TRANSIT ORIENTED DEVELOPMENT:
DOES IT REDUCE HOUSEHOLD EXPENDITURES ON TRANSPORTATION?

by

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To my beloved family, for their unconditional love and support.
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ABSTRACT

TRANSIT ORIENTED DEVELOPMENT: DOES IT REDUCE HOUSEHOLD EXPENDITURES ON TRANSPORTATION?

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This dissertation aims to provide a more complete picture about transit oriented development (TOD) by dealing with two major questions – first, what makes regions more or less likely to encourage the adoption of TOD policy; and second, whether, how and to what extent does TOD influence household expenditures on transportation. The first research question is tested through the discrete event history models, in which a set of key regional characteristics including population density, central-place population, personal income, congestion level, transit service, and political culture that shape the adoption of TOD policy are highlighted. The second research question heavily draws on several rich streams of literature on the built environment and travel behavior. The analysis first focuses on the half-mile radius area around each fixed guideway transit station across the San Francisco Bay Area, using a structural equation modeling approach. Particular emphasis is placed on what TOD characteristics influence average
household transportation costs and how important TOD characteristics are relative to other factors. A number of TOD characteristics do increase transportation affordability to varying degrees, though most elasticities are small in magnitude. Meanwhile, some of these TOD characteristics increase housing costs, further indicating the importance of integrating affordable housing goals into the development of TOD. An independent but closely related analysis on the same research question is followed by, though the emphasis has shifted to the household level analysis. The role of TOD as a distinct planning strategy in affecting household transportation costs is specified within a sample selection model’s framework, while controlling for residential self-selection bias. The finding of the moderately positive contribution of TOD to reducing household transportation costs remains the same. The empirical results also shed light on the effective TOD policy-making and implementation.
CHAPTER 1 INTRODUCTION

Over the past several decades, there has been a groundswell in policy innovation regarding sustainable development and livable communities at all levels of government across the United States (Reconnecting America, 2011). As President Barack Obama (2010) addressed:

It’s time to throw out old policies that encouraged sprawl and congestion, pollution, and ended up isolating our communities in the process. We need strategies that encourage smart development linked to quality public transportation, and that bring our communities together. (para. 31)

Among these policy innovations, transit oriented development (TOD) is particularly considered as a comprehensive approach to sustainable community and regional planning that integrates housing, transportation, environment, economy, and other critical social issues. By creating mixed-use and higher density communities and integrating public amenities around transit stations, TOD has gained in popularity as a key tool to boost public transit use, reduce automobile dependence, and combat urban sprawl. It also serves as an effective economic engine for substantial development and redevelopment in some areas.
The California Department of Transportation (2002) provides a straightforward definition of TOD, which captures the essence of TOD. In general, [TOD is] moderate to higher density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment, and shopping opportunities designed for pedestrians without excluding the auto. (p. 3)

It is a new-fangled notion embedded within an old idea – public transit orients development and vice versa. Public transport had a great impact on the evolving form and structure of the U.S. metropolis in the 19th century (Muller, 2004). Urban development followed transit routes (Black, 1995). Coming into the 20th century, the economic and social activities in the cities gradually began to take on an “auto” structure. The relationship between transit and urban form appeared to be delicate as well (Giuliano, 1995).

What does the future of our communities look like? What is the best way to invest, build, and connect our communities to serve the changing needs of individual and families? For many urban planners and scholars, TOD is a promising choice. Traffic congestion, suburban sprawl, urban revitalization, and pollution mitigation, among many others, are reasons often addressed by TOD proponents (Cervero et al., 2004).

Yet, not everyone sees it in a positive light. TOD has been considered as “a much-hyped concept with a predictable amount of misinformation and misrepresentation within the policy and development worlds” (Costello et al., 2003, p. 10). Though TOD is formulated and implemented to achieve numerous social and economic objectives, it may also result in some unexpected consequences such as the gentrification-induced
displacement (Pollack, Bluestone, & Billingham, 2010). Furthermore, when land and housing values skyrocket near transit, the policy commitment to meeting the affordable housing needs lags far behind in many cities. The debate over whether TOD has allowed residents to have more affordable housing and transportation choices continues unabated. To settle the difference, a deep and well-developed understanding of TOD remains critical.

1.1 MOTIVATION

The recent spurt in TOD literature mostly focused on (1) planning strategies and implementation (e.g. Banai, 1998; Boarnet & Crane, 1998); (2) TOD’s impact assessment (AAA, 2000; The Great Communities Collaborative, 2007; Wilson, 2005); and (3) TOD and travel behavior (e.g. Cervero, 2007; Dill, 2006). Studies in the first two categories are usually from a city or a planning agency’s perspective. Studies in the third category largely center on a sample population living in some particular TOD and non-TOD neighborhoods. A matched-pair comparison or before-after comparison is often conducted to evaluate the impact of TOD on people’s travel behavior. Nevertheless, several limitations still exist. Some of them loosely identify TOD, without distinguishing between stand-alone transit stations and transit stations in the TODs. Some others are too narrative to translate the information into sufficient quantitative or monetary sense.

With these in mind, the primary motivations behind this dissertation are twofold. First, the research aims to highlight a number of key factors behind the adoption of TOD

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1 The gentrification-induced displacement refers to the migration of higher income households to lower income neighborhoods.
policy at the regional level. While many studies have delivered rich information on how TOD can affect our everyday life, little is known about the reasons why this planning effort is addressed and adopted. As more regions begin to consider such a policy, it is important to understand the observed patterns of TOD implementations and the underlying factors that affect such a policy decision.

Second, the research is expected to create a deeper and more objective understanding of TOD’s impact on household transportation spending, which is one of the most important expenditure items in daily life. The image of TOD is often associated with the beautiful community design and friendly non-auto environment. However, instead of leaping out as a buzzword from the planning world, delivering the real benefit to the broad end users is absolutely critical to the survival and success of TOD in the long run. A fundamental question for end users (i.e. travelers) remains under-researched. That is, whether TOD as a planning concept can serve people’s needs and expectations that translate into tangible expenditure savings. Admittedly, there may be a number of benefits associated with TOD based on a wide variety of economic, social and environmental criteria. Monetary savings remain as one of the most visible and tangible benefits for every single traveler. Thus, a key objective for this research is to examine the effectiveness of TOD in cutting people’s transportation burdens.

