, 2014), increased employment prospect and upward mobility (Chetty et al., 2014; Ewing et al., 2016), and increased social interaction (Brown and Cropper, 2001).

Though thousands of pages have been written about accessibility, what economic benefits it offers to individuals is still largely unclear. Early location theorists and urban economists have assumed the value of accessibility nothing more than transportation-cost savings (TCS), which I term as a TCS-based view of accessibility benefits in this paper. Robert Murray Haig (1926, pp. 421) first articulated a TCS-based view of accessibility benefits when describing the relationships between accessibility, transportation costs, and land rent: "Rent appears to be the charge which the owner of a relatively accessible site can impose because of the saving in transportation costs which the use of this site makes possible." This idea was adopted by Alonso (1964), Mills (1972), and Muth (1969), which constitute the fundamental

economists Edward Glaeser and Gottlieb claimed that "cities are ultimately nothing more than proximity (Glaeser and Gottlieb, 2009, pp.984)."

theory of urban economics and residential-location models. In these models, households are assumed to bid for locations based on a consideration of the trade-off between commuting costs and housing costs, as more accessible sites allow households to reduce commute costs but charge a higher housing price.

The Alonso (1964), Mills (1972), and Muth (1969) models are building blocks of modern urban economics theory, which have a significant influence on contemporary academic discussions and policymaking. As I will discuss further below, although there have been many criticisms of these models in recent decades, the core idea underlying these models that land rent arises from the TCS associated with accessibility gains has remained untouched (e.g. Ahlfeldt, 2011).[2] A TCS-based view of accessibility benefits and its logical extension that there is a direct trade-off relationship between transportation costs and housing costs are still widely applied. For example, when examining residential location choice, researchers often treat households preference for job accessibility as equivalent to a desire to reduce commuting costs (Hamilton and Röell, 1982; Paleti et al., 2013; Van Ommeren, 2018). Similarly, the recent literature on location affordability assumes that when households move from a less accessible place of residence to a more accessible one, their travel expenditure must decrease (Haas et al., 2016); this notion has informed the development of the Location Affordability Index by the US Department of Housing and Urban Development and Department of Transportation, which may inform these agencies where to allocate funding on public housing and public transit.

Yet many studies have shown empirical evidence that calls the TCS-based view of accessibility results into question. Researchers often find lower-than-expected or

[2] In a study that examines "if Alsonso was right," Ahlfeldt (2011) empirically tested two major assumptions made by Alonso's urban rent theory. One is its simplifying assumption of a perfectly monocentric city, and the other is the assumption that residential land values arise from a tradeoff of accessibility and commuting cost. While the results rejected the appropriateness of a monocentric-city assumption, Ahlfeldt (2011, pp.335) concluded the following regarding the second assumption: "Our results can therefore well be interpreted in support of Alonsos urban rent theory whose essence is that land values arise from a tradeoff between transport costs and accessibility."

even no travel-cost savings when comparing the travel behavior or transportation expenditure of different households enjoying varying levels of accessibility (Hanson and Schwab, 1987; Metz, 2008, 2010; Smart and Klein, 2018a). For example, Metz (2010) reported that after over a hundred billion pounds in road investments over twenty years, which must have resulted in great accessibility gains, British travelers barely experienced any travel-time savings.[3] Related, in a rare longitudinal study (data are from 2003 to 2013) that examines the transportation-expense change of nearly 11,000 US families moving to neighborhoods with greater transit accessibility, Smart and Klein (2018a) found that families did not experience reductions in their transportation expenses.

Besides, as I have discussed in the introduction chapter, a TCS-based view of accessibility benefits cannot reasonably account for some recent urban trends. These trends include a rapid increase in out-commuting trips in recent decades (Glaeser et al., 2001), the widening gap between the per-square-foot home value in urban areas and suburban areas (Fuller, 2016), and the movement of high-income, car-owning households into areas with high transit accessibility (Chapple and Loukaitou-Sideris, 2019). In all of these cases, the economic actors involved pay a price premium to enjoy a higher level of accessibility, but they do not experience travel-cost savings at all or the associated TCS are not enough to offset this price premium; therefore, the price premium of accessibility must have be compensated by other forms of accessibility benefits rather than TCS. It follows that a mere focus on the TCS aspects of accessibility benefits underestimates the value of accessibility, and if applied for accessibility-based policy evaluation it would consequently weaken the policy importance of these policies.

[3] There can be two explanations for this observation. One is that average travel time would have been higher without the road investments and the other is that people take the benefit of investment in the form of accessing to desirable destinations at further distances rather than travel-time savings. Metz (2008) argued that the first explanation did not hold since average travel time had a steady trend despite large variations in road investments by year.

This paper argues that accessibility has value beyond travel-cost savings. I empirically test this hypothesis in the residential location context, i.e., examining the significance of non-TCS aspects of accessibility benefits (which will be termed as destination-utility gains as I discuss further below) in a residential location choice model. The rest of the paper is organized as follows. The next section reviews the concept of accessibility, its economic value, and the application of different accessibility measurements in residential-location studies. The third section discusses the empirical analysis, which includes the modeling framework, data, and measurements used in this study. In the fourth section, I present and interpret the model outputs. The fifth section discusses the implications of this study for location theory and land-use and transportation planning. The last section concludes.

2.2 A review of the accessibility concept and its application to residential location studies

2.2.1 The concept of accessibility and its economic value

Accessibility is commonly defined as the ease of reaching destinations (Dalvi and Martin, 1976) or the potential to interact with opportunities (Hansen, 1959). Accessibility is jointly determined by two components: a land-use component that denotes the spatial distribution of destinations, and a transportation component that determines the ease of reaching each destination. Accessibility improvements can thus come from either land-use policies such as new urbanism, mixed-use development, and job-housing balance or transportation policies such as travel-demand management and transit investments. In economic terms, an accessibility improvement can be defined as a decrease in the time-plus-money cost of travel to potential destinations or an increase in the value of destinations that can be reached for a given investment of time and money (Levine et al., 2019). When accessibility increases translate into the former, the associated economic benefits are essentially travel-cost savings; and if accessibility increases translate into the latter, I term the associated economic benefits as destination-utility gains here.

Destination utility arises from interacting with or the ability to choose from spatially distributed opportunities, and so it contains two types of economic value—the interaction value and the choice value. The interaction value refers to the utility that individuals gain from the act of interacting with people and opportunities available at the reachable destinations. Normally individuals can gain a higher level utility from more interactions, which means that people are usually better off when they choose to make more trips. Also, each destination conveys a distinctive degree of utility; and if an individual choose a more remote destination rather than a closer alternative, it suggests that the more remote destination produces a higher level of utility. Thus a pursuit for interaction value can lead to more spending on travel, offsetting the potential travel-cost savings associated with accessibility increases.[4] It should be noted that besides interactions resulting from purposeful trips, which are the focus of most transportation studies, individuals also gain great value from random or the so-called non-market interactions (Jacobs, 1970; Glaeser et al., 2000). Random interactions mean the type of human interactions that are spontaneous, unplanned, and usually unrecorded (by existing authoritative data sources). The consumer welfare associated with random interactions is difficult to quantify, but it is an indispensable component of accessibility benefits. In fact, there is a growing understanding among economists that cities thrive because they cultivate random interactions that facilitate knowledge transfer and idea generation (Duranton and Puga, 2004; Rosenthal and Strange, 2004).

The choice value is the welfare gains that individuals derived from the freedom of choice, that is, being able to choose among a range of potential destinations. More

[4] I further explore the idea that destination-utility gains and travel-cost savings are associated with travel-behavior changes in opposite directions in the next chapter.

choices usually mean a larger degree of freedom and hence a higher level of utility. More concretely, having more choices of destinations allow individuals to not only freely choose the most desirable option at a given time, but also to enjoy diversity and flexibility (Levine et al., 2019). While the value of choice is not directly observable, it can be estimated; and one approach to do so is the "logsum" method which is based upon a random-utility choice modeling framework (De Jong et al., 2007). Several researchers have applied this method to estimate the option value of accessibility, such as the option value of transit access (Laird et al., 2009) and the choice value of mode-destination accessibility to job opportunities (Niemeier, 1997).

Both travel-cost savings and destination-utility gains can result from improvements to either the land-use patterns or the transport network. For example, for a low-income woman working at an employment center, potential savings in commuting cost to her can come from either a land-use policy that allows more affordable housing units to be built around her workplace (Levine, 1998) or a transport policy that leads to high-quality transit services from her home to her workplace. Likewise, gains in destination utility for a given individual can come from land-use strategies which bring more valuable destinations with his reach or transportation improvements that allow him to travel to a wider geographic area and hence to reach a greater range of destinations.

Nevertheless, most land-use and transportation studies focus on travel-cost savings only when evaluating accessibility-promoting land-use and transportation strategies. And only a handful of studies recognize the non-TCS aspects of accessibility benefits (e.g., Metz, 2008; Van Wee et al., 2011; Geurs et al., 2010; Merlin, 2015; Levine et al., 2019). In a paper titled "The Myth of Travel Time Savings," Metz (2008) first argued that in the long run, travelers take the benefit of transportation improvements in the form of additional access to more distant destinations rather than travel-time savings. Geurs et al. (2010) further developed a "logsum" approach based on discrete-choice modeling to account for accessibility benefits in three forms: travel-cost savings, destination utility gained from additional trip production, and destination utility gained from visiting different and more desirable destinations. In a think piece, Van Wee et al. (2011) argued that if land-use changes did not lead to travel-behavior changes (or if the impact is smaller than theoretically possible), then it must be that travelers have converted potential travel-cost savings into other kinds of accessibility benefits. Merlin (2015) argued that a primary benefit of compact development is to facilitate the participation of out-of-home nonwork activities and empirically verified this idea using a national travel data set. Finally, Levine et al. (2019) detailed a list of "invisible" accessibility benefits that are unrelated to travel-cost savings, including choice, variety, flexibility, competition, and spillovers.

The need to move beyond a TCS-based view of accessibility benefits is logically compelled by a basic principle of transportation that views travel demand as derived from the need to interact with destinations (Bonavia, 1936); that is to say, individuals usually travel to get to places rather than to enjoy movement. Under this notion, any economic value associated with accessibility arises from the need for interaction, and it is for the purpose of interacting with opportunities distributed across space that individuals are willing to pay a travel cost to overcome the spatial friction between places. It follows that that travel-cost savings should be viewed as subsidiary to the destination-utility aspects of accessibility benefits, since no TCS would exist in the absence of travel driven by the pursuit of destination utility.

Furthermore, the short-run TCS benefits resulting from accessibility improvements are often converted into destination-utility benefits in the long run. For example, while transportation improvements such as the construction of a new highway help drivers travel faster and save the time cost of travel, over time these TCS often end up translating into gains in destination utility. The process may work like this: 1) the transportation improvements first allow individuals to spare some money and travel budget used for travel; 2) instead of keeping the savings, travelers decide to spend the "spared" travel budget (TCS) in order to visit more desirable but further-away destinations or to make more trips that they previously cannot complete due to travel-budget constraints;[5] 3) At the end, little to no TCS exist because individuals travel more and travel to more distant destinations, which means that the initial TCS were converted into gains in destination utility (Van Wee et al., 2011).

2.2.2 Accessibility measures viewed in terms of the economic benefits they capture

I now discuss the commonly used accessibility measures in land-use and transportation studies from the perspective of whether and how they adequately capture both the TCS and destination-utility gains of accessibility benefits. Commonly used accessibility measures can be classified into four categories: distance-based, cumulative opportunities, gravity-based, and utility-based (Handy and Niemeier, 1997; Geurs and Van Wee, 2004).

Distance-based accessibility measures represent the distance from a location to a predetermined (or a set of) destination(s) that individuals would like to interact with. Note that the term "distance" here refers to the spatial impedance between places in general, which in practice may be measured by the general cost of travel, physical distance, or travel time. Commonly used indicators include commuting cost (i.e., distance to one's workplace), distance to the city center, distance to transit stops, and distance to important landmarks (i.e., a historic site) or natural amenities (e.g., a park). By predetermining the destination(s) that individuals would like to

[5]There are two pieces of empirical evidence to support this proposition. First is the finding on constant travel-travel budget, which means that the average time people spend on travel is quite stable all over the world and across different years (Tanner, 1961; Downes and Morrell, 1981; Mokhtarian and Chen, 2004). This suggests that individuals on average allocate a fixed amount of their time to travel regardless of the level of accessibility they enjoy. Second is the "induced travel" literature, which findings that reductions in the generalized cost of travel often induce people to travel more (Cervero and Hansen, 2002; Noland and Lem, 2002). The next chapter engages with this topic further.

interact with, distance-based measures essentially assume away the destination-utility differences across locations of varying distances to this destination. Under this view, the accessibility differences between locations are merely in distances (i.e., travel costs) to the destination considered. Therefore, distance-based accessibility measures essentially represent a TCS-based view of accessibility benefits.

A distance-based accessibility measure is applicable for accessibility evaluation only if the destination considered is indispensable and irreplaceable, since individuals may decide not to interact with this destination at all or they may choose an alternative destination if the distance to it is too large. That is to say, for a given destination, locations closer to it tend to gain a higher level of destination utility from it, since the probability of interaction tends to decrease with distance increases. By assuming away such destination-utility differences, distance-based measures underrepresent the benefits of accessible sites. Therefore, distance-based measures are only applicable to describe accessibility to a limited set of opportunities/activities (e.g., someone's family members), since most destinations (such as dining places, shopping malls, or even employment opportunities) are to some extent dispensable and/or replaceable.

Cumulative-opportunity measures count the number of opportunities (e.g., jobs) reachable from a location within a given time or distance threshold. These measures can, but inaccurately, capture both TCS and destination-utility gains. When individuals have a greater choice of destinations to interact with and choose from, they can derive a higher level of utility from them; and people are more likely to take shorter trips when more opportunities are available at nearby destinations, which means that the potential TCS benefits are also captured. However, since destinations beyond the specified time or limit are not considered, cumulative-opportunity measures are inherently incomplete indicators of accessibility. Moreover, by counting potential opportunities equally regardless of their relative distance to the reference location, these measures ignore that fact when destinations are closer, individuals tend to gain a higher level of utility from them. Thus like the distance-based measures, cumulative-opportunity measures inaccurately represent the destination-utility gains from accessibility improvements.

A logical extension to the cumulative-opportunity measures is the gravity-based potential-opportunity measure proposed by Hansen (1959), which sums up potential opportunities across space but weights down the importance of opportunities at more distant locations. Gravity-based measures overcome the problems associated with cumulative-opportunity measures identified above, thus they are in general regarded as theoretically sound measures of accessibility.[6] Empirical studies that examine the influence of accessibility on residential-location choice and travel behavior have also verified that operationalizing accessibility with gravity-based measures often leads to better model performance (see, e.g., Thill and Kim, 2005; Lee et al., 2010; Baraklianos et al., 2018). These results can be interpreted as suggesting that gravity-based measures can better represent the full range of accessibility benefits.

Finally, utility-based measures conceive accessibility as the utility that individuals can derive from accessing to spatially distributed opportunities (Ben-Akiva and Lerman, 1979). A common utility-based accessibility measure is the "logsum" obtained from a random-utility choice model, which means the expected utility that individuals can derive from a choice when choosing among a set of alternatives. In theory, these measures are able to capture both travel-cost savings and destination-utility gains. For example, Geurs et al. (2010) applied this measure to evaluate the whole range of travel benefits resulting from accessibility-promoting land-use and transport policies,

[6]Related, Harris (1954) made a distinction between a market-potential measure and an aggregate-transport-cost measure when measuring accessibility to regional markets. Similar to the Hansen (1959) gravity-based accessibility measure that gives a lighter weight to potential destinations that are further away, Harris's market potential measure presupposes a declining market with distance. In fact, both measures were adopted from the population potential concept developed by Stewart (1948), which is "an abstract index of the intensity of possible contact with markets (Harris, 1954, p. 321)." On the other hand, the aggregate-transport-cost measure sums up the distances from a location to all potential markets and thus is analogous to a distance-based accessibility measure. In recent regional economics and economic geography literature, the market potential measure receives much wider application (Bartelme, 2015).

including travel-cost savings, welfare gains from destination change, and welfare gains from taking more trips.

2.2.3 A TCS-view of accessibility benefits in residential location studies

Either explicitly or implicitly, researchers have in general adopted a TCS-based view of accessibility benefits in the residential-location literature. As mentioned above, this view is a legacy of the classic urban economics models developed by Alonso (1964), Muth (1969), and Mills (1972). These models assumed a city that sits on a featureless plain where all activities happen at the center (i.e., the assumption of a monocentric city). In addition, households only needed to travel to the city center in order to work, and so the benefit of living at a location closer to the city center (i.e., a more accessible location) was merely the savings in commuting costs. Under a competitive land market, the amount of commuting-cost savings that a piece of accessible land provides would be the price that a household is willing to bid on it, and so any commuting-cost savings resulting from accessibility will eventually be capitalized into land rents. Starting from a TCS-based view of accessibility benefits, these models have elegantly established a theoretical trade-off relationship between transportation and housing costs.

The simplistic assumptions made by the classic residential-location choice models have been subject to numerous attacks, especially the assumption of a monocentric city and the assumption that households only consider commuting and housing costs when deciding where to live (Anas, 1982; Brueckner et al., 1987).[7] Nevertheless, to my knowledge, no studies have explicitly challenged the theoretical connections between accessibility, transportation costs, and land value (housing cost) established

[7] These criticisms have led to extensions to these models which sought to increase their realism. As the discrete choice modeling framework gains increasing popularity, however, recent advances in this area feature with the development and refinement of choice-based models (Eliasson and Mattsson, 2000; Pagliara et al., 2010) instead of the bid-rent model formulated by Alonso (1964), Muth (1969), and Mills (1972). Martinez (1992) demonstrated that the two approaches are equivalent in perfectly competitive land markets.

by these models. More specifically, the idea that the value of accessibility will be captured by land/housing price has been tested by numerous empirical studies, and these studies generally found that accessibility has a positive and significant impact on property value (Knight and Trygg, 1977; Adair et al., 2000; Bowes and Ihlanfeldt, 2001; Armstrong and Rodriguez, 2006; Debrezion et al., 2007; Osland and Thorsen, 2008; Du et al., 2012; Li et al., 2015; Lin and Cheng, 2016). On the other hand, the assumption that the economic value of accessibility is equivalent to travel-cost savings has simply been taken for granted by most researchers.

Based on how researchers define and operationalize the concept of accessibility, existing studies on residential location can be grouped into two categories. The first group of studies holds an explicit TCS-based view of accessibility benefits. They often use the term accessibility and savings in transportation costs (especially commuting costs) interchangeably like (Alonso, 1960) did,[8] and measure accessibility with *only* distance-based measures, including commuting cost and distance to key point-of-interest destinations such as central business center (Kain, 1962), shopping destinations (Burns and Golob, 1976; Chatman and Voorhoeve, 2010), and transportation facilitates (Habib and Miller, 2009).[9] For example, in their study of how households make trade-offs between accessibility, living space, and other neighborhood amenities, Kim et al. (2005) stated: "accessibility variables such as travel time to work, travel cost to work and travel time to supermarket are included to assess the impacts of transport on the intention to move (p. 1628)." Some of these studies may not define the concept of accessibility at all, since they simply assumed that savings in commuting cost is the primary transportation benefit provided by a central location (Wheaton, 1977; White, 1977; Timmermans et al., 1992; Sermons and Koppelman,

[8] Alonso (1960, p. 150) noted: "one encounters, as well, a negative good(distance) with positive costs (commuting costs); or, conversely, a positive good (accessibility) with negative costs (savings in commuting cost)."

[9] The term "only" is used here because some studies have included both distance-based measures and potential-based measures which also capture the non-TCS aspects of accessibility benefits.

2001; Ng, 2008).

A subgroup of these studies engages with the topic of "excess" (also called "wasteful") commuting (Hamilton and Röell, 1982; White, 1988), which refers to the estimated difference between the observed amount of commuting and a theoretical minimum amount of commuting under a certain job-housing distribution (i.e., a type of urban spatial structure). These studies are particularly relevant to my study because of the land-use and transport policy implications underlying the analysis of this phenomenon. While commuting behavior in itself is a subject of major research interest (Cervero and Wu, 1997; Shen, 2000), studies on excess commuting often interpret the amount of excess commuting as indicating the strength of the land-use and transport connection (Giuliano, 1995; Peng, 1997; Yang, 2008). A large amount of excess commuting was frequently cited as evidence suggesting that accessibility/transportation is no longer a major factor in residential location choice as classic urban economics theory assumed and that transportation policies would be ineffective to shape location decisions (Gordon et al., 1989; Giuliano, 1995). If accessibility benefits are beyond savings in commuting (travel) costs, however, these interpretations would wrongly undermine the rationale for accessibility-promoting land-use and transportation policies.

The second group of residential-location studies uses more comprehensive accessibility measures discussed above that can capture both travel-cost savings and destination-utility gains, such as the gravity-based and utility-based measures (Eliasson and Mattsson, 2000; Ben-Akiva and Bowman, 1998; Srour et al., 2002; Zondag and Pieters, 2005; Lee et al., 2010; Baraklianos et al., 2018). However, these studies do not challenge a TCS-based view of accessibility benefits. As Levine et al. (2019) argued, the use of accessibility indicators in these studies are purely positive (for the purpose of predicting location choice); and researchers rarely engage with theoretical discussions on what economic benefits do accessibility offer, let alone the implications of such knowledge on land-use and transportation policy and practice. This line of work can be said to be originated from Walter Hansen. In his seminal piece, Hansen (1959) first proposed the potential-based definition of the accessibility concept, operationalized it with a gravity-model accessibility measure, and applied it to develop a residential land-use model. Hansens definition of accessibility represents a conceptual shift from the first group of studies that used only distance-based measures toward a measure that captures the potential to reach destinations. The concept of potential implies that the value of accessibility is not only in travel-cost savings but also in welfare gains from the capacity to interact with more potential opportunities.

Yet this theoretical implication is barely recognized by the existing literature. After all, like most work in the field of computer-aided modeling and simulation of urban systems (Lowry, 1964; Putman; Pagliara et al., 2010), this group of studies in general are primarily interested in practical applications rather than theoretical discussions of urban processes. In fact, one may infer an implicit TCS-based view of accessibility benefits from some studies. For example, some scholars considered a gravity-based accessibility measure as an aggregate travel-cost measure (Ahlfeldt, 2011),[10] thus essentially neglecting the destination-utility gains picked up by this measure.

2.3 Empirical analysis

2.3.1 Conceptual framework

To test the hypothesis that accessibility has value beyond travel-cost savings, I fit a model that differentiates the influences of TCS and non-TCS aspects of accessibility benefits on household residential location choice. I focus on transit accessibility

[10] Ahlfeldt (2011, pp.328) wrote:"If Alonso was right in the basic idea that commuting costs, and hence access to employment opportunities, (solely) shape the spatial structure of urban land values." Hence an equivalence of commuting costs and access to employment opportunities was implied here.

here, since previous studies have verified a significant impact of transit accessibility on residential location choice, especially among lower-income car-less households (Glaeser et al., 2008; Hu, 2017; de Palma et al., 2007). This influence is further supported by two relevance pieces of empirical evidence. First, the property price of housing units located at transit-adjacent areas is often higher than other areas (Debrezion et al., 2007; Bartholomew and Ewing, 2011). Also, when asked about neighborhood/housing preferences, respondents often list transit access as one of the important factors that they consider (Urban Land Institute, 2015; Canadian Home Builders Association, 2015). Moreover, since it is difficult to directly measure the non-TCS aspects (i.e., destination-utility gains) of accessibility benefits, I adopt the following empirical strategy to distinguish the influence of destination-utility gains from that of TCS on residential location choice.

The basic idea is to examine if transit accessibility still maintains an independent and significant impact on household residential choice once all possible TCS (i.e.,, TCS from commuting trips and nonwork trips) associated it are controlled for. I first fit a benchmark model with a transit-accessibility measure that captures both TCS and non-TCS aspects of accessibility benefits and then fit a comparison model that additionally control for all possible TCS associated with transit accessibility.[11] The coefficient estimate of the transit accessibility is expected to be positive and significant in the benchmark model. In the comparison model, the coefficient estimate of the transit-accessibility measure indicates if non-TCS aspects of accessibility benefits play a significant role in residential location choice. If these accessibility variables are not significant but TCS measures are, then the results lead support to a TCS-based view of accessibility benefits. By contrast, if accessibility variables that can account for non-TCS benefits turn out to be positively significant, it provides empirical evidence

[11]Potential TCS associated with transit accessibility includes commuting-cost savings and TCS for non-work trips. In order to examine the relative influence of the two components of TCS on residential location choice, I fit two comparison models rather than one.

to support the idea that households are often motivated by the non-TCS aspects of accessibility benefits when deciding where to live; in other words, this finding would reject a TCS-based view of accessibility benefits that is commonly assumed by the existing literature.

2.3.2 Modeling framework

I applied a commonly used multinomial logit model to study household residential location choice (McFadden, 1978). In this model, households were assumed to choose a residence by weighing the available alternatives (i.e., residential locations) based on a set of important attributes, which usually include housing cost, housing and neighborhood characteristics, accessibility variables, and local services. In the process, households would make necessary trade-offs between costs and desirable attributes, and decide on a residence that maximizes their utility.