1.2 RESEARCH QUESTIONS

To bridge these literature gaps aforementioned, this dissertation will provide a more complete picture about TOD and its impact on urban life by dealing with two major
questions – first, what evokes local effort to encourage TOD policy; and second, whether, how and to what extent does TOD influence household expenditures on transportation?

The conceptual framework linking these two research questions together is set up as below (Figure 1-1). As shown in the framework, regional characteristics could be an important trigger for a region’s decision to commit to a TOD policy. A number of factors, including population density, personal income level, traffic congestion level, transit service, and political culture, are expected to affect regions’ decisions on TOD. On the other hand, the presence of TOD influences people’s travel, including their household expenditures on transportation.

**Figure 1-1 Conceptual framework on regional characteristics, transit oriented development and household travel.**

In particular, the research will define TOD in two different ways. First, TODs can be distinguished from non-TODs based on a set of the built environment characteristics. By quantifying these built environment characteristics, the strength of TOD can be obtained. Second, at an aggregated level, TOD is simplified as a yes-or-no indication. A number of TOD related databases, surveys, and reports help to specify whether a
neighborhood is a TOD. While the latter approach allows a general comparison between the TOD and non-TOD neighborhoods, the former approach enables an investigation in more details – what TOD characteristics influence household expenditures on transportation and how important these attributes are relative to other factors.

1.3 RESEARCH CONTEXT

1.3.1 Transit Oriented Development in Urbanized Areas

To answer the first research question, the analysis is conducted at the urbanized area level across the United States. The characteristics of different urban areas and how they grow over time are important to be considered when formulating policies such as TOD. Most of the growth-related problems such as congestion and environmental pollution are regional in nature (Burchell et al., 1998). Local organizations and governmental entities such as regional planning councils, metropolitan planning organizations, and local transit agencies usually take the lead to promote TOD. In general, TOD should not be understood as “an isolated occurrence” at individual localities; rather, it is a planning tool to create “a network of places and nodes with community-wide and even regional scope” (Reconnecting America, 2009, p. 2). An important goal for implementing TOD is to produce regional benefits rather than simply station area benefits. For these reasons, the research focuses on an urban area level analysis in the United States. It will provide a meaningful context to understand how TOD policy decisions are shaped.
1.3.2 Transit Oriented Development in the San Francisco Bay Area

The San Francisco Bay Area is chosen to answer the second research question for several reasons. First, this is a metropolitan area that encompasses several large cities including San Francisco, Oakland, and San Jose, along with smaller urban and rural areas. It has one of the most extensive public transit systems and highest transit ridership in the U.S. Yet this area has also suburbanized as rapidly as any large U.S. metropolitan areas during the freeway era. Around 70 percent of both population and employment growth in this area occurred outside of San Francisco, Oakland, and San Jose from 1980 to 1990 (Cervero, 1996). Therefore, the Bay Area provides an ideal context for comparing people’s travel costs in transit-oriented neighborhoods and auto-oriented neighborhoods.

Second, TOD has been at the heart of a regional growth strategy in the Bay Area in recent years (Association of Bay Area Governments, Bay Area Air Quality Management District, San Francisco Bay Conservation and Development Commission, & Metropolitan Transportation Commission, 2006). The Metropolitan Transportation Commission (MTC) is its regional transportation planning agency and has been a national leader in leveraging its authority to promote sustainable communities. The Bay Area’s TOD has enjoyed much more rapid growth than most other areas in the U.S.

Third, more importantly, the San Francisco Bay Area has rich data sources for local TODs, which will facilitate a comprehensive and in-depth analysis of TOD at the regional level. For instance, many TODs are well recorded in the California Transit Oriented Development Searchable Database, which provides station area description and
project information, including project owner, developer, cost, initiated and completed date, as well as other related information. Another important data source is the Bay Area Travel Survey (BATS 2000) that retains detailed information on the precise home locations, origins and destinations of all trips, and travelers’ socioeconomic and demographic information. The National TOD Database, on the other hand, offers detailed social, economic, and built environment information for each fixed guideway transit station area in this region. Combined with data from the Census 2000, they together will provide rich data sources that supply sufficient numbers of cases and appropriate variables to study the development of TOD in the San Francisco Bay Area.

The richness of TOD related data in the Bay Area further allows empirical tests at different levels – the household level and the transit station area level. It is worth noting that this is not simply a model repetition using data at two levels. Rather, different models will be applied to different dataset at these two levels. The household level analysis mainly relies on the Bay Area Travel Survey data, while incorporating other data from the Center for Neighborhood Technology, Census 2000 and the California Transit Oriented Development Searchable Database. The station area level analysis uses data from the National TOD Database, representing a more aggregate-level examination. Particularly, both average household transportation and housing costs are available in the National TOD Database, enabling the test of trade-off between these two largest household expenditure items in the context of TOD. The consistency of the results from these two different models verifies the moderately positive role of TOD in reducing household transportation spending. In addition, each model addresses different issues and
provides additional insights respectively, which will be discussed in detail in the following chapters.

1.4 DISserTATION ORGAnIZATION

Following the introduction in this chapter, Chapter 2 reviews the relevant studies to further demonstrate and detail the literature gaps, thereby creating a rationale for this dissertation. The concept of TOD, including its nature, origin, and development is first discussed to provide a solid foundation for the subsequent analysis. The literature review also draws together different scholars’ research on other two distinct areas: first, policy innovation, and second, the built environment and travel.