Following the standard random utility model formulation, a household i will choose residence j if the utility U_{ij} of choosing j is the maximum among all choices: U_{ij}= Max[U_{i1},U_{i2},,U_{ij}]. The the utility U_{ij} provided by location j to individual i includes a systematic component V_{ij} and a random component ϵ_{ij}. The former can be captured by a vector of observed attributes, and the latter is random noise that is often assumed to follow a Gumbel distribution. The probability of household i choosing location(zone) j thus can be expressed as:

$$\mathrm{P}_{ij} = exp(V_{ij}) / \sum_{j} exp(V_{ij}). \tag{2.1}$$

The systematic component of the residential location choice model V_{ij} can be described as:

$$\mathrm{V}_{ij} = f(\mathbf{A}_j, \mathbf{T}_j, \mathbf{C}_j, \mathbf{S}_j, \mathbf{N}_j, \mathbf{H}_i, n_j), \tag{2.2}$$

where:

A_j is the transit accessibility measured at location j;

$\mathbf{T}_{ij}$ is a vector of travel-cost savings variables which measures the expected travel-cost savings household i can gain from location j;

$\mathbf{C}_j$ is a vector of housing affordability variables measured at location j;

$\mathbf{S}_j$ is a vector of local-services variables measured at location j;

$\mathbf{N}_j$ is a vector of neighborhood-environment variables which measure the built environment and socioeconomic characteristics of location j;

$\mathbf{H}_i$ is a vector of household-related variables that measures the demographic and socioeconomic characteristics of household i;

n_j is a size-correction term that corrects for the fact that when a zone with more housing units would have a higher probability of being selected than a zone with less (Lerman, 1975).

Note that $\mathbf{H}_i$, which do not vary across alternatives, can not enter into the model directly and so these variables were interacted with TAZ-level variables. For example, I have interacted a school-quality variable with a dummy variable which indicates if a household is a high-income household with children to test if higher-income households with children are more likely to live in neighborhoods with better schools.

2.3.3 Data

I built residential location choices for two US regions–Puget Sound and Southeast Michigan. The main data sources used were the Puget Sound Regional Council (PSRC) 2014-2015 regional household travel survey and the Southeast Michigan Council of Government (SEMCOG) 2015 regional household travel survey. The models were built at the traffic analysis zone (TAZ) level instead of the housing-unit level, since the home location of sampled households was reported at the TAZ level in the data. Also, I did not have information regarding which non-chosen housing locations were considered by each sampled household when they decided where to live, and so based on some decision rules I constructed a non-chosen alternative choice set for each household and randomly sampled 29 alternatives from it in the final model. More details regarding this procedure can be found in chapter four of this dissertation.

It should be noted that neither of the household travel surveys sampled a statistically representative population from their respective region. To correct this sampling bias, a common approach is to apply sample weights, i,e, assigning each population group (e.g., segmented by place of residence or income levels) a weight which equals to the ratio of the probability of this population group being randomly selected to the share of this population group in the household travel survey. Nonetheless, specifying sample weights in a residential location choice model with a large alternative choice set is challenging since there is no available software or open-source packages for this purpose. I thus constructed a more statistically representative sub-sample by performing a geographically stratified (at the Census County Subdivision level) sampling procedure on the original survey sample, that is, for each region I drew a total of 1,200 observations (a sub-sample) from the full survey sample by sampling in proportion to each Census County Subdivision's share of households in the region. Although this procedure does not fully address the sampling bias issue, it corrects for over- and under-sampling in certain County Subdivisions.

Besides the regional household travel survey data, PSRC and SEMCOG also kindly provided me with the skim matrix which contains the estimated travel time for each origin-destination zone pair, which was used to calculate the accessibility and travel-cost savings indicators. Other data used to construct the model database include Census Transportation Planning Products (CTPP), American Community Survey (ACS), and Longitudinal Employer-Household Dynamics (LEHD), school quality data extract from the GreatSchools.org API, Walk Score data extracted from the Walk Score.com API, and crime-rate data (for Southeast Michigan but not the other two regions). Table 2.2 describes the independent variables specified in this study and their data sources, and Table 2.2 presents their mean and standard deviation.

Table 2.1: Description of independent variables and data sources

Variable code	**Level of measure**	**Variable description**	**Data source**
Main variable of interest			
TransitAccess	Zonal	Transit accessibility index (first principle component derived from transit accessibility to jobs and to nonwork destinations)	LEHD, skim matrix
Travel-cost-savings variables			
AutoTT	Household and zonal	Sum of the commute time by auto from each household worker's work TAZ to a given TAZ.	Regional household travel survey, skim matrix
TransitTT	Household and zonal	Sum of the commute time by transit from each household worker's work TAZ to a given TAZ.	Regional household travel survey, skim matrix
PredHHVMT	Household and zonal	Predicted household vehicle miles traveled for nonwork trips at a given TAZ	Regional household travel survey
Housing-affordability variables			
HsgCost_HHInc	Household and zonal	Median value (for owners) or median rent (for renters) at a given TAZ divided by household income	ACS, regional household travel survey
Local service related variables			
SchoolQual	Zonal	GreatSchools school rating score at a given TAZ	Greatschools.org API
SchoolQual_HInc	Household and zonal	GreatSchools school rating score at a given TAZ interacted with high-income household with children	Greatschools.org API, CTPP
Crime rate	Zonal	Number of crimes per 10,000 people at a given TAZ	SEMCOG
Neighborhood-environment-related variables			
PopDen	Zonal	Population density in a given TAZ	CTPP
PopDen_HighInc	Household and zonal	Population density in TAZ interacted with high-income household	Regional household travel survey, CTPP
SinFamChd	Household and zonal	Percent of single-family property in a given TAZ interacted with household with children	Regional household travel survey, CTPP
MHH-Size_HHSize	Household and zonal	Absolute difference between median household size in a given TAZ and household size	Regional household travel survey, CTPP
MHHInc_HHInc	Household and zonal	Absolute difference between median household income in a given TAZ and household income	Regional household travel survey, CTPP
Size correction term			
LogHsgUnits	Zonal	The natural logarithm of the number of housing units of the household's chosen tenure in a given TAZ	CTPP

Table 2.2: Mean and standard deviation of independent variables

Variable code	**Sample**	**Puget Sound**		**Southeast Michigan**	
		Mean	Stardard deviation	Mean	Stardard deviation
Main variable of interest					
TransitAccess	Chosen TAZs	0.42	1.21	-0.08	0.89
	Non-chosen TAZs	-0.06	0.83	-0.09	0.63
Travel-cost-savings variables					
AutoTT	Chosen TAZs	27.24	26.94	20.47	26.96
	Non-chosen TAZs	67.07	58.65	36.7	45.07
TransitTT	Chosen TAZs	69.93	83.73	214.16	394.4
	Non-chosen TAZs	143.99	142.83	311	456.26
PredHHVMT	Chosen TAZs	19.24	31.99	14.29	16.76
	Non-chosen TAZs	22.05	33.70	14.87	18.54
Housing-affordability variables					
HsgCost_HHInc (Owners)	Chosen TAZs	8.55	15.2	5.65	6.98
	Non-chosen TAZs	7.19	14.27	5.32	8.6
HsgCost_HHInc (Renters)	Chosen TAZs	0.36	0.62	0.61	0.91
	Non-chosen TAZs	0.33	0.66	0.5	0.77
Local service related variables					
SchoolQual	Chosen TAZs	5.86	2.12	5.64	2.11
	Non-chosen TAZs	5.68	2.02	5.39	2.19
SchoolQual_HInc	Chosen TAZs	0.45	1.73	0.73	2.16
	Non-chosen TAZs	0.38	1.52	0.58	1.83
CrimeRate	Chosen TAZs			3.25	0.31
	Non-chosen TAZs			3.29	0.3
Neighborhood environment related variables					
PopDen	Chosen TAZs	5004.44	6785.83	3299.65	2834.62
	Non-chosen TAZs	2572.85	3799.75	3150.26	2767.97
PopDen_HighInc	Chosen TAZs	1405.71	4470.99	590.4	1408.72
	Non-chosen TAZs	714.13	2281.80	807.42	1923.49
SinFamChd	Chosen TAZs	0.11	0.25	0.21	0.37
	Non-chosen TAZs	0.12	0.27	0.2	0.35
MHHSize_HHSize	Chosen TAZs	0.7	0.79	0.91	0.8
	Non-chosen TAZs	0.83	0.8	0.99	0.91
MHHInc_HHInc (1000s)	Chosen TAZs	4.23	4.37	3.23	2.9
	Non-chosen TAZs	4.81	4.46	4.67	3.81
Size correction term					
LogHsgUnits (Owner-occupied)	Chosen TAZs	276.98	269.89	721.55	460.47
	Non-chosen TAZs	274.35	235.84	553.13	387.59
LogHsgUnits (Renter-occupied)	Chosen TAZs	410.95	366.27	285.69	324.81
	Non-chosen TAZs	184.69	208.45	252.5	285.19

2.3.4 Accessibility and travel-cost savings measurements

The main variables of interest in this study is a transit-accessibility indicator, which was computed from the procedure described below.[12] Figure 2.1 and Figure 2.2 show the transit accessibility across TAZs in the Puget Sound region and Southeast Michigan region respectively. I used a common form of the gravity model such that the amount of interaction between an origin zone i and a destination j is positively related to the number of opportunities at the destination zone but is inversely related to the travel cost (time) between the zones. The accessibility to opportunity type n by transit for location i is expressed as

$$A_{in} = \sum_{j} O_{jn} exp(-\beta T_{ij}), \tag{2.3}$$

where:

A_{in} is the accessibility index to opportunity type n by transit for location i;

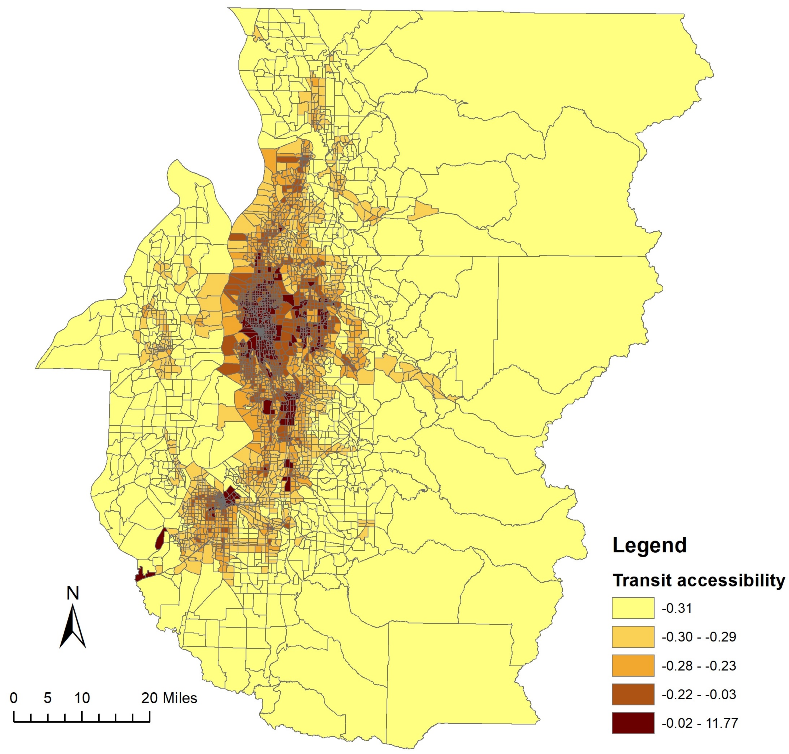
O_{jn} is the attractiveness factor for opportunity type n based on the number of these opportunities in destination zone j;

exp denotes the base of the natural logarithm;

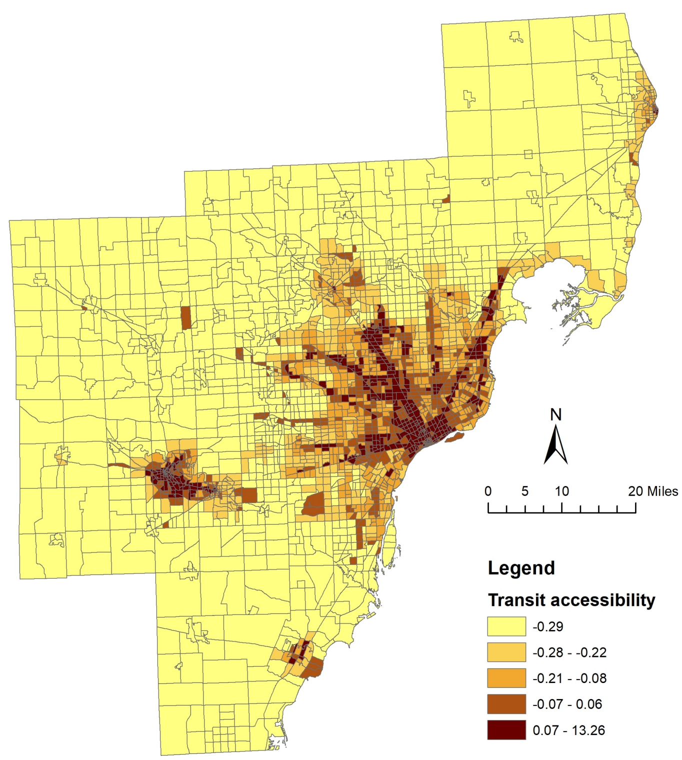
β is the impedance factor that measures the friction of distance, a higher value of which makes distant opportunities contribute to the accessibility index to a lesser degree;

T_{ij} is the travel time by transit in minutes between zone i and j—if transit service is unavailable between zone i and j, the travel time is set to be infinite.

[12] Although I also computed an auto-accessibility indicator in a different study context, it is not included in this study because it had a negative sign in the residential location choice model, possibly because the locations of high auto accessibility often are associated with large degrees of negative externalities (e.g., such as high crime rates and high levels of noise) that were accounted for by the model. This means that the coefficient on the auto-accessibility variable does not only capture household valuation for accessibility benefits but also their inclination to avoid undesirable places.



Map 2.1: Transit accessibility (principle component score) in Puget Sound



Map 2.2: Transit accessibility (principle component score) in Southeast Michigan

In the existing literature, researchers have often used accessibility to jobs as a rough measure of the overall accessibility of a location (Handy and Niemeier, 1997; Boarnet and Wang, 2019). In recent years, however, researchers have started to pay more attention to nonwork accessibility (Grengs, 2015). After all, travelers in the United States made more than three-quarters of their trips for nonwork purposes in 2009 and 2017 according to the two recent national household travel surveys (McGuckin and Fucci, 2018). In theory, therefore, transit accessibility to both employment opportunities and to nonwork destinations are expected to play an important role in household residential location choice. In this study, I used all jobs to indicate employment opportunities and retail and services jobs to indicate nonwork destinations. Retail jobs refer to jobs in North American Industry Classification System sector (NAICS) 44-45 (Retail Trade), and services jobs refer to jobs in NAICS sector 54 (Professional, Scientific, and Technical Services), 56 (Administrative and Support and Waste Management and Remediation Services), 61 (Educational Services), 62 (Health Care and Social Assistance), and 81 (Other Services). In addition, the value of the impedance factor β was specified to be 0.1 and 0.3 respectively for employment opportunities and nonwork destinations, respectively, which were adopted from the estimates in Grengs (2015). To get an aggregate transit accessibility index, I further performed principal component analysis on the two obtained accessibility measures and extracted the first principal component. This principal-component variable (coded as *TransitAccess* here) thus represents the overall transit accessibility of a TAZ.

Now I discuss the TCS variables examined in this study. There are two main types of travel-cost savings that a household can gain from transit accessibility—the savings in commuting costs and the savings in travel costs to nonwork destinations.[13] Ideally,

[13]In addition, when provided with higher transit accessibility, some households may reduce the number of cars they own or not own a car at all, which means that transit accessibility can also result in potential savings in vehicle-ownership costs. I have attempted to control for these potential savings in my residential location choice models. I fitted a household-vehicle count model(with

both the generalized cost of travel (i.e., the time plus money cost of travel) should be measured, but for simplicity I only considered the time cost for commuting trips and applied home-based nonwork-trip vehicle miles traveled (VMT) to represent the travel costs to nonwork. These measures are close proxies for the generalized cost of travel because the time cost of travel, money cost of travel, and trip distance (which makes up VMT) are usually highly correlated.

Since the household travel survey data provided information regarding the workplace of each household worker, the commuting time from each alternative home location (i.e. TAZ) to the workplace of each worker can be directly computed from the skim matrix. If there were more than one workers in a household, their commuting times were summed up. Moreover, in this study I examined two travel modes (i.e., personal vehicle or transit) for commuting trips, and so I constructed two commuting-time-related variables. The two variables were coded as $AutoTT$ and $TransitTT$.

Accurately estimating the total home-based nonwork-trip VMT is challenging. First of all, there are important household-specific destinations (e.g., the locations of family members or friends) that a modeler does not know. These destinations cannot be taken into account in my model. Second, each household has different nonwork travel needs—in terms of the nonwork destinations they hope to visit and the desired trip frequency, but these preferences are difficult to be captured by a nonwork-travel costs indicator. Without fully addressing these issues, I estimated home-based

independent variables similar to the nonwork-trip VMT model) which allowed me to predict the expected household-vehicle count (this variable will be referred to as *PredCarCount*) at a given TAZ. Nevertheless, adding this variable into the residential location choice models resulted in a positive and highly significant coefficient estimate, which means that households often ended up living in more car-dependent neighborhoods (i.e., TAZs with greater values of predicted household-vehicle count) than less car-dependent ones. This result can be explained by two plausible reasons. First is the omitted variable bias problem. That is, there are desirable attributes associated with car-dependent neighborhoods unaccounted for in my models, which made the estimate of *PredCarCount* have an upward bias. Second, some households may have made the decision on vehicle ownership in conjunction with or even before the decision of where to live, which means that the choice of vehicle ownership is better modeled jointly with the residential location choice rather than being modeled as a predictor of it. However, implementing such a joint choice model with thousands of alternative residential zones is technically challenging. Thus while recognizing it as a limitation, I have not modeled potential savings in vehicle-ownership costs in this study.

nonwork-trip VMT for each household at a given TAZ (coded as *PredHHVMT*) with the following procedure.

2.3.5 Estimating nonwork-trip travel costs

I used a Tobit regression model here to estimate home-based nonwork-trip VMT. A Tobit regression model, rather than an ordinary least squares model, was used because a significant proportion (around 30%) of households had zero nonwork-travel VMT on the travel date recorded by the household travel survey (i.e., the sample data was left-censored). Also, following (Boarnet and Wang, 2019), I considered households with a nonwork VMT higher than 200 as outliers and excluded them from the final sample. Two vectors of variables were specified in the model, including a vector of household characteristics such as household income, household size, vehicle access, and number of workers, and a vector of accessibility indicators such as auto accessibility to all jobs and auto accessibility to service jobs. Since the accessibility indicators for a specific travel mode (car/transit) are highly correlated, the coefficient estimates for each variable are not reliable and should not be interpreted as indicating an independent effect on non-work travel VMT. I included the separate transit-accessibility variables (i.e., transit accessibility to all jobs, service, and shopping jobs) rather than the first principal component derived from them in order to reduce the correlation between the estimated nonwork-trip VMT and the transit-accessibility indicator in the residential location choice model.

The model outputs for the two nonwork-trip VMT models are shown in Table 2.3. The estimated model coefficients were then applied to predict the nonwork-trip VMT for each household at the 29 non-chosen TAZs. Since the household characteristics were constant but the accessibility variables varied across different TAZs, the differences in the predicted nonwork-trip VMT indicate the differences in the amount of nonwork trip costs that each household is expected to pay at each TAZ. For some households, the predicted nonwork-trip VMT at some non-chosen TAZs was negative, which is unrealistic; I thus converted the predicted negative values into zero instead.

Table 2.3: Tobit regression model for predicting home-based nonwork-travel VMT

Variable	Puget Sound		Southeast Michigan	
	Coef.	z-value	Coef.	z-value
Intercept 1	-22.07	-5.37***	3.27	2.66***
Intercept 2	3.62		2.96	
		177.59***		346.26***
Number of adults	16.12	9.41***	4.24	12.98***
Number of workers	-5.51	-3.77***	-1.35	-4.10***
Number of children	9.27	8.89***	-0.81	-3.55***
Home Owner	1.36	0.69	-1.53	-4.77**
Household income above 50k	5.04	1.82*	3.44	5.08***
Household income between 50k and 75k	4.05	1.38	5.07	7.10***
Household income bewteeen 75k and 100k	6.36	2.13**	4.40	5.56***
Household income above 100k	6.17	2.13**	6.46	8.74***
Vehicle per adult	15.91	9.61***	3.29	9.55***
Retired household	7.16	2.85**	3.85	5.96***
Householder age below 40, no children	-2.63	-1.33	-3.27	-4.45***
Accessibility to all jobs by auto	-0.05	-0.99	-0.01	-1.69*
Accessibility to all jobs by transit	-0.20	-1.19	-0.13	-0.58
Accessibility to shopping jobs by auto	0.93	0.17	-0.62	-0.86
Accessibility to shopping jobs by transit	-16.27	-0.58	26.55	0.75
Accessibility to service jobs by auto	0.22	0.13	0.00	-0.01
Accessibility to service jobs by transit	4.05	1.10	-11.50	-0.64
Walk Score	-0.07	-1.79*	-0.05	-3.73***
Observations (N)	2609		10857	
Log-likelihood	-9345.84		-39079.29	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

2.4 Results

2.4.1 Estimation and model fit

I estimated three models for each of the two regions with almost identifiable sets of independent variables except differences in the TCS variables. The first model was a benchmark model that does not include any TCS variables. The second model added two commuting-cost variables—aggregate commuting time by auto and aggregate commute time by transit.[14] The third model further added the predicted nonwork-trip VMT variable. Jointly, these models show if transit accessibility maintains an independent effect on residential location choice after controlling for TCS. If the hypothesis that households value accessibility benefits beyond the benefit of TCS hold true, the coefficient estimates on transit accessibility would be positively significant in all three models (more significant in the first model than the other two since it also captures the savings in commuting costs). In addition, similar model outputs across the two regions would enhance the transferability of study findings, given the differences in the regional contexts between the Puget Sound region and the Southeast Michigan region.

The McFadden's adjusted pseudo-R-square, shown at the bottom of the tables, was within the range of 0.2 and 0.3 across the six models, which indicate satisfactory model fit.[15] I focus on the coefficient estimates in the following discussion. I first briefly discuss the control variables and then examine the transit accessibility and travel-cost savings variables.

[14]If no transit service is available between the workplace of a worker and an alternative home location, the value of commuting time by transit is set to be 999.

[15]The McFaddens pseudo-R-square is a measure of the likelihood improvement offered by the full model compared to an intercept-only model, and values between 0.2 and 0.4 are often taken to represent good model fit (McFadden, 1979).

Table 2.4: Residential location choice models in the Puget Sound region

Variable code	Model 1		Model 2		Model 3	
	Coef.	z-value	Coef.	z-value	Coef.	z-value
Transportation-related variables						
TransAccess	0.27	10.28***	0.09	2.90***	0.08	2.40***
AutoTT			-0.06	-18.15***	-0.62	-18.19***
TransitTT			-0.00	-0.65	-0.00	-0.59
PredictVMT					-0.02	-0.72
Housing-affordability indicators						
HsgCost_HHInc	-0.12	-2.32**	-0.29	-5.21***	-0.29	-5.19***
Local service related indicators						
SchoolQual	0.06	3.98***	0.04	2.24**	0.04	2.23**
SchoolQual_HInc	0.13	2.01**	0.12	1.65*	0.12	1.64
Neighborhood environment related indicators						
PopDen	0.31	9.51***	0.12	3.45***	0.11	3.01***
PopDen_HighInc	0.20	3.34***	0.05	0.78	0.05	0.74
SinFamChd	0.01	0.04	0.55	1.76*	0.57	1.83*
MHHSize_HHSize	-0.37	-5.67***	-0.40	-5.67***	-0.40	-5.67***
MHHInc_HHInc	-0.12	-7.13***	-0.08	-4.98***	-0.08	-4.99***
Size correction term						
LogHsgUnits	0.97	21.11***	1.04	20.45***	1.03	20.35***
Observations (N)	1200		1200		1200	
Log-likelihood at convergence	-3399.48		-2676.39		-2676.13	
Log-likelihood (Null Model)	-4081.44		-4081.44		-4081.44	
Adjusted pseudo R-sqaure	0.17		0.34		0.34	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

Table 2.5: Residential location choice models in the Southeast Michigan region

Variable code	Model 1		Model 2		Model 3	
	Coef.	z-value	Coef.	z-value	Coef.	z-value
Transportation-related variables						
TransAccess	0.11	2.80***	0.09	1.96**	0.08	1.73*
AutoTT			-0.05	-18.74***	-0.05	-18.88***
TransitTT			-0.01	-4.70***	-0.02	-5.21***
PredictVMT					0.20	6.88***
Housing-affordability indicators						
HsgCost_HHInc	-0.12	-2.43***	-0.17	-3.10***	-0.15	-2.73***
Local service related indicators						
SchoolQual	0.01	0.66	0.01	0.54	0.01	0.34
SchoolQual_HInc	0.10	1.86	0.09	1.50	0.09	1.54
CrimeRate	-0.02	-6.31***	-0.03	-9.25***	-0.02	-5.85***
Neighborhood environment related indicators						
PopDen	0.01	0.42	-0.09	-2.47***	-0.01	-0.14
PopDen_HighInc	-0.04	-0.83	-0.19	-3.10***	-0.19	-3.04***
SinFamChd	0.38	1.46	0.47	1.69	0.42	1.50
MHHSize_HHSize	-0.08	-1.28	-0.08	-1.33	-0.08	-1.26
MHHInc_HHInc	-0.21	-14.50***	-0.22	-14.25***	-0.22	-13.95***
Size correction term						
LogHsgUnits	0.87	15.45***	0.97	16.27***	0.94	15.61***
Observations (N)	1200		1200		1200	
Log-likelihood at convergence	-3655.40		-3065.31		-3033.08	
Log-likelihood (Null Model)	-4081.44		-4081.44		-4081.44	
Adjusted pseudo R-sqaure	0.10		0.25		0.25	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

2.4.2 Control variables

Within each region, the coefficient estimates on most variables—except the transit-accessibility variable—barely differed across the three models, which is consistent with expectation. After all, the TCS variables are only expected to be correlated with transit accessibility but not other variables. Generally speaking, these coefficient estimates are reasonable and consistent with the existing evidence. First of all, most coefficients had the expected signs. The housing affordability indicator, *HsgCost_HHInc*, was negative and significant at the 0.05 level across all twelve models. This suggests that households are less likely to choose a zone which is less affordable to them. The school-quality variables, *SchoolQual* and *SchoolQual_HInc*, were positive in most models (except that *SchoolQual* was negative in the Southeast Michigan models), which indicate that households, particularly the high-income ones with children, prefer to live in places with access to good schools.