Next, Chapter 3, 4 and 5 empirically test two research questions aforementioned and interpret the results of the analysis. Using the discrete event history analysis, Chapter 3 identifies a number of regional characteristics that encourage the adoption of TOD policies. While Chapter 4 examines the relationship between TOD and average household transportation costs at the transit station area level using structural equation models, Chapter 5 offers additional insights into the same research question at the household level with a Heckman’s sample selection model. Chapter 6 presents a summary of the analyses and concludes with key findings and policy implications from the dissertation. Future research directions are also discussed.
CHAPTER 2    LITERATURE REVIEW

As discussed earlier, this dissertation seeks to provide answers to two key research questions – first, what evokes local effort to encourage the adoption of TOD policies; and second, to what extent and in what manner does TOD influence household expenditures on transportation? This chapter summarizes three strands of literature that provide a background of TOD and help in answering these research questions.

2.1    OVERVIEW OF TRANSIT ORIENTED DEVELOPMENT

2.1.1    A Context: Urban Growth and Public Transportation in the United States

Before defining the concept of TOD as well as its scope and nature, it is necessary to understand how urban growth and public transportation evolved in the United States. The assumption that transit might orient development and vice versa is not new. The history of public transportation is intimately connected to industrialization, urbanization, and the separation of residence from workplace (Pucher, 2004). Adams (1970) identified a framework of four transportation-related eras in his article “Residential Structure of Mid-Western Cities” (Figure 2-1). A particular movement technology and network expansion process dominated each of these four growth stages. It is a reflection of the evolving structure of the U.S. metropolis since the 19th century (Muller, 2004). In short, the evolution of transportation modes conferred accessibility advantages on intra-urban
locations and extended urban boundaries, increasing the need for transportation along the urban periphery (Yago, 1983).

![Figure 2-1 Intra-urban transport eras and metropolitan growth patterns: (I) Walking - Horsecar Era, (II) Electric Streetcar Era, (III) Recreational Auto Era, and (IV) Freeway Era.

2.1.1.1 The Walking - Horsecar Era (1800 - 1890)

When dramatic growth in manufacturing attracted major job population growth, public transport emerged as a critical factor during the early 19th century (Hesen, 2004). The first organized on-road public transit began with the omnibus – the for-hire horse-drawn passenger services. The introduction of horse- or mule-drawn streetcars then displaced omnibuses quickly, taking advantage of their greater capacity and higher speeds (Muller, 2004). By the 1890s, nearly 5,700 miles of horse-car lines were in use in American cities (Kain, 1999). The improved mobility allowed a slow but inexorable expansion of the city’s scale. The downtown central business district (CBD) emerged at the end of the walking-horsecar era, due to the intensified needs for specialized
commercial, retailing, and other services (Muller, 2004). However, the specific limitations such as the high costs, the sanitation problem, and the disease threat made the system unacceptable and yielded to the development of the new transit technology.

2.1.1.2 The Electric Streetcar Era (1890 - 1920)

The invention of the electric traction motor by Frank Sprague revolutionized urban transit system. The first large scale electric powered trolley line was installed in Richmond, Virginia in 1888 (Muller, 2004). The similar streetcar systems were adopted by more than twenty other cities adopted within a year, and quickly became the major mode of intra-urban transit by the early 1890s. These transit lines extended into sparsely developed areas and filled in the gaps between the towns and cities (Black, 1995). Transit enabled real estate development. One of the most dramatic impacts was the swift residential development of urban fringes-radial trolley corridors (Muller, 2004). There was a rapid growth both in transit use and in the size and extent of the cities (Kain, 1999). Most of the residents got access to intra-urban areas, thanks to the low fare trolley. The faster electric commuter trains superseded steam locomotives in the wealthiest suburbs. Heavier electric railways also emerged in some of the newer metropolises that lacked the street-rail legacy.

2.1.1.3 The Recreational Automobile Era (1920 – 1945)

The next technological phase came with the invention of the internal combustion engine. The diesel and electric trolley buses took place of street railway services (Kain, 1999). By 1920, the electric trolleys, trains, inter-urbans, elevateds and subways
blossomed and had gradually transformed many tracked cities into metropolis, whose suburbs and mill-town intercity rail corridors became spatially integrated (Muller, 2004). Many planners and geographers agreed that intra-metropolitan transportation achieved its greatest level of efficiency, as complex transit systems had been developed in every major U.S. city. The structure of the U.S. cities during this time period was best summarized in “the well-known concentric-ring, sector and multiple nuclei models” (Muller, 2004, p. 74). The automobile was introduced into the U.S. cities in the 1920s and 1930s, mostly by the wealthy-class for recreational purposes. However, Henry Ford with his revolutionary assembly-line manufacturing techniques made the automobiles available and popular for a majority of Americans soon (Muller, 2004).

Meanwhile, modern urban transit reached its first crisis point. The suburban home-building industry did not provide subsidy to privately owned streetcar companies any more, making the financial underpinning of the public transit industry collapse (Muller, 2004). On the other hand, the use of automobiles and the opening of freeways effectively contributed to the decentralization of the central city: “[w]ith an ever larger segment of the urban population residing in automobile suburbs, their spatial organization was already forming the framework of contemporary metropolitan society” (Muller, 2004, p. 72). There were no longer large enough passenger volumes to support new fixed-route public transit facilities. The mixed trolleys and auto traffic worsened street congestion (Garrison & Levinson, 2005). The combination of these factors ended the period of urban growth dominated by public transportation in the 1920s.
2.1.1.4 *Freeway Era (1945 – present)*

The Freeway Era represented the coming of age of the automobile culture (Muller, 2004). New freeways across the country led to massive post-war suburban expansion, producing a network based development pattern. The major impetus of freeway expansion was 1956 Interstate Highway Act that created the Highway Trust Fund. The federal government simultaneously fostered suburban growth in many other ways, including the promotion of suburban home ownership by setting up strict lending guidelines that favored the new constructions of single-family houses in suburban areas (Hanlon, Short, & Vicino, 2009). Another enormous influence was from the automobile lobby, who strongly touted the role of freeways in rebuilding American urban life (Mohl, 2002). They assured people that as a positive social good freeway could prevent the spread of blight and slums, stimulate land value, and speed redevelopment of run-down areas.