A crime-rate variable was incorporated into the Southeast Michigan-region models (crime data were not available to me for Puget Sound), and it is negative and highly significant. This finding confirms the conventional wisdom that safety is a major consideration in housing decisions. The degree to which failing to include the crime variable into the Puget Sound models biases the estimates of transit accessibility depends on its correlation with crime rate. Since crime has a negative impact on household residential location choice, the coefficient estimate of transit accessibility is likely to have a downward bias if transit accessibility is positively correlated with crime rate; and the coefficient estimate of accessibility would have an upward bias if the correlation is negative.

Next are the neighborhood-environment related variables. In the Southeast Michigan models, *PopDen* and *PopDen_HighInc* were negatively associated with residential location choice, which reflects the preference for low-density living among the households living in these regions (Myers and Gearin, 2001). By contrast, *PopDen* was positive and highly significant in the Puget Sound models. *SinFamChd* had a positive coefficient across all models, confirming the conventional wisdom that households with children tend to have a stronger preference for single-family homes. Moreover, as suggested by the negative signs on *MHHSize_HHSize* and *MHHInc_HHInc*, there is strong neighborhood sorting by household characteristics and household income.

Finally, the coefficient on the size correction term, *LogHsgUnits*, was reasonably close to unity and highly significant across all twelve models. Theoretically, this variable should have a coefficient of one if all units of a particular type in a given zone are truly homogeneous, a necessary condition underlying the assumption that a zonal-level choice model can result in parameter estimates consistent with a housing-unit level model (Lerman, 1975). Therefore, these coefficient estimates validated the modeling of residential location choice at the TAZ level with a multinomial logit model.

2.4.3 Accessibility and TCS variables

The transit-accessibility variable was positive and significant at the 0.05 level in all models except model 3 in the Southeast Michigan region (but it is statistically significant at the 0.1 level), which suggests that transit accessibility is a highly desirable attribute for households making residential decisions. The fact that transit accessibility remained to be significant when commuting costs and nonwork-travel VMT were controlled for suggests that households prefer accessibility beyond the benefit of travel-cost savings. As I have discussed above, a higher level of transit accessibility (i.e., an increase in the number of potential destinations reachable by transit) can, in theory, result in not only travel-cost savings but also destination-utility gains. It allows individuals to derive more interaction value by facilitating more transit trips and enabling transit trips to more remote but more desirable destinations (e.g., a distant supermarket that offers cheaper and higher quality products), and it allows people to gain a higher level of choice value by granting them greater freedom of destination choices. The empirical results presented here thus verified that these non-TCS aspects (i.e. destination-utility gains) of accessibility benefits exist and matter for household residential location choice.

There are two alternative interpretations to these findings which should be addressed. First, one may argue that the significant influence of transit accessibility on residential location choice does not come from transit accessibility itself but rather from the urbanist environment (e.g., high population density, the concentration of apartment building, and high walkability) that it is highly correlated with.[16] American households' preference for denser and walkable neighborhoods in recent years has been well documented by the literature (Audirac, 1999; Myers and Gearin, 2001; Levine and Frank, 2007). This concern is partially addressed by the fact that I have controlled for population density in my models.[17] In addition, I have fitted additional models that replaced the two population-density variables with a Walk Score variable and an interactive variable between Walk Score and a dummy variable indicating high-income households (results not presented), which did not lead to changes of sign or significance in the transit accessibility variable. Finally, adding both the two population-density variables and the two Walk Score variables into the model (results not shown) caused no major changes to the coefficient estimate of transit accessibility except that it became insignificant at the 0.05 level for the third model in the Puget Sound region.

Moreover, one may argue that households prefer housing units with higher transit accessibility because they see the investment value of these properties, not because they value transit accessibility itself. For example, recent research has shown that

[16] In Puget Sound, the correlation coefficient between transit accessibility and Walk Score (at the TAZ level) is 0.457, and the correlation coefficient between transit accessibility and population density is 0.383; in Southeast Michigan, these coefficients are 0.471 and 0.327, respectively.

[17] Since population density and Walk Score is highly correlated in both regions (the correlation coefficient is greater than 0.7), I only included population density in the models.

transit access not only leads to a price premium (Debrezion et al., 2007), but also makes housing value more resilient in economic downturns (Dong, 2015; Zhang et al., 2018; Welch et al., 2018). A consideration for property-value growth or resilience may indeed explain some households' preference of transit-accessible neighborhoods, but it does not rule out that possibility that many households value the economic benefits that they can directly derive from transit accessibility. Although only a small proportion of Americans households use transit a primary travel mode,[18] a much larger proportion of them use transit at least occasionally (Oram and Stark, 1996; Krizek and El-Geneidy, 2007). Some studies have shown that households derive substantive option value from transit access even though they do not use transit frequently (Roson, 2001; Laird et al., 2009).

Comparing the coefficient estimates on transit accessibility across the three models for the same region generate further insights. The significance level (magnitude of z-value) of transit accessibility was higher in the first model than that in the second model, which indicates that the transit-accessibility variable captures some effects from commuting-cost savings. Both commuting-cost variables (commuting time by auto and commuting time by transit) were negative, which means that households prefer to live in places that reduce commuting cost.[19]

Surprisingly, the predicted nonwork-travel VMT either was insignificant (in Model 3 of the Puget Sound region) or even had a positive sign (in Model 3 of the Southeast Michigan region). I have tested alternative specifications for the Tobit regression models used to predict the nonwork-travel VMT, but they did not result in significant

[18]According to the recent regional household travel survey data used in this study, transit only accounted for 5 percent and 3 percent of all weekday trips in Puget Sound and Southeast Michigan respectively.

[19]In fact, the commuting-cost variables were much more significant (value of z-value is much larger) than the transit-accessibility variable. This is because the commuting-cost variables (i.e. the aggregate commuting costs of household workers from their workplaces to the alternative home locations) are essentially people-based accessibility variables whereas the transit-accessibility variable is place-based. In a residential location choice model where the unit of analysis essentially a household, it is natural that people-based accessibility variables have more predictive power than place-based accessibility variables.

changes. This means that households did not think of reducing nonwork-travel VMT as a major consideration when they decided where to live. Similar findings can be found in (Srour et al., 2002; Chen et al., 2008), and Levine et al. (2019) argued that these findings may be explained by the greater flexibility in choosing where and when to travel in meeting nonwork-travel needs and by the inability of some households to opt into high nonwork-accessibility locations. Another plausible contributing factor is the omitted variable bias problem; that is, there are desirable features (e.g., more open space) associated with more car-dependent neighborhoods unaccounted for in my models, which led to an upward bias for the coefficient estimate of *PredHHVMT*.

2.5 Conclusion

Following the fundamental assumption made by classic urban-economics theory, urban analysts have either implicitly or explicitly equated the value of accessibility to transportation-cost savings. In this paper, I make the argument that this TCS-based view of accessibility benefits ignores the non-TCS accessibility benefits (i.e., destination-utility gains). Destination-utility gains stem from interaction value and choice value; the former refers to consumer welfare resulting from making more interactions and from interacting with different and more desirable destinations and the latter refers to personal utility derived from the freedom to choose from a wider range of destinations. Results of an empirical analysis, which is based on data collected from the Puget Sound and Southeast Michigan region, support this argument by showing that transit accessibility remains to be a significant determinant of residential location choice after controlling for all possible TCS associated with it.

A major limitation of the empirical work presented here is that I did not control for the potential reductions in vehicle-ownership costs associated with transit accessibility in my residential location choice models. When living at transit-rich neighborhoods, some households, especially the lower-income ones, may reduce the number of cars they own or not own a car at all. As I discussed in detail in a footnote (footnote thirteen), a more proper empirical strategy to address this issue is to fit a joint choice model of residential location choice and vehicle ownership. Moreover, the empirical approach presented here is only one of the possible approaches to investigate if accessibility benefits are beyond TCS. Future research may consider fitting a hedonic price model to examine if the price premium commanded by accessibility completely arises from TCS or examining if households derive greater satisfaction from living in more accessible neighborhoods. In addition, I have used cross-sectional data here due to practical limitations. A longitudinal dataset which records individual travel behavior, preferences, and attitudes before and after experiencing significant accessibility gains could greatly enrich the research on the destination-utility gains aspects of accessibility benefits.

This study provides a recent empirical evaluation of the classic urban economics theory developed by Alonso (1964), Muth (1969), and Mills (1972). Here I distinguish between the idea that accessibility (transportation) plays a major role in shaping residential location choice and a simplifying assumption that equates the value of accessibility to travel-cost savings. The results confirm the former, a finding consistent with many previous studies (e.g., Lee et al., 2010; Hu, 2017; Baraklianos et al., 2018). The main innovation of this study is that it empirically examined the latter and resulted in evidence to refute it. Furthermore, results of this study challenge the commonly held notion that there is a direct trade-off relationship between housing and transportation costs, which is contingent on a TCS-based view of accessibility benefits. Since households often value accessibility beyond the benefit of TCS, as the empirical results of this study show, this trade-off relationship no longer holds. This is because both TCS and destination-utility-gains aspects of accessibility benefits are expected to be capitalized into housing prices (Debrezion et al., 2007; Bartholomew and Ewing, 2011), which means that the housing-cost increases resulting from accessibility gains would be greater than the associated TCS benefits.

Findings of this study have important implications for land-use and transportation planning practice and policymaking. In the existing literature, the desirability/effectiveness of accessibility-promoting strategies is usually evaluated on the basis of travel-cost savings (e.g., commuting-cost reduction, or reduced transportation expenditure, or lower vehicle miles traveled) brought by these policies. When a significant amount of TCS is absent, such evidence is often interpreted as suggesting that the transportation benefits of accessibility-promoting policies are over-exaggerated (Crane, 1996a) or that accessibility is not an important factor in household residential location choice (Giuliano, 1995; Smart and Klein, 2018a). However, this study has shown that measures of TCS neglect accessibility benefits in the form of destination-utility gains, which means a TCS-based policy evaluation underestimates the value of accessibility and hence without basis weakens the importance of accessibility-promoting land-use and transport policies. Joining some European scholars who argued for an accessibility-based cost-benefit analysis (Geurs et al., 2010; Martens and Di Ciommo, 2017), I thus call for a shift from a TCS-based to an accessibility-based land-use and transportation policy evaluation.

CHAPTER III

Beyond VMT Reduction: Toward a Behavioral Understanding of the Built Environment and Travel Behavior Relationship

3.1 Introduction

A large and growing number of studies in the planning literature examine the relationship between the built environment and travel behavior (Cervero and Kockelman, 1997; Ewing and Cervero, 2001, 2010; Stevens, 2017). The main focus of these studies is to examine whether and how much compact development can reduce car use. Empirical evidence showing that compact development significantly reduces driving is interpreted as supporting the application of land-use and transportation policies that promote compact development as effective measures to reduce driving (Zhang, 2004). Such evidence also supports the promotion of compact development—as opposed to the prevailing pattern of low-density, auto-oriented growth—as a major planning goal. On the other hand, when empirical evidence suggests that auto travel is not reduced as a result of compact-development strategies, researchers question the use of compact-development strategies to reduce vehicle miles traveled (VMT) and traffic congestion (Salomon and Mokhtarian, 1998; Stevens, 2017). Some researchers further interpret such evidence as suggesting a lack of transportation benefits from compact-development policies (Crane, 1996a) or suggesting that travel impacts are not relevant when considering among alternative land-use planning policies (Gordon and Richardson, 1997).

Implicit in these interpretations is a notion that views only a reduction in VMT as a positive travel impact of compact-development, which I term as a VMT-reduction-based view of transportation benefits in this study. Under this view, compact development results in transportation benefits only if it leads to a reduction in VMT and decreases in VMT's contributing factors such as car-trip frequency, probability of driving, and car-trip length. In other words, if a compact-development strategy does not reduce VMT, it is viewed as not having any transportation benefit. As I will discuss below, this view nonetheless ignores other forms of travel benefits (termed here as destination-utility gains), which are often associated with additional travel that may be induced by compact development. Consequently, representing the transportation benefits of compact-development policies with measures of VMT reduction would lead to a significant underestimate. In cases where a compact-development policy leads to substantive destination-utility gains but little VMT reduction (i.e., the potential VMT-reduction was overwhelmed by induced travel), a VMT-reduction-based evaluation would unfairly weaken the importance of this policy.

When compact development policies lead to little to no VMT reduction, it is possible that the potential VMT reduction from compact development was overwhelmed by its trip-inducing effect. That is, these policies can shapes car travel in opposite directions, i.e., it causes both a reduction in car use in some cases (e.g., individuals take shorter trips than before since destinations are closer) and an increase in driving in other cases (e.g., individuals take more car trips than before since the cost of each trip is lower), which results in a small net effect. When individuals drive less in response to compact development, they get the time-plus-money savings in travel costs associated with any reduced VMT. When individuals respond to accessibility increases (i.e., lower cost of travel to potential destinations) by driving more, the associated travel costs must have been compensated by the resulting trip benefits (termed here as destination-utility gains).

Van Wee et al. (2011) elaborates on these ideas by imagining an “intervention” that shrinks a certain region to 25% of its original size. If all travelers keep their original travel patterns, there would be a 50% reduction in their travel expenses and a 50% reduction in VMT. However, basic economic principles suggest a reduction in the generalized cost of travel (to valuable destinations) would induce individuals to travel more, which means at least some travelers would react to the intervention by making more trips or traveling to more remote but more desirable destinations (e.g., a more remote job with a better pay). The resulting destination-utility gains from the additional travel must be no less than the costs associated with it, otherwise, individuals would not make the additional travel in the first place. In the end, the net effect of the hypothesized intervention on VMT is uncertain, but the reduction, if any, is would be less than the theoretical maximum (50%).

The hypothetical case presented by van Wee suggests that compact development can result in travel-cost savings that are associated with VMT reduction but also destination-utility gains that are associated with induced travel, but the latter is rarely recognized by the existing built-environment and travel-behavior studies. While induced travel from compact development has long been recognized by the existing literature (e.g., Crane, 1996a; Crane, 1996b), few researchers have considered the destination-utility gains associated with it. Since reduced driving can result in a range of benefits such as greenhouse-gas emission reduction, less energy consumption, and traffic congestion relief, emphasizing VMT reduction as a major policy goal is understandable. Nevertheless, VMT reduction is not the only transportation goal, and it should not be regarded as a measure of transportation benefits since the core purpose of transportation is not to reduce VMT but to provide accessibility (Merlin, 2015;

Levine et al., 2019). The destination-utility aspects of accessibility benefits should not be ignored when evaluating accessibility-enhancing land-use and transportation policies.

The van Wee hypothetical case further suggests that VMT can be a misleading indicator of the built-environment and travel-behavior relationship. When compact development leads to accessibility increases (i.e., reducing the cost of travel to potential destinations), it can have two countervailing effects on VMT. It reduces VMT consumption when the resulting accessibility gains translate into travel-cost savings, and it induces additional car travel if a seek for destination-utility gains makes individuals take more trips and switch to more remote but more desirable destinations. Therefore, individual behavioral responses that lead to either increases or decreases in VMT may both indicate a gain in travel benefits from compact development. To accurately measure the travel benefits of compact-development strategies, one must decompose VMT changes into VMT decreases associated with travel-cost savings and VMT increases associated with destination-utility gains. Therefore, the common practice of using a net VMT change measure to indicate the travel impacts of compact development in the built-environment and travel-behavior studies greatly underestimates its actual travel benefits.

This study criticizes the VMT-reduction-based view of transportation benefits in the built-environment and travel-behavior literature. I make the case here that although induced travel leads to higher VMT consumption, they result in accessibility gains that can promote consumer welfare and can sometimes advance equity goals. To gain a comprehensive understanding of the travel impacts of compact development, I further propose a behavioral framework of built-environment and travel-behavior interaction that describes the mechanisms through which compact development shapes travel outcomes. I discuss the behavioral motivations underlying different travel decisions and demonstrate that changes of observed travel-behavior outcomes in either direction (e.g., an increase or decrease in trip length) may indicate a gain in transportation benefits offered by compact development. To augment these theoretical discussions, I further design an empirical strategy to test the idea that compact development has countervailing effects on car travel. I use household travel survey data in the Puget Sound and Southeast Michigan region to conduct the empirical analysis.

The results support my arguments by showing the following: 1) transit accessibility (measure of compact development used in this study) is positively associated with trip frequency by all modes in both regions; 2) transit accessibility is positively associated with car-trip frequency in the Southeast Michigan model but it is negatively associated with car-trip frequency in the Puget Sound Region. These findings suggest that compact development has countervailing effects on car trips, including a trip-generation effect that increases driving and a modal-shift (from driving to alternative travel modes) effect that reduces driving, and whether or not car-trip frequency decreases depends on if the latter outweighs the former.

3.2 Literature review

3.2.1 Empirical studies of the built-environment and travel-behavior relationship

Studying the influences of the built environment (also termed as land use) on travel-behavior started in the 1980s and emerged as a popular research topic in the planning literature in the 1990s (Boarnet, 2011). The motivation behind these studies was mainly to reduce the prevailing low-density, and auto-oriented development patterns and the excessive auto use associated with them. Following Cervero and Kockelman (1997), researchers often described the land-use variables with a list of "D-variables," including density, diversity, design, destination accessibility, distance to transit, and so on; and the commonly examined travel-behavior variables included VMT, mode choice, trip frequency, and trip length (Ewing and Cervero, 2010). Among the travel-behavior outcome variables, VMT attracts the most policy interest since it is the aggregate measure of auto travel that is directly related to traffic safety, air quality, energy use, and other social harms associated with auto use. Also, many other outcome variables such as auto ownership, mode choice, trip frequency, and trip length can be considered as contributing factors to VMT. Consequently, policy debates surrounding the built-environment and travel-behavior relationship usually center on whether and how much built-environment factors affect VMT.

Recent work in this literature focuses on answering if the association between the built environment and travel is causal and on estimating the magnitude of the causal effect. On the "correlation versus causation" question, the problem of residential selection has attracted great attention (Mokhtarian and Cao, 2008; Cao et al., 2009). Residential sorting refers to the fact that individuals who prefer certain travel modes are more likely to live in the type of neighborhoods that support such travel preferences; hence, the significant travel-behavior difference across neighborhoods may not reflect the "treatment effect" of compact development, but rather the inherent preference differences among the residents. As a result, it is commonly believed that statistical models must control for residential-sorting effects in order to produce an accurate estimate of the influence of built-environment characteristics on travel.

With only a few exceptions (Chatman, 2009; Lin et al., 2017), most studies found that failing to control for residential sorting would lead to a overestimate of the treatment effect of built-environment variables on travel. Notably, however, some researchers have questioned the policy relevance of the residential-sorting issue (Levine, 1998; Næss, 2009; Chatman, 2014). In their view, estimating the independent, causal effect of the built environment on travel addresses the wrong policy question (what would be the impact of built-environment changes on a randomly selected group of individuals?) in the first place. In reality, most land-use interventions are likely to affect travel-behavior changes on a self-selected group (those who are more favorable of the changes) instead of a random group of individuals. Therefore, both residential-choice and travel changes should be considered as policy effects of land-use interventions, and controlling for residential self-selection would lead to an underestimate of these effects.

Several review studies sought to synthesize the empirical studies of the built-environment and travel-behavior connection with a single elasticity measure (Ewing and Cervero, 2001, 2010; Stevens, 2017). Notably, a recent meta-regression analysis of the built-environment and travel-behavior relationship found that the elasticity of VMT with respect to density (the most commonly used measure of compact development) was -0.22 (Stevens, 2017). This study triggered a heated debate on whether or not an elasticity value of -0.22 is sufficient to warrant policies to promote compact development (see responses from various scholars on the Stevens study in the 2017 Spring and Summer issues of the *Journal of the American Planning Association*). While this finding made Stevens conclude that compact development has a small influence on driving, a position shared with authors of two responses (Manville, 2017; Knaap et al., 2017), other scholars interpreted the same result as suggesting substantive travel benefits from compact development (Ewing and Cervero, 2017; Handy, 2017; Nelson, 2017). Implied in this debate is an assumption that views only a reduction—not any increases—in driving as a desirable impact of compact development on travel, and I will examine this assumption in detail below.

3.2.2 A VMT-reduction-based view of transportation benefits

This implicit VMT-reduction-based view of transportation benefits is reflected in the use of empirical criterion to evaluate the transportation benefits resulting from land-use and transportation strategies. Most existing built-environment and travel-behavior studies adopt the following empirical approach: travel-behavior outcome variables such as VMT, mode choice, trip frequency, and trip length are regressed on a list of built environment variables while controlling for a list of demographic and socioeconomic variables and occasionally some travel-related attitudinal variables. The functional form of the statistical model usually takes the following form:

$$y = \beta_0 + \boldsymbol{\beta}_1 * \mathbf{X} + \boldsymbol{\beta}_2 * \mathbf{Z} + \epsilon, \tag{3.1}$$

where y is the travel-behavior outcome variable, $\mathbf{X}$ is a vector of built-environment variables, $\mathbf{Z}$ is a vector of control variables, the β terms are coefficients to be estimated ($\boldsymbol{\beta}_1$ is the main focus), and ϵ is the error term. Here, the estimates (sign, statistical significance, and magnitude) of $\boldsymbol{\beta}_1$ are usually interpreted as indicating the travel impacts of land-use and transportation strategies that promote compact development, which consequently serve as the main empirical criterion to evaluate the desirability of these policies.

Consider the case where y is VMT or its contributing factors such as car ownership, probability of driving, car-trip frequency, and car-trip length and $\mathbf{X}$ is a vector of built-environment variables (e.g., transit accessibility) that measure compactness. Under a VMT-reduction-based view of transportation benefits, to establish scientific evidence of positive travel impacts from compact-development policies requires the estimates of $\boldsymbol{\beta}_1$ to be both negative and statistically significant. In addition, a larger magnitude of the estimated coefficients is considered as signaling more transportation benefits from compact development. By contrast, if the coefficient estimates of $\boldsymbol{\beta}_1$ are positive or are negative but statistically insignificant, researchers usually interpret such results as suggesting a lack of significant positive impacts of compact development on travel.

These assumptions are widely shared among researchers who study the relationship between the built environment and travel behavior. For example, based on the model results that suggested job accessibility had no significant correlation with employment status and commuting distance, Hu (2017) concluded that living in places of higher job accessibility had no economic benefits for the lowest-income, long-term residents in Los Angeles. The 2017 Stevens study and the debate on it provide another illustration of these assumptions. As discussed above, the main focus of the debate on Stevens (2017) centered on whether an elasticity of -0.22 (the elasticity of VMT with respect to population density) sufficiently warrants land use and transportation policies that promote compact development. If the magnitude of this elasticity were estimated to be larger than one (a threshold commonly used to determine if the relationship should be called as elastic or inelastic), Stevens would be most likely to label the travel benefits of compact development as substantive rather than "small."

A VMT-reduction-based evaluation of compact-development policies would be valid if compact development affects driving in one direction only, that is, compact development only leads to a reduction but not an increase in driving. If this is the case, the magnitude and statistical significance of the $\boldsymbol{\beta}_1$ coefficient would be a clear and direct indicator of the impact of compact development on driving and the resulting travel benefits. On the other hand, if compact development also induces additional car travel, the $\boldsymbol{\beta}_1$ coefficient would be a measure of compact development's net effect on driving-related outcomes rather than a measure of its VMT-reducing effect only. In theory, compact development would indeed make people take more car trips since it lowers the price of car travel to reach potential destinations, although finding the empirical evidence to show this car-trip-generation effect is challenging because car-trip frequency is an outcome of not only this effect but also a modal-shift effect (i.e., compact development tends to make alternative modes to driving more feasible and attractive). The existing literature has shown that accessibility is positively associated trip frequency by all travel modes (Hanson and Schwab, 1987; Ewing and Cervero, 2001; Ding et al., 2016; Cordera et al., 2017), but few studies have empirically examined if accessibility-promoting compact-development policies have a car-trip-generation effect.