The historic all time high of public transit ridership occurred immediately during the World War II (Garrison & Levinson, 2005). Nevertheless, new transit lines are less likely to influence urban form than a century ago (Black, 1995). Only a few large metropolitan areas still count public transport as an important form of transportation. Transit use grows well beyond the national average as the size of the metropolitan area increases (Pisarski, 2006). Some people even argued that new transit routes have almost no impact on land use today, as most cities in the U.S. are developed in low-density, which counters efficient use of public transport (Black, 1995). The major public transport
modes in the U.S. today are bus, metro (subway), suburban rail, and light rail (Pucher, 2004).

Meanwhile, the new challenge for transportation focused on “the efficiencies of moving people about the dispersed, polycentric city of realms” (Muller, 2004, p. 82). However, public transit systems were obviously incapable of serving such an increasingly dispersed travel demand. Rather, the construction of new public transit systems was considered as an alternative to solve some urban transportation problems, such as congestion and pollution. Especially, they were designed explicitly to work with the automobile, assuming that most people would drive to suburban stations rather than walking, biking, or riding feeder-bus systems (Belzer & Autler, 2002). Transit stations therefore are often surrounded by large amounts of parking lots, being isolated from the neighborhood nearby. Public transit system became more and more auto-oriented.

Auto-oriented transit systems did not get out of the dilemma. The rising income, the rapid growth in automobile ownership, the expanded roadway network provided important impetuses to urban decentralization, and further hurt the development of public transit. Transit agencies gradually began to learn that they could play a role in increasing ridership by guiding the land development near stations (Carlton, 2007). They found neo-traditional neighborhood design could help increasing pedestrian activity and encouraging transit use. Anti-sprawl movement in the 1980s further strengthened the campaign for neo-traditional neighborhood design. It was out of this time period that the concept of TOD emerged and came into formal practice.
The rationale behind this new concept is the long-lasting relationship between transit and land use, which still matters today. The influences of urban form and transit infrastructure on social and economic development still show up in many policy debates, notably urban sprawl versus the compact city (see Cervero, 2001; Ewing, Rolf, & Don, 2002). On the one hand, some scholars find that compactness has a very limited relationship with social equity (Burton, 2000), reduced automobile trips (see Breheny, 1993; Galster et al., 2001), transportation energy use (Bouwman, 2000) and urban sustainability (Galster et al., 2001). Altshuler and Gomez-Ibanez (1993) believe that “[t]he cost of sprawl would be the cost of supplying some infrastructure in advance of its eventual need and would be lower the more rapidly infill was expected” (p. 72). On the other hand, many studies point out that sprawl creates the longer travel distances and ultimately increases automobile dependence and social costs of travel (see e.g. Burchell et al., 1998; Ewing et al., 2002; Holtzclaw, 1994; McCann, 2000). Instead, more compact and mixed land use patterns may reduce vehicle miles traveled and encourage the use of alternative travel modes. Likewise, a rich literature has shown that TOD supports more travel by non-automotive modes (see e.g. Cervero et al., 2002; Transportation Research Board, 2007). TOD is therefore often linked to conservative aesthetic, and environmental improvements (Cervero et al., 2004). In sum, the empirical evidence so far suggests that the debate is still inconclusive. Both positive and negative impacts of urban form and transit use are shown to varying degrees across different study areas and different time periods.
2.1.2 The Concept of Transit Oriented Development

As early as the 1960s, Jane Jacobs (1993) in her book *The Death and Life of Great American Cities*, called for planners to reconsider the single-use housing projects, large car-dependent thoroughfares, and segregated commercial centers that had become the norm. She advocated a dense and mixed-use urban aesthetic that would preserve the uniqueness inherent in individual neighborhoods. Her theory had important influences on urban planning movements such as New Urbanism and Smart Growth (Parker, 2003).

New Urbanism is an urban design movement that began in the United States in the early 1980s (Gillham & MacLean, 2002). The central idea is the push for the creation of compact, walkable and livable neighborhoods with a range of housing and job opportunities. New Urbanists believe that a return to traditional neighborhood patterns is essential to restore functional and sustainable communities. Similar in concept to New Urbanism is Smart Growth. It refers to a set of transportation and land use principles that are the antithesis to sprawl (Soule, 2006). Most Smart Growth strategies encourage compact, transit accessible, pedestrian-oriented, mixed land use development patterns as well as land reuse. In recent years, New Urbanism and Smart Growth are having a growing influence on how and where urban areas choose to allow growth. There is a growing appreciation of potential benefits from integrating transport and land use planning to create more sustainable, accessible, and multi-modal communities.

TOD is a particular design scheme that is based on principles addressed in the movements of New Urbanism and Smart Growth. It is one of the most comprehensive transit-friendly development strategies (Pucher, 2004). Calthorpe (1995) in his book *The
The Next American Metropolis: Ecology, Community, and the American Dream codified the concept of TOD as “a mixed-use community within an average 2,000-foot walking distance of a transit stop and a core commercial area” (p. 56). According to Calthorpe (1995),

[TODs] add emphasis to the integration of transit on a regional basis, providing a perspective missing from strategies which deal primarily with the nature and structure of individual communities and neighborhoods. (p. 41).

The mix residential, retail, office, open space, and public uses in a walkable environment make TOD convenient for residents and employees to travel by public transit, bicycle, foot or car. Commercial areas, residential areas, public spaces, and secondary areas are the four major components of a typical TOD design (Figure 2-2).

![Calthorpe's diagram of transit oriented development.](image)

It should be noted that transit oriented development and transit adjacent development are different. A transit adjacent development can be defined as:

[development that is physically near transit [but] fails to capitalize upon this proximity….It lacks any functional connectivity to transit – whether in terms of land use composition, means of station access, or site design. (Cervero, Ferrel, & Murphy, 2002, p. 6).

On the other hand, a real TOD is usually marked by some key traits: (1) mixed use development; (2) development that is close to and well served by transit; and (3) development that is conducive to transit riding. Some other traits that are less universally discussed and addressed in many studies include: (1) compactness; (2) pedestrian- and cycle-friendly environments; (3) public and civic spaces near stations; and stations as community hubs (Cervero et al., 2002). For TODs incorporating housing, the residential density usually has a minimum average of 15 units per acre, which is much higher than the typical suburban developments of 4 to 5 units per acre (Hess & Lombardi, 2004). In general, most definitions of TOD are built on Calthrope’s synthesis of ecological, aesthetic, pedestrian, anti-sprawl, regional and equitable planning principles (Carlton, 2007).