A handful of researchers have recognized that compact development may induce additional travel by car, suggesting that individuals may respond to compact development by taking more car trips and traveling to more remote destinations (Crane, 1996a; Crane, 1996b; Handy, 2017). In particular, Crane (1996a, 1996b) applied microeconomic theory to provide a detailed explanation of why and how accessibility improvements (i.e., lower distance to access destinations) resulting from land-use policies can lead to more car trips. Nevertheless, like most contributors to the built-environment and travel-behavior literature, these scholars did not consider travel responses that lead to additional car travel as positive travel impacts of accessibility-promoting compact-development strategies.[1] For example, in their critiques of the Stevens study, several scholars have pointed out that compact development has additional benefits beyond those associated with reduced driving, such as increased transit use, reduced energy consumption, and stronger economic vitality (Ewing and Cervero, 2017; Knapp et al., 2017). These additional benefits, however, can be considered as ancillary benefits associated with reduced driving. Moreover, since these researchers did not recognize that there are potential travel benefits associated with induced car travel from compact development due to lower cost of reaching destinations, a VMT-reduction-based view of transportation benefits is still implied.

3.2.3 Induced travel and destination-utility gains

I now present empirical evidence that challenges the VMT-reduction-based view of transportation benefits. Specifically, I review empirical evidence on induced travel, which supports the notion that when compact development leads to little to no VMT

[1]For example, Crane (1996b) proposed a utility-maximizing framework for individual travel, where the consumer welfare was a function of the number of trips taken by each mode. Thus, it is implied that if land-use strategies increase car trips, there would be gains in individual consumer welfare. However, writing at a time when transit- and pedestrian-oriented design were often proposed as strategies to reduce auto use, Crane only considered VMT reduction—while ignoring potential gains in consumer welfare—as the transportation benefits from these strategies.

reduction, it is often not because compact development has no travel impacts but because the potential VMT reduction from it is overwhelmed by induced travel. I further argue that induced travel associated with compact development should be interpreted as signaling gains in transportation benefits for the affected population.

Induced travel, especially induced travel resulting from transportation investments, is a well-studied topic in the literature. The theory behind induced travel is intuitive: When transportation investments (e.g., highway expansions) reduce the generalized (time plus money) cost of travel (to potential destinations), individuals are likely to respond by traveling more. Recent reviews of induced travel associated with road investments have found strong evidence that new transportation capacity generated by these investments would induce additional VMT (Cervero and Hansen, 2002; Noland and Lem, 2002). VMT increases can result from both short-run behavioral changes such as a switch to driving from other travel modes, longer trips, increases in trip frequency and long-run effects such as increases in household auto ownership levels and longer trips resulting from residential and employment relocation (Hills, 1996).

Like road investments, compact-development development strategies such as infill development and transit-oriented development that lead to accessibility gains (i.e., lowered cost of traveling to destinations) can also induce additional travel. Some studies examined the travel-inducing effect of land-use changes, but the outcome of interest is primarily trip frequency or household trip-generation rate rather than VMT. Ewing and Cervero (2001) summarized early work on this topic and concluded that the empirical evidence on the correlation between trip frequency and the built environment was mixed (Hanson and Schwab, 1987; Ewing et al., 1996; Thill and Kim, 2005). More recent work on this topic often showed a significant and positive association between accessibility and trip frequency (Merlin, 2015; Ding et al., 2016; Cordera et al., 2017). Some related studies discussed the association between urban spatial structure and trip distances—particularly commuting distance, and they suggested that while compact-development strategies may reduce trip length in the short run, in the long run such reduction tend to disappear due to household/business relocation (Gordon and Richardson, 1994; Giuliano and Small, 1993). These long-run effects can be considered as induced travel.

The theoretical foundation for induced travel and its associated benefits is the basic principle in transportation that views travel as a derived demand (Bonavia, 1936), which means that travel is usually taken to reach destinations rather than to enjoy travel *per se*. The derived-demand nature of travel suggests that travel is inherently a cost, and so if a trip is taken, the cost associated with it must be compensated by the utility that individuals gain from interacting with the destination. Consider van Wee's hypothetical case that I described in the introduction again. When compact development leads to lower cost of traveling to potential destinations, individuals can potentially drive less; for example, shrinking a region to 25% of its original size can potentially lead to a 50% reduction in the travel of this region's residents. If the observed VMT reduction is less than this theoretical maximum (50% of the original VMT consumption), it indicates that a lowered cost of access has made some travelers drive more frequently and/or drive to more remote destinations; and the destination-utility gains associated with the additional driving must outweigh the time and money costs associated it.[2] An example of trip-frequency increases due to compact-development strategies is that infill development brings a new movie theater that makes nearby residents increase movie-viewing trips. Related, the opening of a wholesale store (e.g., Walmart) can attract away customers who used to frequent nearby local stores.

Therefore, when compact-development policies induce additional travel by car,

[2]Here I reach the same conclusion as van Wee (2011) did, but the underlying reasoning process is different. van Wee reached his conclusion by applying the theory of constant travel-time budget (Van Wee et al., 2006), and I mainly replied on the idea that travel by nature is a derived demand.

individuals must have gained travel benefits in other forms (i.e., destination-utility gains) that can compensate for the time-plus-money costs associated with the induced car travel. But these destination-utility gains are largely unrecognized. Considering the various environmental harms (e.g., degrading air quality and contributing to climate change) associated with driving, it is understandable that researchers tend to hold a negative view on any induced travel by car. Nevertheless, since the purpose of transportation is first and foremost to facilitate individual access to resources and opportunities rather than to reduce driving, VMT reduction should not be regarded as the only goal of transportation and land use planning (Merlin, 2015; Levine et al., 2019). Many policies (such as highway expansion to rural areas) result in significant travel benefits in the form of destination-utility gains for the affected population but simultaneously lead to VMT increases (Levine et al., 2019). And providing car access to the poor would contribute to aggregate VMT consumption, but car access can bring to them higher employment prospects and better options of social services.

Induced travel from compact development can also serve social-equity goals. Findings of a recent study on auto use of the poor and transit-oriented development implied the equity dimension of induced travel: While low-income families drove significantly more when being displaced from rail-station areas, their auto use did not change much (plausibly due to induced auto travel) when moving to these areas (Chatman et al., 2017). Moreover, studies of travel behavior consistently found that low-income households drove less than higher-income ones (Pucher and Renne, 2003; Blumenberg and Pierce, 2012), which is as much by constraint as by choice. For example, empirical studies on activity space showed that lower-income households have a smaller size of activity space compared to other income groups (Hanson, 1982; Manaugh and El-Geneidy, 2012; Chen and Akar, 2016). While a smaller activity-space size means less driving, it is also associated with a higher level of social exclusion and segregation (Schönfelder and Axhausen, 2003; Wong and Shaw, 2011). If compact development expands the destination choice of low-income population and makes them drive more (to interact with valuable destinations), it results in gains in social welfare at the expense of VMT increases.

3.3 Toward a behavioral understanding of the built-environment and travel-behavior interaction

The above analysis suggests that compact development can result in at least two distinct forms of travel benefits: travel-cost savings associated with reduced driving and destination-utility gains associated induced travel. Given that the two forms of travel benefits shape driving in opposite directions, the relationship between compact development and VMT is not a straightforward one. Rather, it depends on the complex interactions of many factors. To unravel these interactions, I propose a behavioral framework of the built-environment and travel-behavior that describes the mechanisms through which compact development shapes travel behavior (see Figure 3.1).

This framework is mainly informed by two insights from the existing literature. First, the microeconomic foundation for the built-environment and travel-behavior connection lies in the idea that the built environment can alter the price of travel to potential destinations (Boarnet and Crane, 2001). Second, travel is derived from the demand for interacting with destinations (Bonavia, 1936), and so it is through shaping the demand for accessing destinations (the decision of which destination to interact with and at what frequency) that built-environment changes influence travel behavior.

In this framework, compact development affects travel behavior by first reducing the cost of travel to potential destinations. A lower price of travel to potential destinations would lead to changes in individual travel decisions (i.e., trip generation, mode

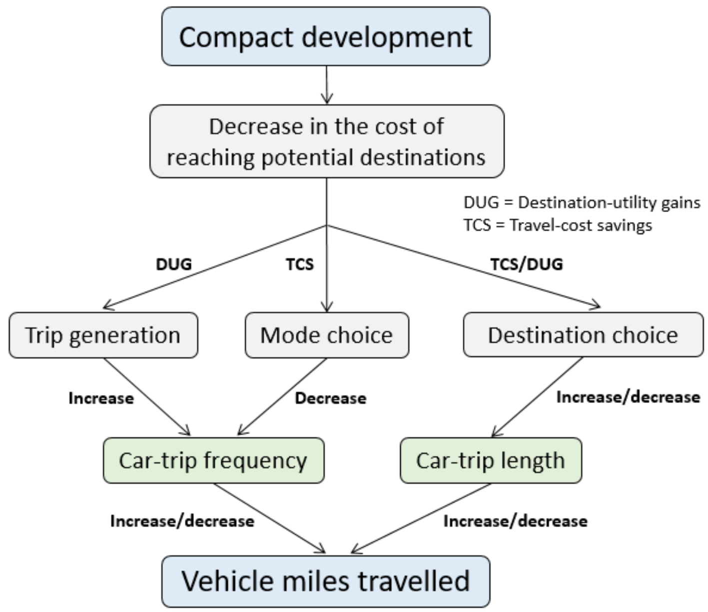


Figure 3.1: A behavioral framework of how compact development shapes travel

choice, and destination choice) that first affect car-trip frequency and car-trip length and consequently VMT. How exactly these linkages play out is primarily determined by individual preferences for the two distinctive types of travel benefits: travel-cost savings and destination-utility gains. A desire for travel-cost savings would make individuals react to compact-development strategies by switching to cheaper travel modes (i.e., non-driving modes) and by choosing closer destinations brought by these strategies. By contrast, a preference for destination-utility gains would make individuals react to compact development by taking additional trips (by all travel modes) and traveling to more desirable but more remote destinations (these destinations were not chosen before because of travel time or money constraints).

Consequently, compact-development policies would have two countervailing effects on driving-related travel outcomes (i.e., car-trip frequency and car-trip length). Individuals who value travel-cost savings are likely to reduce car-trip frequency and length, whereas people who prefer destination-utility gains may increase them. In a given empirical study, the observed changes in VMT or car-trip frequency/length is thus a product of the two countervailing effects. Either effect results in travel benefits for the impacted population—for example, car-trip generation leads to destination-utility gains whereas a modal shift from driving to alternative modes indicates travel-cost savings; therefore, to fully measure the transportation benefits of compact development one needs to decompose the two countervailing effects from observed travel-behavior changes and to sum up the respective benefits associated with them. Using observed travel-behavior changes to indicate the transportation benefits of compact-development policies would lead to a significant underestimate. This is equivalent to the mathematical case where the correct answer is to sum up the absolute values of two numbers with opposite signs but the student summed up the two numbers directly.

The above analysis raises doubt on the common empirical approach adopted by the built-environment and travel-behavior literature to examine the travel impacts of land-use and transportation policies. Notably, the fact that compact development can change travel-behavior outcomes in both directions suggests that the beta coefficients (i.e., the $\boldsymbol{\beta}_1$ discussed above) which indicate the association between a built-environment variable and driving-related travel outcome have no simple interpretation. The interpretation facilitated by a VMT-reduction-based view of travel benefits is problematic because small and insignificant estimates of $\boldsymbol{\beta}_1$ do not necessarily mean that the examined compact-development policies have no travel impacts. In many cases, these policies could have resulted in substantive decreases in VMT but the potential VMT reduction was overwhelmed by induced travel. The $\boldsymbol{\beta}_1$ blurs the impact that compactness has on the utility people receive from their environment.

In sum, the behavioral framework proposed here sheds light on the mechanisms underlying the built-environment and travel-behavior relationship by showing how and why compact development shape travel. To gain a comprehensive understanding of the travel impacts of compact-development strategies thus requires researchers to carefully examine the behavioral motivations behind individual travel changes. They should examine how much the accessibility gains resulting from compact-development strategies translate into travel-cost savings versus destination-utility gains. A plausible empirical method for this purpose is the "logsum" consumer-welfare evaluation approach, which is based on the random-utility discrete-choice modeling technique (Niemeier, 1997; De Jong et al., 2007; Geurs et al., 2010).[3]

3.4 Empirical analysis

To strengthen the theoretical arguments raised above, I further conducted an empirical analysis of the built-environment and travel-behavior relationship. The main purpose of this empirical analysis is to test the idea that compact development has countervailing effects on car travel, that is, it can lead to both a reduction and an increase in driving. An ideal empirical approach to achieve this purpose would be a longitudinal study that collects information on the before-and-after travel behavior of individuals who are affected by accessibility-promoting compact-development policies. Ideally, this longitudinal study should also collect information on individual travel preferences, needs, and constraints that can shed light on the behavioral motivations behind each individual's travel-behavior changes.

Faced with some practical constraints, however, I implemented the following empirical strategy. First, since I have no access to a longitudinal sample that records the before-and-after travel-behavior information, I used cross-sectional datasets instead, i.e., the regional household travel survey data from the Southeast Michigan region and the Puget Sound region. Moreover, since a comprehensive evaluation of the compact development and VMT connection involves too many intermediate steps,

[3] Logsum is a measure of consumer surplus in the context of a random utility choice model. It means the expected utility that individuals can derive from a choice when choosing among a set of alternatives, which has been proposed as a measure of accessibility (Ben-Akiva and Lerman, 1979). Since the logsum measure can link different choices such as the travel-mode and destination choice, it has been widely applied to the practice of integrated land-use and transport modeling (Eliasson and Mattsson, 2000; Yao and Morikawa, 2005).

for convenience I focus on how compact development shapes nonwork trip frequency (i.e., all nonwork trips and nonwork trips by car) only. Empirical evidence that shows compact development induces additional car trips and also promotes a shift from driving to alternative modes would be sufficient to substantiate the main ideas raised in this paper. Finally, for simplicity I examined the relationship between nonwork trip frequency and one built-environment characteristic (transit accessibility) only.

3.4.1 Conceptual framework

I developed two sets of statistical models: a nonwork trip-generation model that estimates if transit accessibility is associated with more personal nonwork trips (i.e., sum of trips by all travel modes), and a nonwork car-trip-generation model that estimates if transit accessibility is associated with more nonwork trips by car. These models can be expressed as following:

$$AllNonworkTrips = a_1 + b_1 * TransitAccessibility + c_1 * Controls + \epsilon_1, \quad (3.2)$$

$$NonworkTripsByCar = a_2 + b_2 * TransitAccessibility + c_2 * Controls + \epsilon_2. \quad (3.3)$$

Here, b_1 indicates the trip-generation (for all travel modes) effect of transit accessibility, and b_2 indicates the net effect of car-trip increases due to trip generation and car-trip decreases due to modal shift.

The two models do not measure the car-trip-inducing and car-trip-reducing effects directly, but when considered together, their model outputs can shed light on if these effects exist and the relative strength of them. For example, if the model outputs show that both b_1 and b_2 are positive and significant, it means that higher transit accessibility generates additional car trips and that this trip-generation effect outweighs the modal-shift effect. If b_1 are positive and significant but b_2 are negative and significant, it means that higher transit accessibility generates additional car trips but this trip-generation effect is smaller in magnitude compared to the modal-shift effect. If b_2 are not significantly different from zero, it means that the two countervailing effects have counteracted each other, which makes the net effect on car-trip frequency very small. On the other hand, if b_1 is negative or if it is not significantly different from zero, it means that transit accessibility does not induce travel This finding would not support my hypothesis.

3.4.2 Data

The main data sources included the 2015 Southeast Michigan Council of Government (SEMCOG) regional household travel survey data collected by SEMCOG and the 2014-2015 Puget Sound regional household travel survey data collected by Puget Sound Regional Council (PSRC). The travel-survey data were used to construct the demographic and socioeconomic control variables, together with the travel-behavior outcome variables (all personal nonwork trips and personal nonwork trips by car). The unit of analysis is thus an individual, and I only analyze data on adults. SEMCOG and PSRC also kindly provided the skim matrix, which contains the estimated travel time for each origin-destination zone-pair. I also obtained employment statistics from the Longitudinal Employer-Household Dynamics (LEHD) data, which is available from the US Census Bureau website. The skim matrix and the LEHD data were used to calculate the transit-accessibility measure.

In this study, transit accessibility is defined as the potential to interact with opportunities distributed across the region via the transit mode. I calculated transit accessibility at the traffic analysis zone level, using a common form of the gravity model developed by Hansen (1959). This gravity-model measure of accessibility assumes that the amount of interaction between an origin zone i and a destination j is positively related to the number of opportunities at the destination zone but is inversely related to the travel cost (time) between the zones. The accessibility to opportunity type n by car for location i can thus expressed as

$$A_{in} = \sum_{j} O_{jn} exp(-\beta T_{ij}), \tag{3.4}$$

where:

A_{in} is the accessibility index to opportunity type n by car for location i;

O_{jn} is the attractiveness factor for opportunity type n based on the number of these opportunities in destination zone j;

exp denotes the base of the natural logarithm;

β is the impedance factor that measures the friction of distance, a higher value of which makes distant opportunities contribute to the accessibility index to a lesser degree;

T_{ij} is the travel time by car in minutes between location i and j.

I used the total number of jobs to indicate the number of opportunities located at a destination zone, a common practice for accessibility measurement. Table 3.1 presents the description and the descriptive statistics of the variables examined in the models.

Table 3.1: Descriptive profile of the dependent and independent variables

Variable code	Description	Puget Sound		Southeast Michigan	
		Mean	Standard deviation	Mean	Standard deviation
Dependent variables					
NonWkAllTrip	Total personal trips (by all modes) taken on survey day	0.65	0.83	0.77	0.42
NonWkCarTrip	Total personal car trips taken on survey day	0.58	0.78	0.55	0.5
Independent variables					
TransitAcc	Transit accessibility index (first principle component derived from transit accessibility to all jobs, and shoping and service destinations)	0.07	0.84	0.03	0.69
Employed	Dummy variable that indicates if a person is currently employed (including self-employed)	0.56	0.5	0.6	0.49
College	Dummy variable that indicates if a person has a bachelor degree or above	0.52	0.5	0.47	0.5
LowInc	Dummy variable that indicates if a household's annual income is $25,000 or less	0.1	0.31	0.13	0.34
HighInc	Dummy variable that indicates if a household's annual income is $100,000 or above	0.39	0.49	0.33	0.47
Age35	Dummy variable that indicates if a person's age is 35 or below	0.4	0.49	0.22	0.41
Age65	Dummy variable that indicates if a person's age is 65 or above	0.16	0.37	0.21	0.41
Female	Dummy variable that indicates if a person is a female	0.51	0.5	0.52	0.5
Own	Dummy variable that indicates if a household lives in an owner-occupied housing unit	0.65	0.48	0.83	0.38
SingleFamily	Dummy variable that indicates if a household lives on single-family housing	0.61	0.49		
VehPerAdult	The number of vehicles in a household divided by its number of adults	0.93	0.5	1.08	0.54
DriverLicense	Dummy variable that indicates if a person has a driver's license	0.79	0.41	0.93	0.25

Table 3.2: Trip frequency and Car-trip frequency models in Puget Sound

Variable code	**NonWkAllTrip**		**NonWkCarTrip**	
	Coefficient	z-value	Coefficient	z-value
Main variables of interest				
TransitAcc	0.01	2.51***	-0.01	-2.06**
Control variables				
Constant	-0.31	-5.81***	-0.98	-15.54***
Employed	-0.19	-7.29***	-0.21	-6.84***
College	0.08	3.24***	-0.01	-0.50
LowInc	-0.01	-0.35	-0.10	-2.19**
HighInc	-0.01	-0.43	0.02	0.79
Age35	0.02	0.65	-0.02	-0.51
Age65	-0.03	-0.99	0.03	0.84
Female	0.03	1.60	0.08	3.22***
SingleFamily	-0.01	-0.47	0.14	4.74***
VehPerAdult	0.04	1.59	0.23	9.62***
DriverLicense	0.01	0.43	0.25	5.96***
Observations (N)	12643		12643	
Log-likelihood at convergence	-12251.90		-10931.60	
Log-likelihood (Null Model)	-12292.50		-11114.08	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

Table 3.3: Trip frequency and Car-trip frequency models in Southeast Michigan

Variable code	NonWkAllTrip		NonWkCarTrip	
	Coefficient	z-value	Coefficient	z-value
Main variables of interest				
TransitAcc	0.03	3.68***	0.02	2.18**
Control variables				
Constant	-0.95	-8.51***	-1.48	-12.24***
Employed	-0.66	-31.03***	-0.65	-28.80***
College	0.14	7.60***	0.12	6.09***
LowInc	0.09	3.17***	0.01	0.38
HighInc	-0.08	-3.83***	-0.09	-4.12***
Age35	-0.40	-14.44***	-0.35	-12.04***
Age65	0.25	11.45***	0.30	12.81***
Female	0.05	2.63***	0.07	3.96***
Own	-0.02	-0.74	0.12	3.69***
VehPerAdult	0.06	3.69****	0.10	5.68***
DriverLicense	0.39	9.36***	0.79	14.48***
Observations (N)	20120		20120	
Log-likelihood at convergence	-20284.89		-19028.29	
Log-likelihood (Null Model)	-21631.74		-20391.85	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

3.4.3 Model outputs

Since the model outcomes (trip frequency) are count variables, I applied a negative binomial model for estimation. To ensure consistency and to enhance the robustness of model results, I specified models with an almost identical functional form for the two study regions.[4] Table **??** and Table **??** presents the model outputs for the two study regions respectively.

I now discuss the coefficient estimates, and I report statistical significance at the

[4]The only difference is in one control variable. I used a dummy variable that indicates if a person lives in a single-family housing unit for the models in the Puget Sound region but a dummy variable that indicates if a person lives in an owner-occupied housing unit for the models in the Southeast Michigan region. The SEMCOG data have no information on what type of housing unit (i.e., if it is a single-family unit) a respondent lives in. The two dummy variables are often highly correlated and so the coefficient estimates on them are likely to be close.

0.05 level. On transit accessibility, the main variable of interest in this study, I obtained the following results. First, the coefficient estimate was positive and significant in the nonwork trip frequency model (i.e., b_1 in Equation 3.3) for both regions. Therefore, as I have hypothesized, transit accessibility indeed has a trip-generation effect. Second, in the nonwork car-trip frequency model, while the coefficient estimate ((i.e., b_2 in Equation 3.3)) was positive and significant for the Southeast Michigan region, it was negative and significant for the Puget Sound region. Considered together with the coefficient estimate of b_1, this means that the modal-shift effect—a shift from driving to alternative mode—outweighed the car-trip-generation effect for Puget Sound, yet for Southeast Michigan it was the other way around.

The fact that Puget Sound has a much stronger modal-shift effect from transit-accessibility increases than Southeast Michigan is not surprising. First, at locations of high transit accessibility, parking is likely to be more expensive and constrained in Puget Sound (especially within the city of Seattle) than that in Southeast Michigan. This makes driving become a less attractive option. Moreover, alternative modes to driving are more available and feasible in Puget Sound than in Southeast Michigan. The traffic analysis zones (TAZ) in Puget Sound have a mean Walk Score of 38, and the mean Walk Score of TAZs in Southeast Michigan is 27. Also, the transit services are better in Puget Sound. For example, the AllTransit perform score rankings developed by the Center for Neighborhood Technology ranked the Puget Sound region at the 30th place and the Southeast Michigan region at the 129th place, respectively, among all U.S. metropolitan planning organizations.[5]

These results thus verify that idea that accessibility-promoting compact-development policies shape auto use in both directions. In addition to the potential VMT-reduction effect which has been the main focus of research efforts in the current literature, these policies also induce additional car trips. In the end, whether or not a policy results

[5] These rankings are available at https://alltransit.cnt.org/rankings/.

in a reduction in VMT depends on if its VMT-reduction effect is greater than the travel-inducing effect. The finding that the association between transit accessibility and nonwork car-trip frequency is negative in the Puget Sound model but is positive in the Southeast Michigan model illustrates this point.

I now briefly discuss the coefficient estimates on the control variables, and I focus on statistically significant (at the 0.05 level) variables only. I first discuss the Southeast Michigan models and compare the results with those of the Puget Sounds models, and I go through the nonwork-trip frequency model first and then the nonwork-car-trip frequency model. Everything else being equal, individuals who are female, 65 years old or above, college educated, and poor (i.e., having an annual household income below $25,000) took more nonwork trips. Moreover, having better access to a personal vehicle and having a driver's license were positively associated with nonwork-trip frequency. By contrast, being employed, having an annual household income of $100,000 or above, and being 35 years old or younger had a negative correlation with the number of nonwork trips that an individual took.

The coefficient estimates for the nonwork-trip frequency and nonwork-car-trip frequency largely agreed with each other with two exceptions. First, while people from low-income households, on average, took more nonwork trips, they did not take more nonwork trips by car. This suggests that the nonwork-travel needs of the poor are often fulfilled by non-driving modes, a finding consistent with results from the national household travel survey (Pucher and Renne, 2003; Blumenberg and Pierce, 2012). In addition, while people living in an owner-occupied unit did not seem to make more nonwork-trips, they tend to make more nonwork trips by car. This is likely because neighborhoods filled with single-family, owner-occupied housing units often lack access to public transit and are less walkable.

Results of the Puget Sound models were in general consistent with those of the Southeast Michigan models. In both the nonwork-trip frequency and nonwork-car-trip frequency models, there was not a single variable which had opposite signs and were at the same time statistically significant across the two regions. However, many of the significant variables in the Southeast Michigan models were insignificant in the Puget Sound models. For example, only two control variables (excluding the constant term) were significant in the nonwork-trip frequency model for Puget Sound, compared to nine significant variables in the Southeast Michigan model. In addition, the following dummy variables that were significant in the nonwork-car-trip frequency model for Southeast Michigan turned out to be insignificant in the Puget Sound region: being college-educated, having an annual household income of $100,000 or above, and is aged no more than 35 years or no less than 65 years.

3.5 Conclusion

Empirical studies on the built-environment and travel-behavior relationship seek to inform two different but interrelated policy questions. One is if compact-development policies such as smart growth and transit-oriented development can be used as an effective environmental policy tool to reduce driving, and the other is if planners can justify the promotion of these policies on the basis of their transportation merits. Underlying the second policy question is a notion that equates the transportation benefits of compact development to VMT reduction, a view termed here as a VMT-reduction-based view of transportation benefits.

This paper argues against this VMT-reduction-based view in the context of compact-development policy evaluation. I make the case that accessibility increases resulting from compact development may not only reduce driving but also induce additional car travel and that both directions of influence are associated with travel benefits for the affected population. My arguments are grounded on two basic theories. One is the basic economic principle which suggests that the consumer demand for an elastic good rises as its price declines; that is, as compact development lowers the cost of travel to potential destinations, it tends to make people travel more. The other is the idea that travel is in general derived from the demand to reach destinations, which means that travel is usually a cost that individuals pay to gain the utility of interacting with desirable destinations. Thus when compact development induces people to make additional travel by car, the associated time-plus-money costs must be compensated by the resulting destination-utility gains. These theoretical arguments are corroborated with an empirical analysis that examines the relationship between transit accessibility and nonwork trip frequency (by all modes and by car) in two U.S. regions.

This study highlights the fact that compact-development strategies often lead to transportation benefits in the form of destination-utility gains. I argue that when measuring the transportation benefits of compact-development strategies, planners should quantify both the potential travel-cost savings associated with less driving and the potential destination-utility gains resulting from induced travel. Very few contributors to the built-environment and travel-behavior studies have recognized travel benefits in the form of destination-utility gains. The van Wee (2011) theoretical piece discussed above is one of the exceptions. And to my knowledge Merlin (2015) is the only published empirical study which was motivated by the idea that compact-development policies have benefits beyond TCS reduction, and Merlin examined if compact development promotes nonwork out-of-home activity participation.

More broadly, this study suggests that there are potential tensions between the fundamental aims of the planning profession (Campbell, 1996). When compact-development policies induce additional car travel, the resulting destination-utility gains can enhance consumer welfare and even advance equity goals (e.g., when low-income people expand activity space). Nevertheless, increases in driving, regardless of the sources, result in environmental harms. Therefore, when compact-development policies induce travel and thus lead to travel benefits in the form of destination-utility gains, it is essentially promoting the goals of economic efficiency and social equity at the expense of environmental protection. How to navigate these tensions and develop policy policies is challenging, just like when planners face the dilemma of whether or not to support car-ownership subsidies to the poor (Grengs, 2010; Blumenberg and Pierce, 2017; Smart and Klein, 2018b). Ideally, planners can develop policies that can serve multiple aims, that it, policies that lead to both reductions in personal VMT and gains in destination utility for the impacted population. The empirical results from the Southeast Michigan region and the Puget Sound region suggest that planners should in particular advocate compact-development strategies that can promote the use of non-driving modes.

CHAPTER IV

Preference versus Constraint: The Role of Walkability, Transit Accessibility, and Auto Accessibility in Residential Location Choice

4.1 Introduction

Accessibility, commonly defined as the potential (from a location) to interact with opportunities/activities distributed across space, is the fundamental service that a transportation and land use system provides to people. As a central indicator of locational advantage and a major performance measure of the land use and transport systems, accessibility has become a fundamental topic in a variety of fields such as urban planning, geography, economics, sociology, and transportation engineering. Numerous studies in the planning literature have provided theoretical arguments and empirical evidence to establish accessibility as a major planning goal (Wachs and Kumagai, 1973; Handy, 2005; Grengs, 2015; Martens, 2016; Levine et al., 2019).

How to properly define and measure accessibility is a challenging topic that researchers revisit time after time (Ingram, 1971; Morris et al., 1979; Handy and Niemeier, 1997; Miller, 1999; Geurs and Van Wee, 2004; Páez et al., 2012; Grengs, 2015; Cascetta et al., 2016). Depending on the study purpose, researchers have developed different types of measures at various levels of complexity, ranging from a simple distance-based measure (e.g., distance to a transit stop) to more comprehensive and sophisticated measures such as gravity-based potential measures and utility-based logsum measures (Geurs and Van Wee, 2004). When measuring accessibility, a major distinction that analysts frequently make is the level of accessibility by different travel modes, such as walkability (accessibility by walking), transit accessibility, and auto accessibility. This distinction is made to mainly serve two purposes: first, to guide the investment decisions of a specific type of transportation infrastructure by identifying the spatial disparity of accessibility levels supported by a given travel mode; second, to identify the accessibility gap between individuals with access to a car and carless individuals, that is, to gauge the disparity between auto accessibility and transit accessibility (Grengs, 2010).

Nonetheless, researchers have generally overlooked another important issue: How individuals value different types of accessibility (i.e., walkability, transit accessibility, and auto accessibility) differently? Walkability, transit accessibility, and auto accessibility can bring both similar and different benefits to a household. A higher level of any type of accessibility may result in two similar benefits: it can help a household reduce travel cost (when the destination to be reached is given) and/or increase choice (when the destination is unknown or whether or not to make the trip or not is undecided in the first place). For example, a higher level job accessibility—more jobs reachable within a given period of time by a travel mode—may not only reduce the commute cost of household workers but also provide a higher chance of finding employment for unemployed household members (Ihlanfeldt and Sjoquist, 1991). On the other hand, walkability, transit accessibility, and auto accessibility can also provide distinctive benefits. For example, more walkable neighborhoods often encourage individuals to exercise more and thus bring health-related benefits (Frank et al., 2006). Transit accessibility provides the benefit of option value, which means that individuals can have the future option to travel by transit even if they are not using it now

(Roson, 2001; Laird et al., 2009). Auto accessibility, by allowing households access to a larger quantity and variety of destinations than transit accessibility and walkability, often means a higher degree of personal freedom (Martens, 2016).

From a policy and practice perspective, assessing the relative value of each type of accessibility matters for at least three reasons. First, it can shed light on the debates on transportation funding allocation and guide transportation spending by incorporating the preferences ("opinions") of the general public. In the U.S., there is a long-standing debate on the fair allocation of transportation funding between highways/roads versus transit; and in everyday transportation investments decision-making, policymakers and transportation planners often need to decide if they should invest to improve pedestrian/cycling facilities or public transit. In the absence of information regarding what type of accessibility that local residents prefer (and hence without an accessibility-based evaluation procedure informed by such knowledge), these decisions are often made on the basis of a conventional cost-benefit analysis that is under increasing criticism (Geurs et al., 2010; Martens and Di Ciommo, 2017).

Second, understanding the varying degree to which individuals value different types of accessibility can help isolate their independent effects. At a given location, its walkability, transit accessibility, and auto accessibility are usually highly correlated since they all share the land use component (i.e., the destinations reachable from a location are fixed). Therefore, when accessibility shapes an outcome, one often cannot discern the effect comes from which type of accessibility, which inhibits the design of clear and targeted policies. Consider the case of transit-oriented development, a major accessibility-promoting policy. While the conventional wisdom is that housing built in transit-oriented development attracts residents to use transit and thus allow them to reduce car use and transportation spending, recent empirical evidence suggests that households were often drawn to transit-oriented development, not because of transit accessibility (Chatman and Noland, 2014; Smart and Klein, 2018a) but rather other location attributes such as walkability (Urban Land Institute, 2015; Canadian Home Builders Association, 2015). These findings suggest that in many cases, planners should prioritize their efforts in promoting pedestrian-oriented development instead of transit-oriented development, especially when the latter requires much more public funding investments. Therefore, a better understanding of what types of accessibility individuals prefer can lead to clearer and more desirable policymaking.

Third, the valuation of different types of accessibility contributes to a thin body of literature regarding accessibility evaluation. Existing accessibility studies have mostly examined accessibility with objective measures (i.e., measures that do not take into account individual-specific evaluation of accessibility benefits).[1], with much less attention paid to understand how individuals perceive and value accessibility. Two exceptions include the use of utility-based logsum approach for accessibility appraisal (De Jong et al., 2007; Niemeier, 1997; Geurs et al., 2010) and the comparison between individuals' perceived accessibility and the objective accessibility they actually received (Scott et al., 2007) Notably, studies in the latter category generally found that large discrepancies exist between individuals' perceived accessibility and objective accessibility they actually received (Curl et al., 2015; Ryan et al., 2016; Lättman et al., 2018). This finding highlights the importance of conducting more accessibility evaluation research in order to validate the findings derived from objective-accessibility-based studies and to refine the path of accessibility research.

Local context is likely to play an important role in the evaluation of different types of accessibility. Basic economic theory suggests that the relative value (price) of a product depends on the demand and supply for it, and there is no exception of such rule to accessibility. A higher level of preference/demand for a certain type of accessibility would drive its value (price) up, as well as a shortage of supply for this

[1]This is understandable because land use/transportation systems are not built to satisfy individual travel needs at specific times, but to provide a capacity that can satisfy the aggregate demand for interaction among all individuals

type of accessibility. Residents living in different regions may prefer/demand accessibility at a varying degree, and the supply of walkability (walkable neighborhoods), transit accessibility (housing units with good access to destinations via transit), and auto accessibility (housing units with good access to destinations via cars) can vary significantly across regions. Therefore, the findings on accessibility evaluation are most likely to be context-dependent, and yet the existing knowledge regarding how context matters in this regard is very limited in the literature because most studies focus on one study area only.

In most U.S. cities/regions, walkable neighborhoods are scarce, transit accessibility is also in short supply but to a less degree than walkability, and auto accessibility is relatively high across most locations given the ubiquity of highways and public roads. This is a general statement, and there are large variations in accessibility across many U.S. regions (Levine et al., 2012; Owen et al., 2015). For instance, one usually believes that the Puget Sound region excels the Atlanta region in walkability and transit accessibility. The existence of these variations means that an inter-regional comparison of accessibility evaluation can not only validate some existing findings but also shed light on how regional differences shape the study findings.

In light of the above analysis, this study presents a multi-region study on how households value walkability, transit accessibility, and auto accessibility in residential location choice. Three regions were studied, including Atlanta, Puget Sound, and Southeast Michigan. Each of these regions is a typical example of a type of U.S. regions distinguished by their economic structure and urban form/structure. The Atlanta region is a booming Southern region featured with sprawling low-density, and auto-dependent development, and only in recent years it has started to emphasize more on mixed-use, transit-oriented development (notably the development of the BeltLine). With the prosperous city of Seattle serving as the urban core, Puget Sound is a monocentric-city region with a diverse housing stock. It is consist of housing units ranging from very low accessibility (in rural areas) to high levels of accessibility in all dimensions (at central locations). Finally, the Southeast Michigan region is a slowly growing Midwest region with a declining central city—the city of Detroit. While it is less sprawled out than the Atlanta region and some parts of it are well served by public transit (central parts of Southeast Michigan and the Ann Arbor area), most neighborhoods are not very walkable. The study results thus can have a higher degree of generalizability, and examining the similarities and differences across regions can generate further insights on how regional context matters for accessibility evaluation.

I built residential location choice models (multinomial logit models) for these three regions, focusing on examining how households value walkability, transit accessibility, and auto accessibility in the decision process by interpreting the coefficient estimates on these variables. The control variables include housing affordability, school quality, and other neighborhood characteristics such as population density, median household income, median household size, and racial compositions. The approach presented in this study is only one of the possible methods to evaluate the importance of accessibility and its various dimensions. Two other commonly used approaches include a logsum method for accessibility appraisal as demonstrated by Geurs et al. (2010) and a hedonic price modeling approach that assesses the contribution of accessibility to the property price.

The main findings that can be inferred from the model outputs are: 1) Walkability is a major consideration in residential location choice for Puget Sound households but not for Atlanta and Southeast Michigan households, possibly because of the adequate supply of walkable neighborhoods in Puget Sound and a dearth of them in the other two regions; 2) Transit accessibility is an important determinant of household residential choice across all three regions; 3) Auto accessibility does not appear to have a significant impact on household residential location choice; 4) Overall, location accessibility plays an important role in residential location choice, although its impact is modest compared to other factors such as commuting cost and housing affordability.

4.2 Literature review

4.2.1 The definition and measurement of accessibility

Accessibility is a widely used term in the literature that may convey a variety of meanings, and so it is helpful to clearly define it first. This study views accessibility to be the defining indicator that distinguishes compact development from sprawled growth, which measures *the extent to which the land-use and transport systems of a location enable individuals to interact with potential destinations or activities* (Hansen, 1959). To measure this multifaceted concept, the most comprehensive measurement should include four essential components: a *land use* component that reflects the value of spatially distributed opportunities, a *transportation* component that describes the impedance from an origin to reach a destination via a specific travel mode, an *individual* component that reflects the attributes of a particular person's ability and willingness to take advantage of the potential opportunities, and a *temporal* component that reflects temporal constraints such as individual's schedule constraint or the availability of opportunities at different times of the day (Geurs and Van Wee, 2004). Given the focus of specific studies, however, researchers have only emphasized a subset of these components; for example, when the focus is on long-term transportation and land use planning, the most commonly used accessibility measures—a cumulative-opportunity measure or a gravity-based measure (Hansen, 1959)—generally ignore the individual and temporal component (Handy and Niemeier, 1997; Levine et al., 2019).

A narrow definition of accessibility, which equates accessibility to (savings in) commuting cost, has prevailed the residential location choice literature. This notion of accessibility originates from classical residential location models developed by Alonso (1964), Muth (1969), Mills (1972), which simplifies the process of housing decisions into a trade-off between housing cost and commuting cost. The underlying factor for this trade-off relationship is accessibility: more accessible locations can allow households to save commuting cost, which would in turn capitalize into the site rent that households need to pay. Since accessibility itself is invisible and site rent is influenced by a host of factors besides accessibility, the differences in commuting cost are commonly used to indicate the accessibility differentials across locations.

This commuting-cost-based view of accessibility is commonly—arguably even more frequently than the definition used in this study—applied in planning and policy discussions. For example, when predicting how changes in gas costs or transportation technologies would affect residential location patterns, researchers usually examine the intermediate changes in commute costs instead of gravity-based accessibility measures (e.g., Evans, 1973; Zhang and Guhathakurta, 2018). Moreover, the phenomenon of "excess commuting," which indicates the differences between the observed amount of commuting and a theoretical minimum amount of commuting suggested by a given job-housing relationship (Hamilton and Röell, 1982; White, 1988), is often interpreted as indicating a weakening role of commuting (and hence accessibility) in location decisions (Giuliano and Small, 1993; Yang, 2008).

Nonetheless, since there are other destinations or activities that a household would want to interact with besides the workplace of its household members, savings in commuting-cost is an incomplete measure of accessibility. This suggests that a mere focus on commuting cost may undermine the role of accessibility in location decisions and hence the policy importance of transportation and land use planning. Beside commuting-cost reduction, other aspects of accessibility benefits may include reduced transportation cost to nonwork destinations, freedom of choice, option value (e.g., of having access to transit), and spillover effects (Martens, 2016; Levine et al., 2019).

While these additional benefits are often invisible and hard to quantify, in theory, they may be captured by potential-based accessibility measures such as cumulative opportunities or gravity-based measures (Hansen, 1959); and the empirical soundness of these measures have been verified by studies on a variety of subjects such as employment growth, housing price, and labor productivity (Chatman and Noland, 2014; Giuliano et al., 2012; Osland and Thorsen, 2008). These additional accessibility benefits (beyond commuting-cost reduction) can be revealed with positive and significant coefficient estimates on the potential-based accessibility measures in a residential location choice model that also includes commuting cost as an independent variable.

4.2.2 Place-based versus people-based accessibility measures in residential location choice models

In the previous section, I argue that potential-based accessibility measures are more comprehensive than commuting cost in capturing the accessibility of a location. However, in residential location choice models, analysts often (unexpected) found that commuting cost had much higher explanatory power than potential-based accessibility measures (see, e.g., Lee et al., 2010; Srour et al., 2002). In fact, in some cases, researchers found that while some potential-based accessibility measures (especially auto accessibility measures) had insignificant or even negative coefficient estimates, commuting cost was highly significant in the same model (e.g., Zolfaghari et al., 2012).[2] Therefore, studies that used commuting cost or other household-specific accessibility measures (e.g., distance to social contacts) tended to conclude that accessibility played a significant role in household residential decisions whereas studies that used potential-based accessibility measures often concluded that accessibility played a minor role.

[2]Previous research usually interpreted this finding as suggesting that accessibility was trumped by other considerations when people decided where to live or that there were high levels of negative externalities associated with locations of high (auto) accessibility.

This debate can be explained by an analysis of the influence of place-based and people-based accessibility in residential location choice models. Here, place-based accessibility refers to the level of accessibility to all potential destinations whereas people-based accessibility indicates the level of accessibility to household-specific destinations (e.g., the workplace of a household member). Potential-based accessibility measures are place-based, and commuting cost and other household-specific accessibility measures such as distance to social contacts are people-based. For a given household, the level of accessibility it actually receives (i.e., people-based accessibility) at a location can be very low even though the level of place-based accessibility at this location is quite high. For example, while the downtown provides a very high of accessibility to all potential employment opportunities (i.e., place-based accessibility is high), it also incurs very high commuting costs for a household whose members work at the airport (i.e., people-based accessibility is low).

For a given household that is choosing where to live, it usually seeks to maximize the accessibility to a limited set of destinations that matter to itself (e.g., the workplace of a household worker and family and friends) rather than to maximize the accessibility to all potential destinations. Therefore, in a residential location choice model in which the unit of analysis is a household, it is natural that people-based accessibility measures such as commute cost, distance to social contacts (Guidon et al., 2019), and utility-based measures (Lee et al., 2010) can explain household choice better than place-based accessibility measures (Guo and Bhat, 2007; Chen et al., 2008).

In practical applications of residential location choices, both people-based and place-based accessibility measures may be included in the model to account for the impact of different dimensions of accessibility. If a higher model fit is the goal, the modeler should try his best to take into account the accessibility to all important destinations matter to each household to construct a set of people-based accessibility measures. Besides, since the analyst can never know all the important destinations to a given household, including some place-based accessibility measures may help capture the impacts of accessibility to other potential destinations that were not accommodated by people-based accessibility measures. Another factor that influences the inclusion of place-based versus people-based accessibility measures in residential location choice models is policy relevance. In the context of land use and transportation planning, place-based accessibility can be viewed as the direct policy outcome as it measures the overall performance of the land use/transportation system, whereas people-based accessibility is the indirect outcome for a particular individual. In practice, researchers often examine place-based accessibility when studying land-use and transportation policies (Grengs et al., 2010), and they analyze people-based accessibility when the key concern is transport justice (Martens, 2016).

4.2.3 Household preference for different types of accessibility in residential location choice model

Households may be drawn into "compact" neighborhoods (as oppose to low-density, auto-oriented bedroom communities) because of the different types of accessibility they provide. For example, a multi-worker household may have a preference for neighborhoods with high auto accessibility in order to reduce the aggregate commute time for all households, a carless household may strongly prefer to live at a place with high transit accessibility, and a senior household may particularly like walkable neighborhoods. Often, a compact neighborhood excels in all three dimensions of accessibility, but it is not always the case. For example, in many suburban locations where auto accessibility is relatively low compared to places closer to the central city, they provide relatively high transit walkability and accessibility.[3]

A clear understanding of household preferences for different types of accessibility

[3] In the metro Southeast Michigan context, many neighborhoods in the city of Ann Arbor, Michigan fits into this description.

can help guide land-use and transport policymaking and planning practices. A recent study on the impact of transit-oriented development on travel behavior illustrates this point (Chatman, 2013). The common assumption on rail-based transit-oriented development is that individuals move in there to take advantage of the accessibility provided by the rail infrastructure. Somewhat surprisingly, however, Chatman (2013) finds that household auto ownership and auto travel were mainly explained by local and subregional density (i.e. walkability and job accessibility by bus) rather than rail access. This finding suggests the need for planners to broaden efforts to develop dense and mixed-use neighborhoods at locations beyond areas adjacent to rail stations. In the current study context, Chatman's study implies that efforts to promote transit accessibility for individuals who actually prefer walkability would be misguided and ineffective. In addition, even if households prefer all types of accessibility, there is a practical need to understand the relative importance of each to help planners prioritize their efforts.

The existing studies regarding household preferences for different types of accessibility can be grouped into two broad categories. One body of literature examines how accessibility impacts property values, and these studies typically apply a hedonic-price modeling approach. The main relevant insights from these studies can be summarized as follows: 1) Accessibility is in general found to have a positive and significant effect on property (land or housing) values (Debrezion et al., 2007; Bartholomew and Ewing, 2011; Pivo and Fisher, 2011; Song and Knaap, 2003; Osland and Thorsen, 2008); 2) The impacts of transit walkability and accessibility appears to be stronger than auto accessibility, which may result from the fact that public roads are much more ubiquitous than transit services and pedestrian-oriented infrastructure (Lin and Cheng, 2016); 3) The magnitude of accessibility's impact on property values varies with certain contextual factors such as distance to the central business zone and neighborhood composition in terms of property types, socioeconomic status, and physical-design characteristics, which means that there are significant intraurban sub-market effects (Adair et al., 2000; Bartholomew and Ewing, 2011; Li et al., 2015; Du et al., 2012).

The second body of literature examines the role of accessibility in residential location choice. By shedding light on how different factors of a housing unit shape household preferences for it, this literature can be viewed as providing the theoretical foundation for the relationships discovered in a hedonic price model. The study approach commonly applied by this body of work is discrete choice modeling or attitude surveys that ask respondents to report/rank their preference for different attributes of a housing unit or residential neighborhood. Besides confirming some findings of the hedonic-price studies, this literature generates several additional valuable insights: 1) while accessibility is commonly found to be a significant factor in residential choice, its importance is secondary to dwelling-unit attributes and socioeconomic and demographic characteristics (Zondag and Pieters, 2005; Lee et al., 2010); 2) There is great preference heterogeneity for accessibility, for example, lower-income people tend to have a stronger preference for transit accessibility (Liao et al., 2015; Hu and Wang, 2017); 3) There is significant unmet demand for compact neighborhoods (in terms of high walkability and transit accessibility) in many U.S. metropolitan regions (Levine and Frank, 2007; Frank et al., 2019). Nonetheless, existing studies have barely touched on the issue of how individuals value auto accessibility, transit accessibility, and walkability differently.

4.2.4 Differences in stated preference versus revealed behavior

Studies that examine household preferences in residential location choice are either based on revealed-behavior (often called revealed-preference) data or stated-preference data. The former reflects true market behavior whereas the latter are assertions of preference or responses to hypothetical situations. Revealed-preference data are commonly believed to have high reliability and validity, but they are only suitable for short-term forecasting with small departures from the current state of affairs (Louviere et al., 2000); on the other hand, despite the potential bias of stated-preference data, they may be more suitable for long-term predictions with structural shifts in the current market conditions.

Significant discrepancies exist in empirical studies that use stated-preference data versus revealed-preference data to examine household preferences for accessibility. Discrete-choice models that are based on stated-preference data consistently showed that accessibility has a strongly significant and positive effect on residential location choice (Kim et al., 2005; de D. Ortuzar et al., 2000). This finding is consistent with the responses to attitude surveys, as survey respondents often reported accessibility factors to have a high priority in their housing decisions (e.g., Myers and Gearin, 2001; Chatman, 2009). By contrast, while some discrete-choice models that examine the actual residential location choice of households reported similar results (Lee et al., 2010), other revealed-preference studies estimated accessibility variables to be marginally significant (Ben-Akiva and Bowman, 1998) or even to have a negative sign (Guo and Bhat, 2007; Zolfaghari et al., 2012; van de Vyvere et al., 1998). Among the different types of accessibility, it appears that the coefficient estimates for transit-accessibility measures are in general significant and positive but those for auto-accessibility measures are mixed; and to my knowledge no residential location choice models have incorporated comprehensive walkability measures (i.e., cumulative-opportunity or gravity-based measure that considers both the land use and transport systems).

These discrepancies may result from two possible sources. First, it may be the effect of real-life constraints on revealed preferences. In the process of actual housing consumption, it is common that individuals' preference for accessibility was trumped by other household priorities due to the lack of choice. For example, in a housing market where compact neighborhoods are scarce, households whose first priority is school quality (but second priority is accessibility) often have to live in a low-density, auto-oriented neighborhood to pursue good schools (Levine et al., 2005). In stated preference surveys, however, survey respondents may not recognize the real-life choice constraint. Related, the ubiquity of accessibility may also explain the difference. For instance, although people think auto accessibility to be important, it can not end up being a determining factor since the ubiquity of road infrastructure in the U.S. facilitates high levels of auto accessibility at almost all locations. These explanations imply that the regional context, particularly in terms of the diversity of choice offered by its housing stock, are likely to shape individuals' housing choice behavior (i.e., revealed preference for accessibility) to a large degree. Therefore, comparing residential location choices across different regions can shed light on how altering land use and transportation planning practices would impact results on the valuation of accessibility in household residential decisions.

4.3 Modeling framework

The state-of-art method for residential location choice modeling is the logit-family of models, which is built on the random-utility maximizing theory (Anas, 1982). Households are assumed to choose a residential location by weighing the attributes of each available alternative, such as housing cost, dwelling characteristics, accessibility, school quality, and neighborhood characteristics, and by choosing the alternative that maximizes utility. Theoretically, this process can be modeled by constructing an household-specific choice set for each household (to ensure that only housing units considered by each household are modeled) and specifying a random utility function for each alternative (i.e., each alternative can have its own utility function).