TOD can be categorized by both scope and size. It is not a one-size-fits-all phenomenon. White and McDaniel (1999) identified six modes of TOD: (1) single-use corridor development that concentrates single transit-intensive uses in transit corridors; (2) mixed-use corridor development that focuses on a variety of land uses on a single parcel; (3) neotraditional or traditional neighborhood development that focuses on design
features to reproduce traditional town or village settings with small lots, narrow streets, detached parking behind houses, reduced setbacks and front porches; (4) transit oriented development and pedestrian pockets that encourage compact, mix-used development concentrated near transit stations; (5) hamlets and villages that feature a cluster of single-family homes around a central green area; and (6) purlieu, which is a community with approximately 150 acres and 7,000 residents, with comprehensive urban design regulations but few use restrictions. Similarly, Dittmar and Poticha (2004) define six TOD types, ranging from highly urban to commuter town centers, based on seven factors including land use mix, residential density, housing types, scale, regional connectivity, transit modes, and transit frequencies.

While considerable attention has been given to TOD at the station and community levels, TOD corridors have taken or are beginning to take shape in many cities (Cervero et al., 2004). Examples include the Rosslyn-Ballston corridor in Arlington County, Virginia, and the Vermont/Western district in Los Angeles’s Hollywood area. TOD at a more macro scale can be understood as the well-coordinated transit-supportive development at a metropolitan area, where transit and the city co-exist in harmony (Cervero, 1988). In Cervero (1998)’s book *The Transit Metropolis: A Global Inquiry*, he illustrated twelve transit metropolises that have successfully meshed their transit systems and cityscapes in different urban contexts. As he addressed in the book,

[These successful transit metropolises] not only enjoy high levels of regional mobility but support larger policy objectives as well – sustainability, accessibility,
livability, social diversity, entrepreneurship, and the broadening of choices in

2.1.3 Measuring Transit Oriented Development

Quantitative measures for TOD are central to the present research. There have
been many research efforts in this area. The geographical scale for these land use
variables vary enormously, ranging from census block, census tract, transportation
analysis zone (TAZ), zip code, to very highly aggregated city, regional and metropolitan
level data (see e.g. Boarnet & Sarmiento, 1998; Cervero & Murakami, 2010; Holtzclaw,

The foregoing discussion has illustrated that there is no single definition of TOD.
Nevertheless, most of these definitions share common traits, including “close proximity
to a transit station, a mix of land uses, and conduciveness to transit riding, most often in
the form of pedestrian and bicycle-friendly environs and nearby public spaces for riders”
(Lund, Cervero, & Willson, 2004, p.5). Bernick and Cervero (1997) also enumerate the
essential elements of TOD, including enhanced mobility and environment, pedestrian
friendliness, alternative suburban living and working environments, neighborhood
revitalization, public safety, and public celebration.

By and large, three dimensions of the built environment are addressed when
measuring TOD – density, diversity, and design (Cervero & Kockelman, 1997). Cervero
and Kockelman (1997) use factor analysis to combine a large set of built environment
variables into “three Ds”. Factor analysis enables the built environment being captured
from various dimensions and allows for collinearity at the same time. Studies then
expand the so-called “three Ds” to “seven Ds”, in which destination accessibility, distance to transit, demand management, and demographics are added (Ewing & Cervero, 2010).

A large body of literature has been developed on measuring density. The most common measurement is population density. Other density measures that are often used include employment density, retail density and housing unit density (see e.g. Cervero & Kockelman, 1997; Cervero & Murakami, 2010). Built form density can also be found in several studies (see e.g. Chatman, 2006). It is defined as total workers and residents per developed acre of land. Diversity is usually defined as land use mix level, which is measured by an entropy index or a dissimilarity index (Boarnet, 2011). The entropy index reflects the evenness of distribution of different land use types within a study area. The dissimilarity index, as defined by Cervero and Kockelman (1997), is the fraction of adjacent parcels or grids that have different land use patterns from the parcel or grid of interest. Finally, the dimension of design is commonly measured by block size and the proportion of intersections that are four-way (Boarnet, 2011).

Instead of using the traditional “three Ds”, the latest TOD strategic plan in Portland uses “five Ps” to measure TOD and its readiness (Center for Transit-Oriented Development & Nelson/Nygaard, 2011). These five TOD-supportive physical forms are:

- People: the number of residents and workers in an area has a direct correlation with reduced auto trips;
- Places: areas with commercial urban amenities such as restaurants, grocers, and specialty retail not only allow residents to complete daily activities without getting in
a car, but they also improve the likelihood of higher density development by increasing residential land values;

- Physical form: small block sizes promote more compact development and walkability;
- Performance: high quality, frequent bus and rail service makes public transportation a more reliable means of getting around and can be correlated to less driving;
- Pedestrian/bicycle connectivity: access to sidewalks and low stress bikeways encourages many more people to walk or cycle to transit and neighborhood destinations.

These attributes are further compiled into a single, meaningful, and measurable indictor to measure “TOD Readiness” for each light rail station and major bus corridors. They are categorized into three groups: transit oriented, transit related and transit adjacent. The final results are presented as both 2D and 3D visualization (Figure 2-3). Compare to 2D, the 3D visualization provides a clearer and more intuitive way to visualize the TOD performance.

Figure 2-3 TOD readiness in Portland (2D and 3D visualization).
Although population density, mix of employees and residents, and block size, among many others are the most widely used measurement in this regard, neighborhood is sometimes generalized to a single dichotomous variable in many studies (Cervero & Radisch, 1996; Khattak & Rodriguez, 2005). For instance, a neighborhood is either traditional or suburban, TOD or non-TOD. While informative, it does not tell much about how different dimensions of related neighborhood characteristics respectively may influence people’s travel. The multidimensionality and interconnections that exist between these characteristics should be addressed (de Abreu e Silva & Goulias, 2009).