However, there are several practical challenges to a modeler that result in several compromises to this ideal approach. First, often the residential location choice is modeled at a zone level instead of a housing-unit level because the available home-location information for the studied population is often at a zone level only. For example, the household regional travel survey data released to the public often report respondents' home location at the level of traffic analysis zone, census tract, or block group. This means that one can only use aggregate-level housing characteristics such as median home value and median lot size to represent individual housing-unit features such as its sale price and lot size in the modeling process. As long as the housing units within a zone is reasonably homogeneous, however, Lerman (1975) have demonstrated that one can still obtain consistent estimates of parameters describing how households perceive the dwelling units themselves.

Second, since modelers usually do not know which housing units (zones) that a particular household had considered or which criteria that it applied to screen out possible housing units (zones), the modelers had to arbitrarily decide a credible non-chosen alternative choice set for each household. The common practice is to set up a choice-set pruning procedure based on plausible affordability criteria and behavioral rules. For example, one can assume that a low-income household would not be able to afford an expensive neighborhood and that one is only willing to commute within a certain distance or time threshold (Lerman, 1975; Levine, 1998). Deciding these pruning rules is an empirical question that lacks clear answers in the literature (Zolfaghari et al., 2012), and so researchers often set up rules based on common sense or observed data patterns. In the process, it is unavoidable that some feasible alternatives would be eliminated whereas some infeasible ones would remain. In the context of a multinomial logit model, however, it is believed that it is better to exclude feasible alternatives from the final choice set than to include infeasible ones into it (Lerman, 1975).

Finally, a sampling of the available alternatives (i.e., results of a choice set pruning process) is usually applied in order to reduce the computational burden of model estimation. Since the number of housing units (zones) that each household can possibly choose from can be extremely large (thousands or even millions), modeling the choice probability for each available alternative is a formidable task. To circumvent this issue, one can estimate a choice model with a random sample of the non-chosen alternatives as the coefficient estimates would be consistent with those obtained from a model with the full choice set (McFadden, 1978).

Carefully conducting a choice-set pruning procedure represents the best efforts that a modeler can do to build a realistic residential location choice model. In practice, however, the non-chosen alternative choice set specified for each household is still most likely to be different from the actual residential location choice set that it evaluates when it decides where to live. This is because the decision process of every household is likely to be very different, but the modeler usually has little information regarding the unique considerations of each household and how it prioritizes these considerations. The resulting non-chosen alternative choice set constructed from a modeler-defined pruning procedure is thus usually much larger than the actual choice set that each household evaluates, since in practice households often face (or set up on their own) more constraints than what the modeler assumes. For example, while a modeler may assume that a rural household has considered the possibility of living in a walkable neighborhood in the central city, in reality, this may not be true if the scarcity of walkable neighborhoods in the region precludes walkability from the consideration of this household.

The differences between the modeler-defined alternative choice set versus the actual alternative choice set have implications for the coefficient estimates—or to state more precisely, the appropriate interpretations of these coefficients—in a residential location choice model. In the existing literature, the coefficients of a residential location choice model are often interpreted as reflecting household preferences. However, since the modeler-defined choice set often contains infeasible alternatives (i.e., alternatives that a given household cannot choose in reality due to constraints introduced by the market conditions or household-specific situations) for many households, the estimated coefficients are likely to be a product of both household preferences and market constraints; therefore, desirable attributes such as accessibility tend to have a downward bias in their coefficient estimates when market or individual constraints exclude accessible neighborhoods from the actual choice set of household residential location decisions. This is especially true for U.S. regions that have a undersupply in walkable and transit-accessible neighborhoods (Levine et al., 2005).

4.4 Model specification, data, and measurement

4.4.1 Model specification

This study applies the commonly used multinomial logit model to examine household residential location choice at a traffic analysis zone (TAZ) level (McFadden, 1978). There are a total of 2024, 2811, and 3700 TAZs in the Atlanta, Southeast Michigan, and Puget Sound region, respectively. In a multinomial logit model, the utility a TAZ j for a household i U_{ij} is assumed to be made of a systematic component V_{ij} and a random component ϵ_{ij}. The former is a function of observed attributes whereas the latter is an unobserved error term which is assumed to be identically and independently distributed across alternatives and across observations following a type I extreme distribution. Under these assumptions, it can be deduced that the probability of a TAZ j being chosen by household i is:

$$\mathrm{P}_{ij} = exp(V_{ij}) / \sum_{j} exp(V_{ij}). \tag{4.1}$$

This systematic utility component V_{ij} can be modeled as

$$\mathrm{V}_{ij} = f(\mathbf{A}_j, \mathbf{C}_j, \mathbf{S}_j, \mathbf{N}_j, \mathbf{H}_i, n_j), \tag{4.2}$$

where:

$\mathbf{A}_j$ is a vector of accessibility variables measured at TAZ j;

$\mathbf{T}_{ij}$ is a vector of travel-cost savings variables which measures the expected travel-cost savings household i can gain from TAZ j;

$\mathbf{C}_j$ is a vector of housing affordability variables measured at TAZ j;

$\mathbf{S}_j$ is a vector of local-services variables measured at TAZ j;

$\mathbf{N}_j$ is a vector of neighborhood-environment variables which measure the built environment and socioeconomic characteristics of TAZ j;

$\mathbf{H}_i$ is a vector of household-related variables that measures the demographic and socioeconomic characteristics of household i;

n_j is a size-correction term that corrects for the fact that a TAZ with more housing units would have a higher probability of being selected than a TAZ with fewer units (Lerman, 1975).

Note that $\mathbf{H}_i$, which do not vary across alternatives, can not enter into the model directly and so these variables were interacted with other location variables. For example, I have interacted a school-quality variable with a dummy variable which indicates if a household is a high-income household with children to test if higher-income households with children are more likely to live in neighborhoods with better schools. Most residential location choice models that model household choice at a zone level are variations of this function form, but the exact list of independent variables may differ across studies in accordance to data availability and research focus. Table **??** presents the independent variables specified in this study.

Moreover, as discussed above, the modeler needs to construct a credible non-chosen alternative choice set for each household (i.e., conduct a choice-set pruning procedure). In this study, the following decision rules were applied to exclude alternatives from a given household' choice set:

1) Delete TAZs with less than five housing units of the household's chosen tenure;

2) Delete TAZs with less than five housing units of the household's chosen property type (i.e., single-family property versus other types of properties);

3) Delete TAZs that would require the household's female worker to drive more than 60 minutes for a one-way work trip;

4) If the household has children, delete TAZs for which the proportion of households with children is smaller than 1%;

5) If the household resides in a TAZ where the proportion of households of a certain race is above 95%, delete TAZs for which the proportion of households of that race is below 5%.

Performing this procedure excluded some TAZs (e.g., TAZs with no residential units) from the choice set of all sample households, and so only a total of 2018, 2612, and 3596 TAZs in the Atlanta, Southeast Michigan, and Puget Sound region, respectively, were retained for further analysis. Also, applying these decision rules may eliminate some feasible alternatives from a household's choice, but this would not affect the properties of the parameter estimates in a multinomial logit model thanks to its independence of the irrelevant alternative property (McFadden, 1978). Also, a small number of observations may have selected an alternative that violates these rules. These observations were deleted to avoid the logical inconsistency of having households choose an alternative which is deemed unavailable. Since the number of alternatives (thousands of TAZs) in each household's choice set was still formidably large, I randomly sampled 29 alternatives from this subset of feasible alternatives in order to reduce the computational burden.

4.4.2 The data

This study builds residential location choices for three US regions–Atlanta, Puget Sound, and Southeast Michigan. The main data source used is the recent regional household travel survey data collected by the local metropolitan planning organizations, i.e., Atlanta Regional Commission (ARC) 2011 survey, Puget Sound Regional Council (PSRC) 2014-2015 survey, and Southeast Michigan Council of Government (SEMCOG) 2015 survey. These metropolitan planning organizations also kindly provided me with the skim matrix which contains the estimated travel time for each origin-destination zone-pair, which was used to calculate the auto and transit accessibility measures. Other input data used to construct the model database include census data—Census Transportation Planning Products (CTPP), American Community Survey (ACS), and Longitudinal Employer-Household Dynamics (LEHD), school quality data extract from the GreatSchools.org API, Walk Score data extracted from the Walk Score.com API, and crime-rate data (obtained from Southeast Michigan Council of Government but not the other two regions).

It should be noted that none of the household travel surveys sampled a statistically representative population from their respective region. To correct this sampling bias, a common approach is to apply sample weights, i,e, assigning each population group (e.g., segmented by place of residence or income levels) a weight which equals to the ratio of the probability of it being randomly selected to the share of this population group in the household travel survey. Nonetheless, specifying sample weights in a residential location choice model with a large alternative choice set is challenging since there is no available software or open-source packages for this purpose. I thus constructed a more statistically representative sub-sample by performing a geographically stratified (at the Census County Subdivision level) sampling procedure on the original survey sample, that is, for each region I drew a total of 1,200 observations (a sub-sample) from the full survey sample by sampling in proportion to each Census County Subdivision's share of households in the region. Although this procedure does not fully address the sampling bias issue, it corrects for over- and under-sampling in certain County Subdivisions.

Essential information extracted from these regional household travel surveys includes the following: a household's home address, the work address of each household worker, basic socioeconomic characteristics of the household (i.e., household income, housing tenure, household size, and life-stage status).[4] The CTPP data are special tabulations of American Community Survey (ACS) data at the TAZ level, based on which I constructed the following variables: number of housing units, median household income, median household size, proportion of households with children, proportion of single-family properties, proportion of non-single-family properties, proportion of rental properties, proportion of owner properties, and proportion of households in each of the following racial/ethnic categories: White, Black, Hispanic, Asian, and other. Since the CTPP data does not contain information regarding median home value, median rent, and number of owner-occupied/rental units, these variables were constructed based on the ACS 5-year estimates data; and to convert the ACS data from the census block-groups level to the TAZ level, an area-weighted average approach (i.e., proportional allocation based on area size) was used. A similar conversion was made on the LEHD data since LEHD summarizes employment data by industry at the census block level instead of at the TAZ level.

GreatSchools.org kindly provided me with an API key to query their school-rating data for each K-12 school in the United States. The GreatSchools summary rating for each school, which ranges from 1 to 10, takes into account five factors, including test scores, student or academic progress, college readiness, equity (relative performance of disadvantaged students), and student enrollment in advanced courses.[5] To construct

[4] Unlike ARC and PSRC, SEMCOG did not collect the home- and work-location information from the survey respondents. Therefore, I estimated this information based on the following procedure. The TAZ at which the majority of the household members reported to start their day was assumed to be the home location. In addition, the destination TAZ at which a household worker reported to arrive for a "Work at fixed work location" trip was assumed to be the work location; If a worker has multiple jobs, the job that he worked for the longest hours was assumed to be the primary job and the TAZ where this job locates was assumed to be the work location.

[5] A more detailed description of the school-rating calculation methodology can be found at https://www.greatschools.org/gk/summary-rating/. Official data sources—including the overall school index constructed by the Michigan Department of Education, the school achievement in-

a school-quality variable for each TAZ, I first decided which school district that each TAZ (its centroid) belongs to and then assigned the GreatSchools rating of the nearest *public* school within that school district to the TAZ. I obtained the Walk Score for each TAZ (its centroid) using the Walk Score API. Walk Score ranges from 0 to 100, which measures the potential from a location to reach nine categories of amenities such as grocery stores, restaurants/bars, and coffee shops by walking. The calculation of Walk Score only accounts for destinations within a 30-minute walk (1.5 miles), and a distance-decay function is applied to give destinations closer to the location of interest a higher weigh.[6]

Table 4.1 presents a description of the independent variables used in this study and their data sources. The ARC 2011 survey, PSRC 2014-2015 survey, SEMCOG 2015 survey collected valid data from a total of 6789, 10278, 12394 households in total.[7] After removing incomplete responses, I randomly sampled 1200 households from the remaining sample to fit the residential location choice models. I did not use the full sample because of computational limitations, and using a subset of the full sample shall not affect the parameter estimates. I performed data processing in R and fit the multinomial location choice model using the *choicemodels* Python library developed by the UrbanSim team (Waddell, 2002). Table 4.2 shows the mean and the standard deviation of the independent variables.

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dex data generated by the Washington State Board of Education, and the Georgia school grades report data available at the Governor Office of Student Achievement—were also evaluated but these school-quality data did not result in better parameter estimates on the school-quality related variables.

[6]A more detailed description of the Walk Score methodology can be found at https://www.walkscore.com/methodology.shtml

[7]The PSRC 2014-2015 survey was administrated in two waves, one in 2014 and the other in 2015, resulting in a total of 8340 responses. However, the 2015 sample contains 2850 households who also participated in the 2014 survey, and so the total number of households surveyed was 6789. For the panel sample—households who responded to the survey twice, I used their responses in 2015 for this study.

Table 4.1: Description of independent variables and data sources

Variable code	Level of measure	Variable description	Data source
Transportation-related variables			
Walkability	Zonal	The Walkscore (0-100) of the centroid of a given TAZ	Walkscore.com API
TransitAccess	Zonal	Transit accessibility index (first principle component derived from transit accessibility to employment and to nonwork destinations)	LEHD, skim matrix
AutoAcc	Zonal	Auto accessibility index (first principle component derived from auto accessibility to all jobs, and shopping and service destinations)	LEHD, skim matrix
AutoTT	Household and zonal	Sum of the auto commute time from each household worker's work TAZ to a given TAZ	Regional household travel survey, skim matrix
Housing-affordability variables			
HsgCost_HHInc	Household and zonal	Median value (for owners) or median rent (for renters) at a given TAZ divided by household income	ACS, regional household travel survey
Local-service-related variables			
SchoolQual	Zonal	Average school rating of a given TAZ	Greatschools.org API
SchoolQual_HInc	Household and zonal	Average school rating of a given TAZ interacted with high-income household with children	Greatschools.org API, CTPP
Crime rate	Zonal	Number of crimes per 10,000 people at a given TAZ	SEMCOG
Neighborhood-environment variables			
PopDen	Zonal	Population density in a given TAZ	CTPP
PopDen_HighInc	Household and zonal	Population density in a given TAZ interacted with high-income household	Regional household travel survey, CTPP
SinFamChd	Household and zonal	Percent of single-family property in a given TAZ interacted with household with children	Regional household travel survey, CTPP
MHH-Size_HHSize	Household and zonal	Absolute difference between median household size in a given TAZ and household size	Regional household travel survey, CTPP
MHHInc_HHInc	Household and zonal	Absolute difference between median household income in a given TAZ and household income	Regional household travel survey, CTPP
Size correction term			
LogHsgUnits	Zonal	The natural logarithm of the number of housing units of the household's chosen tenure in a given TAZ	CTPP

Table 4.2: Mean and standard deviation of the independent variables

Variable code	Sample	Atlanta		Puget Sound		Southeast Michigan	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Transportation-related variables							
Walkability	Chosen TAZs	14.40	20.41	61.31	32.45	23.48	22.90
	Non-chosen TAZs	14.01	19.21	37.79	30.90	25.82	22.74
TransitAccess	Chosen TAZs	-0.03	0.80	0.42	1.21	-0.08	0.89
	Non-chosen TAZs	-0.12	0.83	-0.06	0.83	-0.09	0.63
AutoAccess	Chosen TAZs	-0.09	0.92	0.72	1.32	-0.19	0.96
	Non-chosen TAZs	-0.15	0.83	-0.02	0.95	-0.07	0.88
CommuteTT	Chosen TAZs	41.78	41.03	27.24	26.94	20.47	26.96
	Non-chosen TAZs	80.09	75.05	67.07	58.65	36.70	45.07
Housing-affordability variables							
HsgCost_HHInc	Chosen TAZs	8.93	16.56	8.55	15.2	5.65	6.98
(Owners)	Non-chosen TAZs	7.71	19.34	7.19	14.27	5.32	8.60
HsgCost_HHInc	Chosen TAZs	0.68	1.13	0.36	0.62	0.61	0.91
(Renters)	Non-chosen TAZs	0.53	1.06	0.33	0.66	0.50	0.77
Local-service-related variables							
SchoolQual	Chosen TAZs	5.89	2.19	5.86	2.12	5.64	2.11
	Non-chosen TAZs	5.79	2.05	5.68	2.02	5.39	2.19
SchoolQual_HInc	Chosen TAZs	1.04	2.58	0.45	1.73	0.73	2.16
	Non-chosen TAZs	0.91	2.28	0.38	1.52	0.58	1.83
CrimeRate	Chosen TAZs					3.25	0.31
	Non-chosen TAZs					3.29	0.30
Neighborhood-environment variables							
PopDen	Chosen TAZs	1797.40	2251.17	5004.44	6785.83	3299.65	2834.62
	Non-chosen TAZs	1927.25	2871.15	2572.85	3799.75	3150.26	2767.97
PopDen_HighInc	Chosen TAZs	527.61	1473.10	1405.71	4470.99	590.40	1408.72
	Non-chosen TAZs	533.45	1680.09	714.13	2281.08	807.42	1923.49
SinFamChd	Chosen TAZs	0.29	0.41	0.11	0.25	0.21	0.37
	Non-chosen TAZs	0.27	0.39	0.12	0.27	0.20	0.35
MHHSize_HHSize	Chosen TAZs	1.03	0.95	0.70	0.79	0.91	0.80
	Non-chosen TAZs	1.10	0.97	0.83	0.80	0.99	0.91
MHHInc_HHInc (1000s)	Chosen TAZs	3.92	3.19	4.23	4.37	3.23	2.90
	Non-chosen TAZs	4.75	3.75	4.81	4.46	4.67	3.81
WkPctWt	Chosen TAZs	0.53	0.38				
	Non-chosen TAZs	0.47	0.37				
BkPctBk	Chosen TAZs	0.14	0.30				
	Non-chosen TAZs	0.08	0.21				
AsPctAs	Chosen TAZs	0.00	0.02				
	Non-chosen TAZs	0.00	0.02				
HpPctHp	Chosen TAZs	0.00	0.02				
	Non-chosen TAZs	0.00	0.02				
Size correction term							
LogHsgUnits	Chosen TAZs	1095.83	663.65	276.98	269.89	721.55	460.47
(Owner-occupied)	Non-chosen TAZs	798.34	571.43	274.35	235.84	553.13	387.59
LogHsgUnits	Chosen TAZs	574.02	614.98	410.95	366.27	285.69	324.81
(Renter-occupied)	Non-chosen TAZs	439.64	470.01	184.69	208.45	252.5	285.19

4.4.3 Accessibility measurements

The main variables of interest in this study are walkability, transit accessibility, and auto accessibility. Broadly defined, there are four commonly used categories of accessibility measures: 1) proximity-based measures, including proximity to key destinations such as urban cores and proximity to transportation infrastructure such as transit stops; 2) cumulative opportunities measures, which estimate the quantity of opportunities reachable within a predefined threshold; 3) gravity-based measures, which is very similar to the cumulative opportunities measure except that a distance-decay function is specified to weight down the contribution of more distant opportunities; 4) utility-based measures, which can be obtained from random utility choice models to represent the welfare benefits that people derive from access to opportunities. The first three are location-based measures whereas the fourth one is a person-based measure. Among the three location-based measures, the gravity-based measures are usually believed to be more comprehensive and conceptually appealing (Geurs and Van Wee, 2004; Handy and Niemeier, 1997). In addition, empirical studies have verified the usefulness of the gravity-based accessibility measures in predicting a variety of socioeconomic outcomes such as housing value (Ahlfeldt, 2011), travel behavior (Kockelman, 1997), labor productivity (Chatman and Noland, 2014). Therefore, this study measures accessibility with a gravity-model approach.

I used a common form of the gravity model such that the amount of interaction between an origin zone i and a destination j is positively related to the number of opportunities at the destination zone but is inversely related to the travel cost (time) between the zones. The accessibility to opportunity type n by travel mode m for location i is expressed as

$$A_{imn} = \sum_{j} O_{jn} exp(-\beta T_{ij}), \tag{4.3}$$

where:

A_{imn} is the accessibility index to opportunity type n by travel mode m for location i;

O_{jn} is the the attractiveness factor for opportunity type n based on the number of these opportunities in destination zone j;

exp denotes the base of the natural logarithm;

β is the impedance factor that measures the friction of distance, a higher value of which makes distant opportunities contribute to the accessibility index to a lesser degree;

T_{ij} is the travel time in minutes between zone i and j.

Assuming that employment to be a coarse indicator of overall activity, researchers have often used accessibility to jobs as a measure of the overall accessibility of a location (Handy and Niemeier, 1997; Boarnet and Wang, 2019). In recent years, however, researchers have started to pay more attention to nonwork accessibility (Grengs, 2015). After all, travelers in the United States made more than three-quarters of their trips for nonwork purposes in 2009 and 2017 according to the two recent national household travel surveys (McGuckin and Fucci, 2018). In theory, therefore, nonwork accessibility is expected to play an important role in household residential location choice.[8] In this study, I use accessibility to retail and services jobs to indicate nonwork accessibility. Retail jobs refer to jobs in North American Industry Classification System sector (NAICS) 44-45 (Retail Trade), and services jobs refer to jobs in NAICS sector 54 (Professional, Scientific, and Technical Services), 56 (Administrative and Support and Waste Management and Remediation Services), 61 (Educational Services), 62 (Health Care and Social Assistance), and 81 (Other

[8] The empirical evidence regarding how nonwork accessibility influences is nonetheless mixed. Some studies have found a significant impact (e.g., Lee et al., 2010; Kim et al., 2005; Chen et al., 2008) whereas others found an insignificant influence (e.g., Srour et al., 2002). In general, researchers have found that job accessibility has a larger effect on residential location decisions than nonwork accessibility, and Levine et al. (2019) provides an interpretation on this issue.

Services).

By taking into account both work and nonwork accessibility, this study uses more comprehensive (in terms of the range of destinations considered) accessibility measures than most previous residential location studies. The calculation of the auto accessibility and transit accessibility of a TAZ takes two same steps. First, I applied equation 4.3 to calculate accessibility to work opportunities (all jobs) to nonwork opportunities (retail and services jobs). The value of the impedance factor β was specified to be 0.1 and 0.3 respectively for work and nonwork opportunities, which were adopted from the estimates in Grengs (2015). Second, I performed principal component analysis on the two obtained accessibility measures and extracted the first principal component. This principal-component variable thus represents the overall auto/transit accessibility of a TAZ.

I was not able to calculate the walkability of a TAZ with the same procedure, because I did not have the data regarding the walk time for each origin-destination pair. Two alternative secondary data sources were thus considered: one is the Walk Score data from walkscore.com, and the other is the "Access Across America: Walking 2014" data published by the Accessibility Observatory at the University of Minnesota. The latter source was rejected because it does not cover all member counties of the ARC, PSRC, and SECMOG.

4.5 Results

4.5.1 Estimation and model fit

I estimated three models for each of the three regions, which include the same set of independent variables except a different accessibility measure (walkability vs. transit accessibility vs. auto accessibility). I estimated three separate model instead of one model that includes all three accessibility measures because they are highly correlated, which means that there would be multicollinearity if they are all included in the same model. Table 4.3, Table 4.4, and Table 4.5 present the correlation coefficients of the three accessibility measures across the three regions. Jointly, the three models help decide if accessibility maintains an independent effect on residential location choice after controlling for commuting cost and if households value walkability, transit accessibility, and auto accessibility differently. In addition, to facilitate regional comparisons, the models in each region were estimated with a nearly identical set of independent variables to minimize the impacts of unobserved factors (i.e., model output differences resulting from omitted variable bias). The model outputs were presented in Table 4.6, Table 4.7, and Table 4.8.

Table 4.3: Correlation of accessibility indicators in Atlanta

	Walkability	Transit accessibility	Auto accessibility
Walkability	1	0.694	0.766
Transit accessibility		1	0.666
Auto accessibility			1

Table 4.4: Correlation of accessibility indicators in Southeast Michigan

	Walkability	Transit accessibility	Auto accessibility
Walkability	1	0.471	0.646
Transit accessibility		1	0.565
Auto accessibility			1

Table 4.5: Correlation coefficients of the accessibility variables in Puget Sound

	Walkability	Transit accessibility	Auto accessibility
Walkability	1	0.457	0.663
Transit accessibility		1	0.623
Auto accessibility			1

Table 4.6: Residential location models in the Atlanta region

Variable code	Model 1		Model 2		Model 3	
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
Transportation-related variables						
Walkability	0.06	1.64				
TransitAccess			0.09	2.86***		
AutoAccess					-0.15	-2.94***
CommuteTT	-4.02	-29.56***	-4.00	-29.48***	-4.11	-29.40***
Housing-affordability variables						
HsgCost_HHInc	-0.76	-7.14***	-0.76	-7.26***	-0.66	-6.06***
Local-service-related variables						
SchoolQual	0.07	1.78*	0.08	1.91*	0.04	1.06
SchoolQual_HInc	0.18	1.57	0.18	1.58	0.18	1.57
Neighborhood-environment variables						
PopDen	-0.32	-6.11***	-0.32	-6.48***	-0.20	-3.46***
PopDen_HighInc	-0.06	-0.23	-0.06	-0.24	-0.06	-0.24
SinFamChd	0.25	2.44***	0.25	2.45***	0.17	1.68*
MHHSize_HHSize	-0.29	-4.89***	-0.30	-4.93***	-0.30	-4.94***
MHHInc_HHInc	-0.46	-8.55***	-0.47	-8.57***	-0.46	-8.49***
WtPctWt	0.52	7.06***	0.50	6.78***	0.56	7.49***
BkPctBk	0.40	8.57***	0.40	8.52***	0.39	8.11***
AsPctAs	0.05	1.03	0.05	1.05	0.05	1.06
HpPctHp	-0.04	-0.93	-0.04	-0.92	-0.04	-0.85
Size correction term						
LogHsgUnits	1.07	16.24***	1.07	16.36***	1.03	15.52***
Observations (N)	1200		1200		1200	
Log-likelihood at convergence	-2810.22		-2807.77		-2807.01	
Log-likelihood (Null Model)	-4080.44		-4079.44		-4081.44	
Adjusted pseudo R-square	0.31		0.31		0.31	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

Table 4.7: Residential location choice models in the Southeast Michigan region

Variable code	Model 1		Model 2		Model 3	
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
Transportation-related variables						
Walkability	0.02	0.04				
TransitAccess			0.09	3.80***		
AutoAccess					-0.29	-5.32***
CommuteTT	-2.89	-23.93***	-2.88	-23.90***	-2.97	-24.20***
Housing-affordability variables						
HsgCost_HHInc	-0.24	-2.31**	-0.20	-1.89*	-0.23	-2.21**
Local-service-related variables						
SchoolQual	-0.05	-1.13	-0.07	-1.56	-0.03	-0.61
SchoolQual_HInc	0.23	2.27**	0.24	2.32**	0.23	2.28**
CrimeRate	-0.43	-8.61***	-0.45	-9.37***	-0.28	-5.02***
Neighborhood-environment variables						
PopDen	-0.14	-2.54***	-0.14	-2.87***	-0.05	-0.92
PopDen_HighInc	-0.54	-2.61***	-0.53	-2.56***	-0.54	-2.59***
SinFamChd	0.11	1.09	0.11	1.17	0.09	0.09
MHHSize_HHSize	-0.05	-0.87	-0.05	-0.83	-0.05	-0.88
MHHInc_HHInc	-0.77	-13.72***	-0.77	-13.72***	-0.78	-13.83***
Size correction term						
LogHsgUnits	0.95	16.22***	0.94	16.21***	0.92	15.74***
Observations (N)	1200		1200		1200	
Log-likelihood at convergence	-3160.42		-3154.86		-3145.57	
Log-likelihood (Null Model)	-4081.44		-4081.44		-4081.44	
Adjusted pseudo R-square	0.22		0.22		0.23	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

Table 4.8: Residential location choice models in the Puget Sound region

Variable code	Model 1		Model 2		Model 3	
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
Transportation-related variables						
Walkability	0.33	6.41***				
TransitAccess			0.06	2.59***		
AutoAccess					-0.07	-1.94*
CommuteTT	-3.32	-25.30***	-3.39	-25.80***	-3.48	-25.72***
Housing-affordability variables						
HsgCost_HHInc	-0.74	-5.15***	-0.83	-5.46***	-0.96	-6.72***
Local-service-related variables						
SchoolQual	0.04	1.12	0.05	1.44	0.05	1.57
SchoolQual_HInc	0.17	1.65*	0.16	1.52	0.16	1.52
Neighborhood-environment variables						
PopDen	0.05	0.81	0.27	5.23***	0.33	5.93***
PopDen_HighInc	0.02	0.08	0.08	0.28	0.04	0.14
SinFamChd	0.14	1.63	0.09	1.03	0.07	0.81
MHHSize_HHSize	-0.32	-5.69***	-0.35	-6.16***	-0.36	-6.33***
MHHInc_HHInc	-0.39	-5.44***	-0.39	-5.36***	-0.38	-5.15***
Size correction term						
LogHsgUnits	1.03	20.52***	1.06	20.87***	1.08	21.62***
Observations (N)	1200		1200		1200	
Log-likelihood at convergence	-2714.71		-2734.02		-2733.49	
Log-likelihood (Null Model)	-4081.44		-4081.44		-4081.44	
Adjusted pseudo R-sqaure	0.33		0.33		0.33	

Note: *Significant at the 0.1 level, **Significant at the 0.05 level, ***Significant at the 0.01 level

The McFadden's adjusted pseudo-R-square, shown at the bottom of the tables, is within the range of 0.2 and 0.3 across the twelve models. The McFaddens pseudo-R-square is a measure of the likelihood improvement offered by the full model compared to an intercept-only model, and values between 0.2 and 0.4 are often taken to represent good model fit (McFadden, 1979).

I focus on the coefficient estimates in the following sections. Note that given the nature of the models estimated (i.e., generic coefficients were specific for all households in a given region), the results should be interpreted as applying to a hypothetical *average* regional household rather than specific population groups. That is to say, when a policy intervention (e.g., expansion of transit services) leads to changes in a given variable (transit accessibility), the coefficients show the potential impacts on *a random group of households in the region* rather than on a specific group of households. In practice, however, due to the existence of preference heterogeneity specific population groups are more likely to respond to policy changes than a random group of households; for example, individuals who have a stronger preference for transit accessibility are more likely to move into newly built transit-oriented development areas. Therefore, the actual policy effects are likely to be larger than what the estimated coefficients indicate.

Also, the estimated coefficients here were not regular coefficients but X-standardized coefficients. They were obtained by fitting multinomial logit models on standardized input data, i.e., each variable except *LogHsgUnits* was standardized by subtracting its mean from each of its values and then dividing these new values by the standard deviation of the variable. Like the standardized coefficients in regression analysis, these X-standardized coefficients allow the modeler to directly assess the strength of the effect of each independent variable on the choice outcome, and the variable with the largest coefficient has the strongest influence. There is a notable difference between regular standardized coefficients and the X-standardized coefficients used here. Regular standardized coefficients were derived by standardizing both the X and y variables. In logit models, however, only the X variables were standardized because y, the utility of an alternative, is a latent utility variable unobserved to the modeler. If one is only interested in the rank order of the magnitude of the effects of the independent variables on the utility, however, X-standardization is sufficient (Menard, 2004)

4.5.2 Control variables

In this section, I discuss the sign and statistical significance (at the 0.05 level) of the coefficient estimates for the control variables (non-accessibility variables). Within each region, the coefficient estimates barely differ across the three models that included a different location-accessibility measure. Generally speaking, these coefficient estimates are reasonable and consistent with the existing theoretical and empirical evidence.

First of all, the coefficient of $CommuteTT$ was negative and highly significant in all twelve models, indicating a strong impact of commute time on housing decisions. This finding was not new, since almost all previous studies on residential location choice found the same (e.g., Lee et al., 2010; Levine, 1998). However, by estimating residential location choice models with an identical model structure across three U.S. regions with distinctive urban structures, my study confirms with robust empirical evidence that $CommuteTT$ remains a top consideration in household residential decisions. In fact, the magnitude of the $CommuteTT$ coefficient was the largest among all independent variables, a finding similar to previous studies that used regional household travel survey data to examine the relative importance of different factors (Liu, 2012; Lee et al., 2010).

The housing affordability indicator, *HsgCost_HHInc*, was negative and significant at the 0.05 level across all twelve models. This suggests that households are less likely to choose a zone which is less affordable to them. The school-quality variables, *SchoolQual* and *SchoolQual_HInc*, were positive in most models (except that *SchoolQual* was negative in the Southeast Michigan models), which indicate that households, particularly the high-income ones with children, prefer to live in places with access to good schools.

A crime-rate variable was incorporated into the Southeast Michigan-region models (crime data were not available to me for Atlanta and Puget Sound), and it is negative and highly significant. This finding confirms the conventional wisdom that safety is a major consideration in housing decisions. Failing to include the crime variable into the Atlanta and Puget Sound models would likely bias the estimates of other independent variables that are correlated with crime rate. Since crime has a negative impact on household residential location choice and accessibility variables are likely to be positively correlated with crime rate, the coefficient estimates of *CompactAcc, Walkability, TransitAcc, AutoAccess* in the Atlanta and Puget Sound models are likely to have a downward bias.

Next are the neighborhood-environment related variables. In the Southeast Michigan and Atlanta models, *PopDen* and *PopDen_HighInc* were negatively associated with residential location choice, which reflects the preference for low-density living among the households living in these regions (Myers and Gearin, 2001). By contrast, *PopDen* was positive and highly significant in the Puget Sound models. *SinFamChd* had a positive coefficient across all models, confirming the conventional wisdom that households with children tend to have a stronger preference for single-family homes. Moreover, as suggested by the negative signs on *MHHSize_HHSize* and *MHHInc_HHInc*, there is strong neighborhood sorting by household characteristics and household income.

Several race-related variables were specified in the Atlanta models but not the Southeast Michigan and Puget Sound models because the ARC survey collected the race information of the household members but the other two household surveys did not. *WtPctWt, BkPctBk, and AsPctAs* had a positive sign, which suggests that Whites, Blacks, and Asians tend to sort into neighborhoods of the same race. By contrast, *HpPctHp* had a negative but insignificant sign, meaning that Hispanics were more likely to disperse into mixed-race neighborhoods. I also tested a model specification without these race variables, and the coefficient estimates on the accessibility-related variables did not change much. Therefore, while race-based sorting plays an important role in residential decisions, without accounting for it may not create a serious omitted variable bias problem for estimating the impact of accessibility on residential location choice.

Finally, the coefficient on the size correction term, *LogHsgUnits*, was reasonably close to unity and highly significant across all twelve models. Theoretically, this variable should have a coefficient of one if all units of a particular type in a given zone are truly homogeneous, a necessary condition underlying the assumption that a zonal-level choice model can result in parameter estimates consistent with a housing-unit level model (Lerman, 1975). Therefore, these coefficient estimates validated the modeling of residential location choice at the TAZ level with a multinomial logit model.

4.5.3 Accessibility variables

I now focus on the accessibility-related variables, which are the main variables of interest. I mainly examine the sign and statistical significance (at the 0.05 level) of their coefficients. I also compare the magnitude of the (X-standardized) coefficients on accessibility variables with the control variables in order to assess their relative influence on residential location choice.

Walkability

Two possible reasons may account for the difference in the coefficient estimates of *Walkability* across regions. One is that households living in the Puget Sound region have a stronger preference for walkability than households in the Atlanta and Southeast Michigan region. The other is that there is a great scarcity of walkable neighborhoods (housing units) in Atlanta and Southeast Michigan; that is, if walkability is a rare "commodity", most households simply do not or cannot actively seek for it. The first argument attributes the results on *Walkability* to household preferences whereas the second attributes them to the constraints they face, and both preferences and constraints may explain individual choice outcomes.

Which of these two arguments is true have important implications on land use and transportation policies. If the empirical evidence better supports the first argument, it means that compact-development efforts are less justifiable in the Atlanta and Southeast Michigan region than in the Puget Sound region. To the least, the implementation of compact-development initiatives is likely to face more oppositions from the Atlanta and Southeast Michigan region residents than from the Puget Sound Region residents. If the second argument is true, however, it suggests that the revealed behavior (in terms of matching the preferences for walkability) in the Atlanta and Southeast Michigan region may be the preferred behavior. That is to say, due to the lack of choice, households in the Atlanta and Southeast Michigan region often had to choose a residence with a lower level of accessibility than what they prefer. It follows from this reasoning that compact development is warranted to expand choice for households in the Atlanta and Southeast Michigan region (Levine et al., 2005).

Whether the regional differences in walkability's coefficient estimates result from household preference differences or market constraints is an empirical question. My review of the relevant literature leads me to conclude that market constraints probably play a greater role. My conclusion is based on the following observations. First, in a study that compares the fit between people's transportation and land-use preferences (i.e., preferences for compact neighborhoods) and actual neighborhoods across the Atlanta and Boston metropolitan areas, the researchers found that Boston allowed a much closer fit than did Atlanta (Levine et al., 2005). They showed that Atlantans indeed have a relatively weaker preference for compact neighborhoods than Bostonians. However, the difference in preferences is far from enough to explain why Atlantans were much more likely to end up living in low-density, auto-dependent neighborhoods than Bostonians, which suggests that the scarcity of compact development plays a major role (Levine et al., 2005).

Table 4.9 presents the distribution of TAZs and housing units in terms of their walkability level across three regions. These statistics clearly show that there is a great scarcity of walkable neighborhoods—more accurately, a scarcity of housing units locating in walkable neighborhoods—in the Atlanta and Southeast Michigan region compared to the Puget Sound region. Only 3.2% and 4.3% of the housing units in the Atlanta and Southeast Michigan region, respectively, were in the "very walkable" category, compared to a 14.8% in the Puget Sound region. By contrast, 90.7% and 80.4% of housing units in the Atlanta and Southeast Michigan region respective were in car-dependent neighborhoods, whereas only 72.2% of housing units in the Puget Sound region were. Alarmingly, a large majority of housing units were built in car-dependent neighborhoods, although surveys frequently report that only a minority of American households prefer such neighborhoods (Levine et al., 2005; Frank et al., 2019; Myers and Gearin, 2001).

Another piece of empirical evidence that leads support for the "market constraint" view is the studies on how walkability affect property values. To my knowledge, almost all of these studies found that walkability provided a significant boost to land and property prices (Li et al., 2015; Bartholomew and Ewing, 2011; Pivo and Fisher, 2011). These studies were conducted in different cities, suggesting that walkability is a desirable neighborhood attribute among the general population. This is evident in the two regions themselves: in the Atlanta region, the redevelopment of the Beltline that turns the surrounding areas into walkable and transit-accessible neighborhoods has led to rapid property price increases (Immergluck and Balan, 2018); and in the Southeast region, some walkable neighborhoods in downtown and midtown Southeast Michigan have attracted many new businesses and residents in recent years (Riley, 2018).

The fact that walkability had a positively significant coefficient in almost all hedonic-price regression models whereas it was insignificant in two of the three res-

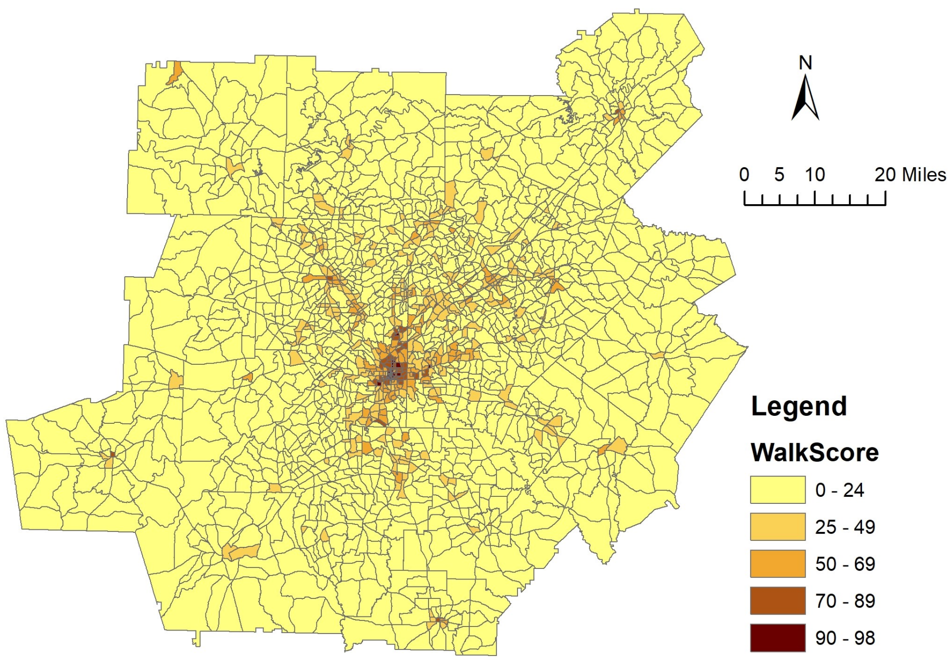
Table 4.9: The distribution of walkability (across TAZs and housing units) in the three regions

	Atlanta		Southeast Michigan		Puget Sound	
	TAZ	Housing units	TAZ	Housing units	TAZ	Housing units
Very walkable	4.5%	3.2%	5.6%	4.3%	21.3%	14.8%
Somewhat walkable	5.9%	6.2%	12.9%	15.3%	15.5%	13.0%
Car dependent	89.7%	90.7%	81.4%	80.4%	63.2%	72.2%

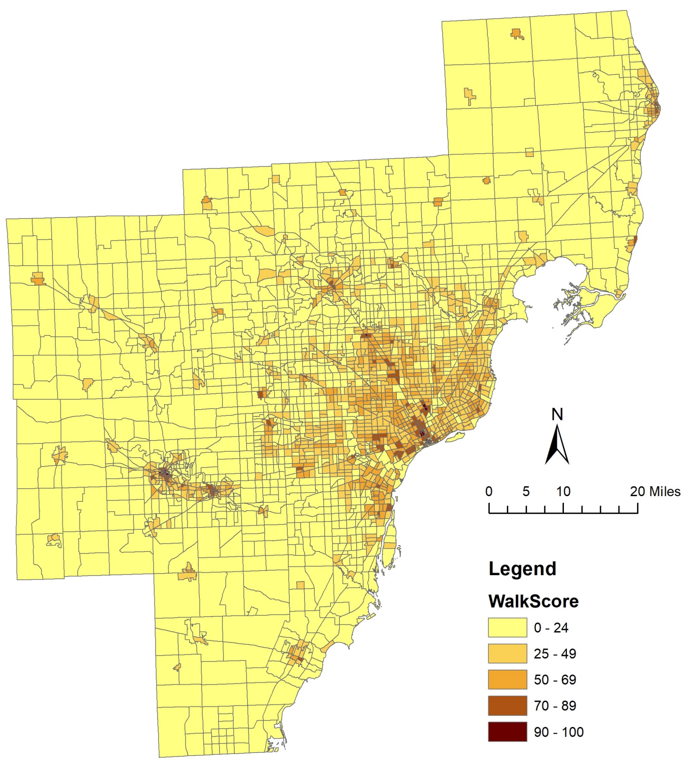
Note: Walk Score ranges from 0 to 100. A Walk Score of 70 and above is defined as very walkable, 50 to 69 is somewhat walkable, and 49 and below is car-dependent.

idential location choice models is a subject that needs further study. I provide two possible explanations here. One explanation is that the walkable neighborhoods in the Puget Sound region are more desirable compared to the walkable neighborhoods in the Atlanta and Southeast Michigan regions (see Figures 4.1, 4.2, and 4.3). This can result from two factors. First, walkable neighborhoods in the Puget Sound region (mostly in the city of Seattle) are better designed (in terms of aesthetics and pedestrian friendliness) than walkable neighborhoods in the Atlanta region (mostly in downtown and midtown Atlanta) and in the Southeast Michigan region (mostly in downtown and mid-town Southeast Michigan). Second, in the Atlanta and Southeast Michigan region, housing quality is negatively associated with walkability (suburban housing units are in general of better quality than urban housing units in these two regions). Since housing quality is expected to be positively associated with residential location choice and my models did not control for it, there is likely to be a downward bias for the coefficient estimate on walkability.

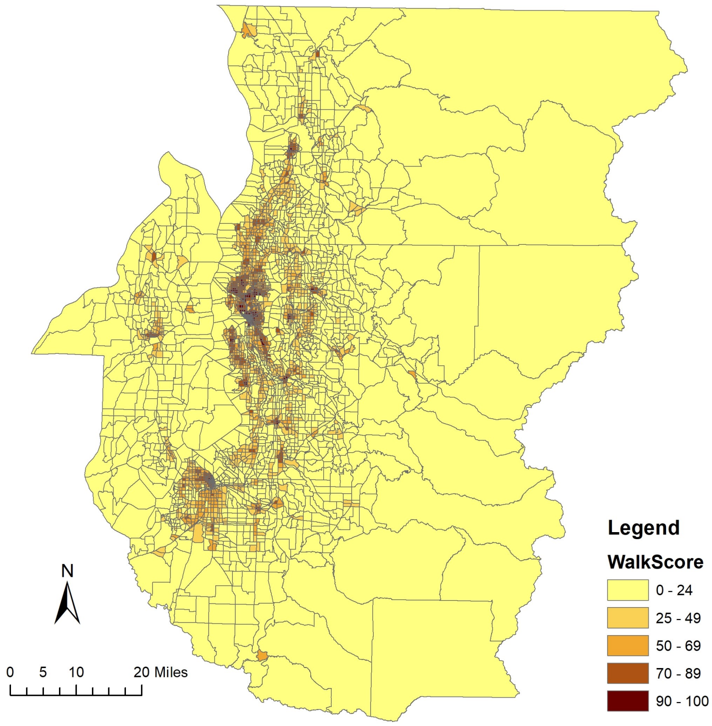
The second explanation is that the alternative choice set that the modeler arbitrarily constructed for each household may not be the actual choice set considered by that household. If neighborhoods of high walkability were included in the choice set of households that in reality only considered auto-dependent neighborhoods when deciding where to live, the coefficient estimates on walkability are likely to be biased downward (Lerman, 1975). Given the scarcity of walkable neighborhoods in the Atlanta region and the Southeast Michigan region, one can expect that walkability is



Map 4.1: The WalkScore of TAZs in the Atlanta region



Map 4.2: The WalkScore of TAZs in the Southeast Michigan region



Map 4.3: The WalkScore of TAZs in the Puget Sound region

considered by a small minority of households in their housing choice; however, neighborhoods of high walkability were inevitably included into the choice set of most households in the two regions since I had no information on if a household considered walkability or not.

Transit accessibility

The estimated coefficients on transit accessibility were positive and statistically significant at the 0.05 level in models across the three regions. While I am more inclined to view this established relationship between transit accessibility and housing choice as causal, there is also reason to believe that it is a pure correlation. The "correlation" case can be supported by two main arguments. First, the data used in my study are cross-sectional rather than longitudinal. Results of a cross-sectional study are highly subjective to omitted variable bias and are commonly believed to be insufficient to determine causal relationships. Second, there can be a reverse causality issue. Transit lines and stops are usually located at high-density places to achieve the goal of serving more people, that is to say, transit infrastructure (and hence transit accessibility) may come after housing choice.

However, the case for "transit accessibility causing residential location choice" is corroborated by two further pieces of empirical evidence. First, in surveys of residential preferences, households frequently indicated that transit access was an important consideration (Chatman, 2009). People may value good transit access not only for the actual use of the service but also for the opportunities it offers for unexpected future use (Roson, 2001). Second, hedonic-price models generally estimate a positive and significant impact of transit accessibility on property values. Scholarly inquiry into how transit accessibility impacts land value and housing prices has existed for decades, and the empirical evidence accumulated so far largely support the notion that transit accessibility has a sizeable impact on property values (Mulley et al., 2016; Knight and Trygg, 1977). For example, Armstrong and Rodriguez (2006) found that properties located in municipalities with commuter rail stations were valued about 10% higher than properties in municipalities without a commuter rail station.

Auto accessibility

Auto accessibility had a negative coefficient in models across all three regions. While a negative coefficient on auto accessibility was unexpected, previous studies frequently reported the same (see, e.g., Guo and Bhat, 2007; Zolfaghari et al., 2012; van de Vyvere et al., 1998). Previous studies often interpreted the negative sign as suggesting that most people in the study area lived in neighborhoods of low auto accessibility or that neighborhoods of high auto accessibility were often associated with high levels of negative externalities (e.g., noise and traffic). Besides these reasons, this may result from the fact that public roads are ubiquitous in U.S. metropolitan regions and so the level of auto accessibility is sufficiently high at most locations. In this context, households with cars would be indifferent to the variation in the level of auto accessibility across locations. For households without cars, they are likely to be even more indifferent since they cannot take advantage of auto accessibility anyway.

It should be noted that in separate models where I excluded the commute cost variable (results not shown here), the coefficient on auto accessibility became positive and statistically significant at the 0.05 level. This finding supports the construction of more housing units at locations of high auto accessibility, in order to allow households that wish to cut commute costs to have more housing options (Levine, 1998).

Relative influence of accessibility on residential location choice

As discussed above, comparing the magnitude of the estimated X-standardized coefficients can shed light on the relative influence of each variable on the choice outcome. Across all three models, $CommuteTT$ had the largest coefficient, suggesting a very strong influence of commuting time on residential location choice. By contrast, the magnitude of other accessibility indicators (i.e., overall accessibility, walkability, transit accessibility, and auto accessibility) was relatively small, which ranked almost at the bottom when compared with all other independent variables in terms of their relative influence on residential location choice. One exception is the relative influence of walkability in the Puget Sound region model, which ranked at the third place. These findings are largely consistent with the results in several other resident location choice studies that examined the relative influence of each independent variable on the choice outcome (Lee et al., 2010; Liu, 2012).

4.6 Implication and discussion

These findings have important implications for land use and transportation planning practice and policymaking. First, the different impacts of walkability, transit accessibility, and auto accessibility on residential location choice shed light on the design of land use and transportation policies to promote accessibility. In addition, the differences in model results across regions reveal that accessibility evaluation is highly dependent on the regional context. Finally, the study calls into question the existing long-term land use and travel models that are calibrated based on revealed location- and travel-choice behavior, since revealed behavior is shaped by the existing choice constraints and it can be different from preferred behavior.

4.6.1 The design of accessibility-promoting policies

The finding that transit accessibility exerts a significant influence on residential location choice suggests that transit accessibility is a highly desirable attribute among many households across U.S. regions. This finding explains the increases in housing price in areas adjacent to transit infrastructure (Bowes and Ihlanfeldt, 2001) and also provides empirical support for the planning practice of promoting more transit-oriented developments in order to meet the market demand (Levine et al., 2005). In addition, since transit accessibility is the only type of accessibility that has a positive and significant coefficient across all three regional models, policies that promote transit accessibility are more likely to have a significant influence on residential patterns than measures that promote walkability and auto accessibility. However, one should not interpret this finding as suggesting that local residents are more supportive of policies that promote transit accessibility than policies that promote walkability and auto accessibility, since my models examine how households react to the level of different types of accessibility already available at different locations rather than how they react to proposals to enhance accessibility. Such policy proposals usually come with a cost and thus requires a different cost-benefit analysis in order to assess their relative merits and disadvantages (Levine et al., 2018).