2.1.4 The Merits of Transit Oriented Development

TOD is designed to accomplish several key social and economic objectives. Proponents believe that TOD can be an effective tool in curbing sprawl, reducing traffic congestion, and expanding housing choices (Cervero et al., 2002). The most direct impacts of TOD include increased ridership of public transportation, the associated tax revenue gains from the revitalization of declining neighborhoods, the increases in land values, the increased supply of affordable housing by social programs and governmental subsidies, and regional economic development (Cervero et al., 2004). Among TOD’s secondary benefits are congestion relief on streets and highways, land conservation, reduced outlays for roads, and improved environment for pedestrians and cyclists through better streetscape designs.

However, skeptics question the merits of TOD mentioned above. Generally, there is high confidence in TOD’s ability to improve local conditions such as neighborhood quality, but less faith in its role in relieving region-wide problems like sprawl and traffic
congestion (Cervero et al., 2004). For instance, critics challenge the premise that TOD relieves traffic congestion (Cox & O’Toole, 2004). TOD could add more traffic to nearby streets, as the majority of travel to transit oriented areas will still be by automobile. As for the environmental concerns, the contribution of public transit as a means for sustainable development is by no means automatic (Bae, 2004). More particles and sulfur dioxide and fewer volatile organic chemicals would derive from public transport. Therefore, the net reduction in the pollution damages from the increased transit use at TODs might also be very limited. Pro-sprawl studies even try to challenge the rationale behind TOD, arguing that urban sprawl is inherent to urbanization, and the individual’s need is actually the invisible hand behind urban sprawl (Bruegmann, 2005).

From a cost perspective, Cervero et al. (2004) suggest that “a stepped-up transit investment and TOD program that effectively curbed sprawl would likely save the United States over $10 billion annually in public infrastructure expenditures” (p. 128). On the contrary, other researchers argue that the comparison of costs between low- and high-density areas is meaningless, as the housing units, attendant scale, and other related services are not comparable at all (see e.g. Altshuler & Gomez-Ibanez, 1993). They believe that “the cost of sprawl is the cost of supplying some infrastructure in advance of its eventual need and will ultimately be lower the more rapidly than infill takes place” (p. 72-73).

2.2 POLICY INNOVATION

The theories on policy innovation help to understand the adoption of TOD policy. Policy innovation has been extensively examined in the existing literature. It is found that
various internal and external regional characteristics can elevate or diminish the likelihood that a region adopts certain policies (F. S. Berry, 1994; F. S. Berry & Berry, 1990, 1992). Internal characteristics refer to a region’s political, social and economic characteristics. Particularly, internal characteristics mainly address the severity of a certain problem, resources available to policy makers, political ideology and interest group pressures (Daley & Garand, 2005; Doyle, 2006; Miller & Richard, 2010). On the other hand, external characteristics refer to the factors outside of this region that can aid or deter policy innovation. For instance, the possibility of certain policy adoptions at one region is associated with the previous adoptions at its neighboring areas. In general, Walker (1969) believes that states with higher level of education, income and urbanization are the most frequent policy innovation leaders.

External characteristics are mainly investigated by the analysis of diffusion. Policymaking is argued as a diffusion of policy ideas across different levels of governments, both vertically and horizontally (Daley & Garand, 2005). The motivation behind it may vary. Shipan and Volden (2008) identify four major mechanisms of policy diffusion – learning from earlier adopters, economic competition among proximate cities, imitation of larger cities, and coercion by state governments. The effects of such diffusion may also vary across policy areas. A large group of studies claim to find a positive regional diffusion effect, while numerous others find ambiguous and even contradictory evidence for it (see e.g. Haider-Markel, 2001; Hays & Glick, 1997; Mooney, 2001).
Scant empirical evidence has been systematically provided to indicate what regional factors matter behind the implementation of TOD. However, it is not difficult to find that areas with a strong interest toward TOD strategies are facing great development pressures driven by a group of social, demographic, and economic issues, including:

- Traffic congestion: Traffic congestion is getting worse in recent years. According to the 2011 Annual Urban Mobility Report (Schrank, Lomax, & Eisele, 2011), annual delay per peak period traveler at 439 U.S. urban areas has grown from 14 hours in 1982 to 34 hours in 2010. The delay was even worse in large urban areas with over one million population, reaching 44 hours in 2010.

- Suburban sprawl: Suburban sprawl, featured by low-density settlements, unlimited outward extension, and segregation of land use type, has dominated American growth for decades (Downs, 1999; Ewing et al., 2002). Studies find that people living in more sprawling areas tend to have higher rates of driving and vehicle ownership, spend more on transportation as a percentage of total household income, suffer more polluted air, face a greater risk of fatal accidents, and walk and use public transit less (Burchell et al., 1998; Ewing et al., 2002; McCann, 2000).

- Urban decay: The decay of urban centers is characterized by widespread physical deterioration, a lack of investment in buildings and services and a high concentration of visible and invisible social problems (Andersen, 2003). It results from a combination of socioeconomic factors, including the expansion of highway systems, suburban sprawl, industrial decline, real estate neighborhood redlining, social inequality and local planning policies (Andersen, 2003).
Population and family structure: Over the next twenty years, the population in the U.S. is getting older and more diverse (Harrel, Brooks, & Nedwick, 2009). At the same time, singles are replacing families with children as the new majority in this country. While population and family structures are changing, the housing market is changing – more and more people show great interest in walkable, livable, and mixed-use communities. The market demand estimate for TOD rises from 14.6 million households by 2025 to 15.2 million by 2030 (Center for Transit-Oriented Development, 2006).

2.3 HOUSEHOLD TRANSPORTATION COSTS IN THE CONTEXT OF TOD

The investigation of the relationship between TOD and household transportation costs is in line with the broad-spanning research on travel and the built environment. The spending on transportation is a reflection of travel decisions made by a consumer of transportation. When households engage in more activities related to transportation, this may directly lead to a higher level of transportation spending. Hence, interpreting the relationship between TOD (i.e. the built environment) and travel behavior is an important first step to understand how TOD affects household expenditures on transportation.

According to Chatman (2005), exogenous changes in the built environment may affect both people’s travel quality and quantity, where the latter is the major concern in this dissertation. The qualities of travel refer to comfort, convenience, annoyance, safety, privacy, noisiness, physical effort, and aesthetics. For instance, more mixed land use types may be more attractive for pedestrians and transit users. Quantitatively, travel can be further characterized by travel distance and frequency. Modal choice and auto ownership are also widely discussed in the literature. In addition, per-unit price of travel
by different modes is also affected by the built environment (Chatman, 2005). These travel characteristics that can be captured quantitatively will be illustrated respectively in the following sections.

Lastly, it should be noted that though not typically addressing the concept of TOD, a large number of studies examine a variety of built environment features, many of which can be commonly found in TOD. As such, these studies are incorporated into the subsequent discussion on travel patterns and TOD.

2.3.1 Travel Patterns and TOD

2.3.1.1 Travel Distance

A key transportation objective for TOD is to reduce motorized travel distance (Cervero & Kockelman, 1997). Cervero and Kockelman (1997)’s analysis support the positive role of compact, mixed-use, pedestrian-friendly development in shortening motorized non-work trips. The average personal vehicle miles traveled (VMT) in dense and mixed-use neighborhoods is significantly lower. Similarly, Kockelman (1997) discloses that land use balance and mix substantially affect vehicle kilometers traveled (VKT). Vehicle trips appear to be as frequent but shorter in more balanced and mixed land use neighborhoods.

Cao (2009) examines the causal inference in land use and travel, using a self-administered survey data of eight neighborhoods in Northern California. He confirms the ability of changes in the built environment to stimulate changes in travel behavior, after controlling the effect of residential self-selection resulting from individual preference and
attitude related to neighborhood choice and travel outcomes. On average, people living in suburban neighborhood drive 25.8 miles more per week (i.e. 16 percent of individuals’ overall vehicle miles driven per week) than those in traditional neighborhood. The effect of residential self-selection accounts for less than 25 percent of the total impact of neighborhood type on driving distance.

The article by Ewing and Cervero (2010) is an ambitious feat of synthesis, encompassing diverse collections of studies on travel and the built environment. The results from meta-analysis show that the elasticities of VMT are in the range of 0.00 to -0.22 for variables in the dimensions of density, diversity, design, destination accessibility and distance to transit. Though these built environment variables are largely significant, their magnitudes are quite small. Likewise, Bento et al. (2005)’s study also reaches similar conclusion, finding that population centrality, job-housing balance and transit availability have modest impact on annual VMT of U.S. households. The elasticities of VMT with respect to individual measures of urban form features are on the order of 0.2 in absolute value or less. However, VMT can be significantly reduced when several measures of urban form are changed simultaneously. When a typical household in Atlanta is moved to Boston and all land use patterns are changed to the average values in Boston, its annual VMT is cut by 25 percent. Hence, the impact of land use variables on travel distance is additive.

By contrast, other studies show a more conservative attitude, suggesting little or no relationship between the built environment and motorized travel distance. Tracy et al.

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2 Self-selection refers to the tendency of people to choose where to live based on their anticipated or current travel patterns and preferences (Chatman, 2006). A detailed discussion on self-selection is in Section 2.4.2.
(2011) indicate that among seventeen built environment variables tested, only street kernel density is found to be statistically significant in the home-based vehicle miles traveled (VMT) model. Socio-economic factors, rather than the built environment, have more power to explain the change in travel distance.

Crane (1996) presents a model of travel demand, and finds that the grid street pattern, traffic calming and mixed land use can either increase or decrease the vehicle miles traveled. As he suggests,

[T]he result in any instance depends in part on how sensitive the demand for each mode is to changes in the time required for each trip, how well one mode substitutes for another, and the particular manner in which the plan is implemented…[The new designs such as TOD] can thus cause problems when naively applied. (p. 118).

2.3.1.2 Travel Frequency

In looking at the impact of built environment on travel frequency, the findings are very similar as in the preceding section. The general consensus is that built environment features such as pedestrian-friendly design, land use mix, and density are negatively associated with motorized trip frequency.

Cao et al. (2009a) investigate the relationship between the built environment and non-work trip frequency. After controlling for socio-demographics factors, a variety of neighborhood characteristics are significant in predicting non-motorized and motorized trip frequency. Traditional neighborhoods with higher density, and more land use mix are associated with more walking and biking trips and fewer auto trips. Though a few built
environment variables turn out to be insignificant after controlling for attitudinal factors, more remain significant in the model. The impact of built environment features on trip frequency therefore is not negligible.

The impact of the built environment on trip frequency also varies by trip purpose (Schwanen & Mokhtarian, 2003). Grocery shopping frequency is affected most by the built environment characteristics (Handy, 1992). A better accessibility to commercial service encourages more grocery shopping trips. Like grocery shopping trips, the frequency of discretionary trips is also greatly influenced by the built environment.

Despite a number of studies claiming that land use patterns do influence trip frequency, some scholars believe such a relationship has not been “well enough understood to inform policy” (Boarnet & Sarmiento, 1998, p. 1167). Women and household with more children make more non-work trips, while the elderly have fewer non-work trips. Household income is positively related to non-work trip frequency. However, among four land use variables at census block or tract level including population density, the percentage of the street grid within a quarter-mile radius of each person’s residence which is characterized by four-way intersections, retail employment density and service employment density, none of them is significant either individually or jointly. While the zip code level data is brought into the same model, retail density and employment density become significant – higher service employment density is associated with more non-work automobile trips, and higher retail employment density is associated with fewer non-work automobile trips. The author therefore addresses that
geographical scale needs to give sufficient attention when examining the relationship between land use and travel.