After controlling for commuting cost, households across all three regions do not value auto accessibility in residential location choice (in fact, auto accessibility has a negative coefficient). As I discussed above, this finding is not surprising: The comparative advantage and the relative attractiveness of a location depend on if it offers a much higher level of accessibility than other locations; and in many U.S. regions where there is almost ubiquitous road access across all locations, it is reasonable for the locational advantage of central locations in auto accessibility to be perceived as unimportant. This suggests that road investments are likely to have a relatively small influence on location patterns in an environment of ubiquitous road access. On the other hand, the finding that commuting cost is a highly significant factor across all models provides empirical support for policy measures (e.g., job-housing balance) that seek to reduce commuting cost. This contradicts an earlier claim which asserts that commuting cost plays a decreasing role on household residential decisions and that the land-use and transport link is weakening (Giuliano and Small, 1993; Giuliano, 1995).

The limited influence of auto accessibility on residential location choice should nonetheless not be interpreted as suggesting that auto accessibility is not an important and desirable location attribute. Beyond shaping location choice and development patterns, land use and transportation planning policies and practices that promote auto accessibility can result in other desirable social outcomes such as reduced vehicle miles travelled (Ewing and Cervero, 2001), higher economic growth (Banister and Berechman, 2001), and better employment prospects (Ihlanfeldt and Sjoquist, 1991). When planning for the future, promoting auto accessibility—as opposed to promoting automobility—should still be a fundamental planning goal (Martens, 2016; Levine et al., 2019). A region that is experiencing decreasing auto accessibility would have a lower level of attractiveness to potential future comers and lose in competitiveness compared to other regions.

4.6.2 The importance of regional context in accessibility evaluation

A comparison of the similarities and differences of the model outputs across regions can generate valuable insights on how regional context influences accessibility evaluation in residential location choice modeling. Since the models specified in this study have almost identical sets of independent variables and the measurement of accessibility indicators (and most other variables) are the same, this study provides robust empirical evidence (by ruling out the influences of model specification and measurement) to understand how regional context matters. Nonetheless, I also bring into discussion findings from other studies in order to have a more comprehensive understanding of the generalizability of findings in this study.

The finding that transit accessibility has a significant impact on residential location choice across all three regions is also consistent with most previous studies (e.g., Olaru et al., 2011; Hu and Wang, 2017).[9]. This means that one can comfortably generalize this finding to other locations. Regarding auto accessibility, this study shows that it has a negative coefficient in the models of all three regions, which indicate a limited influence of auto accessibility on household location decisions. While this finding is not uncommon, this finding contrasts with many other studies that reported a positive and significant impact of auto accessibility on residential location choice (e.g., Lee et al., 2010; Srour et al., 2002) While this difference may result from differences in model specifications and measurements, regional context is also likely to play a role. The regions studied here are all large U.S. metropolitan regions with an extensive built-out area that is full of self-contained suburbs and an extensive road network that well connects the region. This means that a household with access to personal vehicles can enjoy a very high level of auto accessibility (accessibility to over millions of job with an hour drive) at most locations. Since the marginal benefit that

[9] It should be noted, however, most previous studies use a distance-based accessibility (e.g., distance to transit stop) rather than the more comprehensive gravity-based accessibility measure used here.

a household gains from additional accessibility increases at a high level of accessibility is likely to be low (due to a decreasing marginal utility of accessibility), a household may place little value on locations with higher auto accessibility. If the study area is a smaller region with a much lower level of overall auto accessibility, it is likely that households would value locations of higher auto accessibility more.

An intriguing finding of this study is that walkability was highly significant in the Puget Sound region model but not significant in the Atlanta and Southeast Michigan region. As I discussed above, this is most likely because there is a great under-supply of walkable neighborhoods, particular walkable neighborhoods with better housing quality and urban design, in the Atlanta and Southeast Michigan region. This under-supply results in a lack of choice, causing most households living in these two regions to be unlikely to consider walkability as an important factor when deciding where to live. To my knowledge, walkability has not been incorporated into the residential location choice models of previous studies, although existing residential preference surveys often show that many residents view walkability to be important (Schwanen and Mokhtarian, 2004; Urban Land Institute, 2015; Canadian Home Builders Association, 2015; Frank et al., 2019). Therefore, my study fills an important gap in understanding the role of walkability in residential location choice modeling.

The findings on walkability in this study is consistent with another important study that examines the degree to which residents in Boston and Atlanta are able to translate their residential preference for walkable and transit-accessible neighborhoods into their actual residence choice (Levine et al., 2005). In this study, Jonathan Levine and his co-authors found that Boston—by providing a greater range of neighborhood types—allowed a closer fit between household neighborhood preference and the actual neighborhood choice than Atlanta. The major improvement of my study to the Levine et al. study is that my residential choice models control for a range of other factors such as housing affordability, local services, and neighborhood characteristics, which greatly mitigates the omitted-variable-bias concern associated with the model specified in the Levine et al. study. Together with the Levine et al. study, my study highlights the importance of regional supply factors in shaping residential location decisions and the valuation of accessibility in the process. From a policy perspective, findings of both studies suggest the need for increasing the supply of walkable and transit-accessible neighborhoods—for example, through the relaxation of zoning regulations (Levine, 2006)—to allow households to have more choice in housing decisions.

4.6.3 A need to incorporate "preferred" behavior in integrated land use and transport modeling

The residential location choice models implemented in this study are standard models used in an integrated land use and transportation modeling procedure (Waddell, 2002), which was conducted by metropolitan planning agencies to guide land use/transportation investments and decisions. In the process, residential location choice models are used to predict the distribution of population growth, usually in the next twenty or thirty years, in different parts of the region. As is the case in this study, the main data source for residential location modeling is the regional household travel survey.

Results of my study point to a potential issue with the current standard practice. The issue is that residential location choice prediction is only based on the revealed behavior of regional households, which is necessarily constrained by the existing market and individual constraints and thus may not be the preferred behavior (Handy and Niemeier, 1997). As I have discussed above, the coefficient estimates on walkability—for the Atlanta and Southeast Michigan region—do not indicate that residents in the Atlanta and Southeast Michigan region do not value walkable neighborhoods, but rather suggest that they are not able to choose walkable neighborhoods due to the lack of choice. These households may well consider moving to a more walkable neighborhood if more walkable neighborhoods with better schools and local services are built in the future and thus bring a greater diversity of choice.

However, a standard application of the residential location choice models in the Atlanta and Southeast Michigan regions, which assumes that the model outputs reflect the preferences of future residents, would signal to planners and policymakers that households in the two regions do not value walkability and thus the provision of walkable neighborhoods is unwarranted. Also, since the outputs of a residential location choice model are inputs the subsequent travel-demand models, an under-prediction of population growth in walkable neighborhoods would lead the modelers to predict less nonmotorized trips. When the predicted future travel is used to guide transportation investments and decisions, more resources are likely to be diverted to motorized travel at the expense of undermining nonmotorized travel. This practice thus constitutes another form of the "predict and provide" approach in transportation planning that has been widely criticized in recent decades (Kenworthy, 2012).

Therefore, I argue that residential location choices with prediction purposes (e.g., when performing as a component of integrated land use-transport model systems) should incorporate both information regarding the preferred behavior of households and also their revealed behavior at present. One possible approach to achieve this can be adding some stated-preference questions in the existing regional household travel surveys, and incorporate such information into the land use and transport modeling procedure. Research on joint modeling of revealed-preference and stated-preference data has been ongoing for decades, which has been widely applied in travel modeling (e.g., Ben-Akiva and Morikawa, 1990) but much less so in location choice modeling.

4.7 Conclusion

In recent years, there are two major debates in the planning literature related to accessibility: one is the debate on the desirability of compact development versus sprawled growth (Ewing, 1997; Gordon and Richardson, 1997), and the other is accessibility-based versus mobility-based transportation and land use planning (Cervero, 1997; Salomon and Mokhtarian, 1998; Levine et al., 2019). These normative debates are still ongoing but the scale is gradually shifting toward the direction of accessibility, with accessibility and its corresponding policies gaining more and more support among researchers and making inroads into planning practices (Boisjoly and El-Geneidy, 2017; Proffitt et al., 2019). A much less discussed and less well-understood topic, however, is how to plan for accessibility; specifically, little knowledge is available regarding which types of accessibility to prioritize when planners and policymakers establish the goals of transportation and land use planning.

This study fills this gap by examining how regional households value walkability, transit accessibility, and auto accessibility differently in their residential location choice. To further evaluate the generalizability of study findings and to investigate how regional context matters for accessibility valuation in household residential decisions, I fit residential location choice models for random samples of households living in three U.S. regions, namely, the Atlanta region, the Puget Sound region, and the Southeast Michigan region. Since accessibility is a "good" with many proven benefits, in theory, they should all have a positive influence on household residential location choice. The model outputs only partially confirm this notion. The results show that transit accessibility has a significant influence on household residential location choice across all regions. Walkability is an important determinant of residential location for the Puget Sound households, but not for the Atlanta and Southeast Michigan households. Somewhat surprisingly, auto accessibility, perhaps the type of accessibility mostly discussed and measured among the three, appears to have little influence on residential location decisions.

The valuation of accessibility in residential location choice is jointly determined by two major factors: the preferences of local residents (i.e., demand factor), and the supply of different types of accessibility in the regional housing stock. However, previous studies on residential location choice have generally interpreted the model outputs as an indication of resident preferences while ignoring the potential influences of the supply factors. That is to say, if the coefficient of an accessibility indicator is statistically insignificant, it would be interpreted as suggesting that residents do not have a strong preference for it when deciding where to live. The findings of my study suggest that this interpretation can be erroneous. I argue that the insignificant coefficients on walkability in the Atlanta and Southeast Michigan models are more reflective of the scarcity of walkable neighborhoods in these two regions rather than the fact that households in the two regions do not value walkability as much as households in the Puget Sound region. Likewise, the limited influence of auto accessibility on residential decisions across all three regions is better interpreted as suggesting that the ubiquity of road access evens out the accessibility differences across locations instead of suggesting that auto accessibility are not important.

My study also has important implications for land-use and transportation planning practice and policymaking. First of all, it appears that for U.S. regions, policy measures that promote transit accessibility are more likely to shape residential location outcomes than measures that promote walkability and auto accessibility. In fact, new road investments are likely to have a minimal influence on residential location patterns considering an environment of ubiquitous road access in major U.S. metropolitan regions. These findings are supported by the model outputs in all three regions, which ensure a high degree of generalizability to other large metropolitan regions. The results on auto accessibility are less transferable to smaller regions, however, because the absolute level of auto accessibility is lower (accessibility is likely to be valued more at a lower absolute level due to decreasing return in utility) and the road infrastructure is likely to be less pervasive. Moreover, the fact that walkability has a varying degree of influence on household residential decisions across the three regions highlights the importance of regional context in accessibility valuation. Whereas households in the Puget Sound region can enjoy a better fit between their residential preferences for walkability and actual neighborhood choice, the scarcity of walkable neighborhoods in the Atlanta and Southeast Michigan region often force households in the two regions to live in less walkable neighborhoods in order to satisfy other needs such as good schools and good municipal services. This finding suggests the need for increasing the supply of walkable neighborhoods (such as by relaxing zoning regulations) to expand the choice of walkability-preferring households.

Finally, this study call for a need to incorporate information regarding the "preferred behavior" of households into land use and transportation modeling. The existence of market constraints means that people's actual choice may not be their desired choice, and so there is often a disparity between revealed behavior and preferred behavior. This means that a sole reliance on revealed-behavior data for land use and transportation modeling, whose outputs are consequently used to guide land use and transportation planning, can lead to future scenarios that reinforce the status quo, which are most likely to be very different from the preferred scenario of local residents. Eliciting information regarding households' preferred behavior and incorporating it into the process of land use and transportation planning can thus lead to better policy prescriptions and planning outcomes.

CHAPTER V

Conclusion

Access is a basic human need. People need access to other people: to family and relatives, to friends, to potential mates, to business partners, and to a variety of casual acquaintances. They also need access to activities, goods, services, and natural amenities, such as to job opportunities, food, medical services, and parks or other recreational sites.

These needs in turn shape individual residential location and travel decisions. When people decide where to live, an important factor they consider is the level of accessibility a location offers, that is, the convenience/potential from it to reach desirable destinations (i.e., people and opportunities) distributed across space. Everything else being equal, individuals in general would prefer a site that offers a higher level of accessibility to work and nonwork destinations because it provides them more choices when making travel decisions. By determining the price of travel from a location to potential destinations (Boarnet and Crane, 2001), accessibility shapes individual travel decisions regarding how many trips to take, which destinations to visit, and which travel modes to use and at what frequency.

Land-use and transportation planning shapes the spatial distribution of people and activities (i.e., land-use patterns) and the ease of travel between them (i.e., the transport system), the two major components of accessibility.[1] Thus to enhance indi-

[1]Geurs and Van Wee (2004) decomposed accessibility into four components: land use, trans-

vidual residential and travel satisfaction, an intuitive approach is to promote land-use and transportation planning policy and practice that can enhance accessibility. Accessibility improvements can come from either land-use policies such as new urbanism, mixed-use development, and job-housing balance that promote the proximity between origins and destinations or transportation policies such as travel-demand management and rail investments that promote travel speed (Grengs et al., 2010; Levine et al., 2012). Nevertheless, proximity-enhancing policies such as job-housing balance and transit-oriented development (often jointly referred to as "compact development" or "smart growth") have been heatedly debated in recent decades.

Up until the early 2000s, a major focus of the debate is whether compact-development policies are justifiable on the basis of free-market principles. While critics of compact development assert that the prevailing low-density, auto-dependent development patterns (urban sprawl) across the U.S. is a result of market forces and an expression of consumer preferences (Gordon and Richardson, 2001, 1997; Glaeser and Kahn, 2004), supporters argue that urban sprawl results from both market failures (Ewing, 1997; Brueckner, 2000) and planning failures (Levine, 2006). Major market failures associated with urban growth include a failure to account for the benefits of open space, a failure to account for the social costs of driving, and a failure to make new development pay for the infrastructure costs it generates (Brueckner, 2000). And the planning failure lies in the inadequate supply of walkable and transit-friendly neighborhoods that households prefer due to the pervasive single-family, exclusionary zoning practices (Levine and Inam, 2004; Levine et al., 2005; Levine, 2006). The debate on compactness-versus-sprawl has cooled down in recent years, with a grow-

portation, temporal, and individual. The temporal component distinguishes accessibility by time of the day or day of the week (Miller, 1991; Kwan, 1998; Miller, 1999), which can be captured by the land-use and transport components if the "operating" hours of activities (e.g., business hours of stores) and transportation services (e.g.. operating hours of transit services) are accounted for. The individual component further accounts for individual preferences, needs, and constraints; however, the focus of this dissertation is on location accessibility (i.e., place-based accessibility) instead of people-based accessibility.

ing majority of scholars recognize the inefficiency, environmental harms, and social inequality associated with sprawl (Anderson et al., 1996; Johnson, 2001; Owen et al., 2004; Clifton et al., 2008).

More recent debates on accessibility-promoting land-use and transportation policies center on if these policies are effective tools to achieve planning goals such as reducing car use (Ewing and Cervero, 2010; Stevens, 2017) and whether or not accessibility remains to be an important locational factor in an era of declining transport costs (Glaeser and Kohlhase, 2004). Naturally, evidence showing that accessibility significantly affects travel behavior (e.g., reduce driving or promote the use of non-motorized modes) and shapes locational decisions supports these policies, whereas the absence of significance influences undermines the rationale for accessibility-based planning policymaking and practice. The existing empirical evidence on these topics is extensive but mixed. While many researchers have argued that accessibility-promoting compact-development policies can reduce car use (Cervero and Kockelman, 1997; Ewing and Cervero, 2001, 2010) and that accessibility is a main determinant of residential location choice (Lee et al., 2010; Hu and Wang, 2017; Baraklianos et al., 2018), other scholars have questioned the merits of accessibility-promoting policies; they argue that these policies do not necessarily reduce driving and traffic congestion (Crane, 1996a,b; Salomon and Mokhtarian, 1998; Mokhtarian and Salomon, 2001) or that accessibility is playing a declining role in shaping household residential decisions (Giuliano, 1995).

The capacity of research to support or reject the merits of accessibility is greatly influenced by the empirical measures of accessibility benefits. In both the residential-location choice and travel-behavior studies, researchers have mainly relied on measures of travel-cost savings (TCS) to represent the benefits of accessibility. In the residential location choice context, the measures are commuting-cost savings or reduced household travel expenditure; and in the travel-behavior context, they are reduced vehicle-mile-traveled (VMT) reduction or decreases in the contributing factors of VMT such as trip frequency, trip length, or the probability of driving. In other words, these studies have applied TCS as the main criterion to evaluate accessibility-enhancing land-use and transportation policies. And researchers have often cited the absence of significance TCS to question the merits and importance of these policies (Hamilton and Röell, 1982; Giuliano, 1995; Crane, 1996b; Stevens, 2017; Smart and Klein, 2018a).

In this dissertation, I have argued that a TCS-based accessibility policy evaluation ignores the non-TCS aspects (i.e., destination-utility gains) of accessibility benefits, which underestimates the value of accessibility and hence without basis weaken the policy importance of accessibility-promoting strategies. This argument is supported by both theoretical reasoning and empirical evidence. Based on data collected from the Puget Sound and Southeast Michigan region, I find that transit accessibility remains to have a significant impact on residential location choice after controlling for all TCS associated with, which I interpret as suggesting that individuals derive destination-utility gains (mainly option value) from transit access. A search for destination-utility gains often motivates individuals to make more trips and/or to travel to more remote (and more desirable) destinations, which in turn induces additional car travel; this travel-inducing effect was verified by the trip-frequency models estimated in the Southeast Michigan region, which show that transit accessibility was positively associated with car-trip frequency.

In fact, that the economic value of accessibility is beyond travel-cost savings has long been recognized by a branch of the urban and regional economics literature that concerns agglomeration economies, which refers to the positive externalities that individuals and firms gain from accessing to nearby individuals and firms (Marshall, 1890). While the classic urban and regional economics theories such as the firm-location theory (Weber, 1909), central place theory (Christaller, 1933; Lösch, 1940), and regional economy (Isard, 1956) were all built on transportation costs, in recent decades economists have increasingly relied on the concept of agglomeration economies to explain the concentration of activities in metropolitan areas and urban centers (Fujita and Ogawa, 1982; Lucas Jr et al., 2001; Glaeser, 2010). The main mechanisms of agglomeration economies include labor pooling, input sharing, and knowledge spillovers (Duranton and Puga, 2004).

The theory of agglomeration economies is well known, but its connection with accessibility research is not well understood.[2] Existing research tends to examine agglomeration economies at the city-level or regional-level, without distinguishing the intraurban differences (Duranton and Puga, 2004; Rosenthal and Strange, 2004). In recent years, however, a limited number of studies have sought to incorporate a consideration of the production externalities available at different locations into the modeling of urban spatial structure (Fujita and Ogawa, 1982; Imai, 1982; Lucas Jr et al., 2001; Allen et al., 2015), and the location-production functions applied in these studies can be essentially thought as a type of accessibility measure. This means that accessibility can also be thought of as an indicator of agglomeration economies. By establishing this connection in this dissertation, I not only add theoretical depth to the argument that accessibility has benefits beyond travel-cost savings but also bridges two large and disconnected bodies of literature—land-use and transportation research and agglomeration economies.

A marriage between two bodies of literature generates valuable insights for urban research and policymaking. For example, the fact that agglomeration economies operate in the form of production externalities provides a rationale for government intervention to promote overall regional accessibility. For example, as Anas et al. (1998) suggests, the inability of economic actors to internalize agglomeration economies can prevent the free market to form optimal urban spatial structure, which thus opens

[2]Exceptions include a few recent studies have empirically established the link between accessibility and labor productivity (Chatman and Voorhoeve, 2010; Melo et al., 2017).

the door for government interventions such as assisting sub-center formation by providing infrastructure or relaxing the land-use regulations. This is in line with what land-use and transportation planners have argued for—establishing accessibility as a central goal of social policymaking (Wachs and Kumagai, 1973; Cervero, 1997; Levine et al., 2019). Notably, this efficiency-based rationale (i.e., addressing externalities) adds further theoretical underpinning to the promotion of accessibility as a major planning goal.

My dissertation also opens the door for a new direction of accessibility research to investigate the nature and magnitude of destination-utility gains. The empirical work presented here is tentative and preliminary steps to verify its existence and its influence on residential location and travel decisions. As I have discussed in the body of the work, an ideal empirical approach to destination-utility gains requires the use of longitudinal data that records the behavioral changes of individuals who experience accessibility gains. I have resorted to cross-sectional data here due to resource constraints, which is a major limitation of my work. Future work should address this limitation. In addition, future work should examine how different population groups value travel-cost savings and destination-utility gains differently, which can generate insights which population groups to target when specific policy goals are set. For example, an understanding of which population groups have a stronger preference for destination-utility gains can inform policymakers with VMT-reduction goals to avoid targeting areas with large concentrations of these population groups.

On planning policy and practice, findings of this dissertation highlight the need to shift from a TCS-based to an accessibility-based land-use and transportation policy evaluation. Until now, the destination-utility aspects of accessibility have rarely been discussed or even mentioned in planning-related discussions, whether it is an infill-development project or a transit-investment proposal. To better promote accessibility-based planning strategies, planners should stress to policymakers and the general public the various forms of destination-utility gains, such as the choice value derived from greater flexibility and variety, enhanced social and economic interactions, and the associated spillover effects such as knowledge transfer and social learning. These arguments would be further strengthened if the regional household travel survey incorporates questions regarding individual preference for various forms of destination-utility gains and if empirical indicators of these destination-utility gains are incorporated into the land-use and transportation plans developed by metropolitan planning organizations.

Moreover, standard tools of transportation planning, such as traffic-impact analysis and level-of-service modeling, are based strictly in a mobility paradigm. An expanded accessibility view as outlined here highlights the urgency of shifting from mobility to accessibility as the basis for prospective and retrospective planning evaluation. While a shift in the evaluative tools does not equate to changes in the physical environment, such a shift can remove impediments to on-the-ground accessibility-based planning implementation. As I have noted in chapter two, the recent integrated land-use and transport models have already modeled accessibility with more comprehensive measures (e.g., gravity-based and utility-based measures) that can capture both the TCS and destination-utility gains. By elaborating on the different types of economic benefits picked up by these measures, My dissertation thus provides a theoretical underpinning to the accessibility modeling approach in these models.

My dissertation further contributes to planning practice by identifying a major methodological flaw in existing land-use and transportation modeling and simulation work. When metropolitan planning organizations calibrate regional land-use and transportation models to forest future land-use patterns, they usually rely on current or historical data on household travel and residential location behavior to estimate household preference for accessibility. These preference estimates are then directly applied to the forecasting models. Chapter 4 of the dissertation shows that such practice is problematic because households' revealed behavior, which these preference estimates are derived from, is often different from their "preferred behavior" because of the existence of supply constraints. These constraints prevent them from expressing their true preferences, which implies that solely relying on revealed behavior for land-use and transportation modeling can exaggerate the problematic "predict-and-provide" transportation-modeling approach that has been heavily criticized in the literature (Owens, 1995; Banister). Therefore, I argue that land-use and transport models with predictive purposes should incorporate information regarding the preferred behavior of households.

Written at a time when fully automated vehicles will soon (at least according to optimistic predictions) pour into our streets, this dissertation sheds light on the question of how autonomous vehicles will shape individual residential-location and travel patterns. Autonomous vehicles free people from driving and allow them to work, entertain, or rest in the car, which means that the disutility associated with in-vehicle travel time would decrease significantly. That is to say, autonomous vehicles will lead to substantive reductions in the time cost of travel perceived by travelers. As the time-plus-money cost of travel declines, individual travel and residential-location decisions are likely to be less driven by travel-cost savings than the competing factors (e.g., neighborhood quality in the context of residential location choice). Thus under a TCS-based view of accessibility benefits, geographical proximity between people and activities would become less important in an era of autonomous vehicles; individuals are likely to live further away from their jobs and would be more willing to take long trips. It follows that autonomous vehicles would lead to further suburban sprawl and greater VTM consumption.

While I do not negate these potential impacts, I stress here the existence and importance of destination-utility gains, another form of accessibility benefits that can hold people and activities together in an era of autonomous vehicles. While autonomous vehicles are expected to reduce the TCS associated with proximity, they are less likely to reduce the interaction value (a component of destination-utility gains as I described in chapter two) brought by it. Holding the transport network constant, greater proximity to spatially distributed opportunities (i.e., people and activities) leads to more interactions within a given amount of time. Any additional minute spent on travel, in either an autonomous vehicle or a regular car, means lost time and potential opportunity for meaningful interactions. Therefore, if people live too far away from work or take longer trips, they would be able to make fewer trips (purposeful interactions) in a given day; and if people are far away from other people and activities, they are less likely to gain from random interactions, i,e,, knowledge spillovers (Jaffe et al., 1993) and social learning (Glaeser, 1999). Therefore, under emerging technologies, as with the transportation and communication technologies of the past, it remains important for us to build cities and regions that facilitate better accessibility.

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