Crane and Crepeau (1998) propose a car trip frequency model as a function of trip price, household characteristics, and land use characteristics. At the household level, they find that increases in vacant and undeveloped land uses and dense street patterns are closely associated with fewer non-work car trips. As the distance from the central business district increases, the number of car trips increases. Nevertheless, at the individual level, none of these variables remain significant, except for the vacant share of land uses. The more vacant land use, the fewer non-work car trips. In addition, the share of commercial land uses in the trip origin stands out as a significant factor associated with trip generation. The larger the share of commercial use in the trip origin, the more non-work car trips are.

2.3.1.3 Travel Mode

As illustrated in Cervero (2002)’s study:

Mode choice is usually treated as an application of consumer choice theory, grounded in the belief that people make rational choices among competing alternatives so as to maximize personal utility, or net benefit. (p. 206)

Under the theoretical framework of consumer choice, the allocation of land spaces to different transportation modes has a direct impact on modal supply (Zhang, 2004). For instance, density reduces spatial separation and therefore may encourage travel by all modes. Since non-motorized modes are more sensitive to travel distance than motorized
modes, density’s influence on non-motorized modes appear to be greater than it is on motorized modes.

Cervero (2002) frames a utility-based model that takes into account the built environment features, generalized cost of travel as well as demographic, and socioeconomic attributes of travelers. A persistent strong relationship between mode choice and land density and diversity is identified. Other design factors such as sidewalk ratio appear to be far weaker in shaping mode choice among local residents. Similarly, Zhang (2004) in his case study of Boston finds that the use of non-auto modes is positively and significantly associated with population density, and network connectivity at trip origins. However, land use balance does not have a significant impact on mode choice for commuting to work. In all, the impact of individual aspects of land use on mode choice is relatively small though largely significant. The composite effect of land use can still be considerable, which should not be ignored by policy makers.

Frank and Pivo (1994) measure land use mix and density in terms of population density and employment density at both trip ends and explore their impact on mode choice for transit, walking and single-occupant vehicle (SOV). The findings show that density and land use mix are both related to mode choice, even when controlling for non-urban form factors for both work trips and shopping trips. As density and land use mix increase, the use of transit and walking increase, while the use of SOV declines. While population density matters more at the trip origin, employment density matters more at the trip destination. In addition, the relationship between density and mode choice is
nonlinear. Their analysis sees a dramatic increase in the percentage of trips by transit as employment density increases to more than seventy-five employees per acre.

Cervero and Kockelman (1997) also offer some encouraging findings to support this claim, revealing that denser and more pedestrian-oriented neighborhoods are associated with a higher-level use of shared-ride, transit, and non-motorized modes for non-work travel. The study further points out that the presence of retail activities within a quarter of mile of residences can greatly encourage commute trips via transit and non-motorized modes. Its role is more significant than residential density in the model that predicts the probability of choosing a non-personal vehicle mode for commute trips. As the authors concluded, their findings based on experiences from the Bay Area “suggest that diversity and design within residential neighborhoods appear capable of yielding transportation benefits not only for non-work travel, but for work trips as well” (Cervero & Kockelman, 1997, p. 216).

On the other hand, attitudinal factors are believed to be more strongly and more directly associated with travel than land use characteristics, as shown in Kitamura et al.’s research (1997). They report that neighborhood characteristics such as residential density, transit accessibility, mixed land use, and the presence of sidewalks are statistically associated with mode split and amounts of travel for five diverse neighborhoods, in the San Francisco Bay Area, when only socio-economic differences are controlled for. Once the attitudinal factors are introduced into the model, neighborhood characteristics largely lose their significance to explain the change in travel. Instead, personal attitudes toward travel are much more strongly associated with travel than are land use characteristics.
Similarly, Stead (2001) believes socio-economic characteristics are much more important than the built environment to explain travel mode choices.

While the research discussed above suggests the positive or partially positive impact of built environment characteristics on mode choice, some studies negate such a role completely. In a study by Hess (2001), he finds a significant impact for parking charges on mode choice, but pedestrian friendliness and proximity to light rail remain insignificant in the same model. Boarnet and Sarmiento (1998) claim that higher transit use in TOD is a result of self-selection and not the built environment at all.

2.3.1.4 Vehicle Ownership

The built environment does not only affect the travel distance and mode choice, but also changes in auto ownership (Handy, Cao, & Mokhtarian, 2005). Auto ownership plays an intermediary role to connect the built environment and travel behavior. Statistics shows that car ownership in TODs is lower than other areas (Renne, 2005). Hess and Ong (2002) introduce a model to examine auto ownership based on household, neighborhood, and urban design characteristics. They find that households living in mixed land use areas are more likely to walk or bike to nearby locations, and thus their need for autos are substantially less. In Zegras (2010)’ study, apartment living, dwelling unit density, diversity index and local street network pattern appear to be significant in influencing household vehicle ownership.

Shay and Khattak (2005) compare vehicle ownership in a matched pair of neighborhoods – one conventional and one neo-traditional. The results suggest that vehicle ownership is more responsive to household income and household size, rather
than to neighborhood designs. The relationship between ownership of particular vehicle classes and neighborhood design is also examined. Households in conventional neighborhoods tend to have a higher level of passenger car ownership, but no significant difference exists for other vehicle types such as sport utility vehicles (SUVs) and light trucks and vans (LTVs).

To control for self-selection bias that has been largely neglected in earlier research, Bhat and Guo (2007) propose a joint mixed multinomial logit-ordered model to explore the impact of built environment features respectively. Residential and employment density are found to be marginally significant to insignificant negative in predicting car ownership. Street block density and transit availability have significant and negative impacts on car ownership. On the other hand, demographic and housing tenure have strong effects on car ownership propensity.

In another study by Cao et al. (2007), the findings from cross-sectional and quasi-panel data appear to be different. The cross-sectional analysis tells that the observed correlation between the built environment and car ownership is mainly a result of self-selection. The quasi-panel analysis, on the other hand, shows that some built environment features such as mixed land use and outdoor spaciousness remain significant even after attitudinal factors are controlled. Though statistically significant, these built environment characteristics are small and marginal. In contrast, the impact of socio-demographics is dominant. It indicates that the decision on auto ownership relies on people’s “mobility needs” and “purchasing power” (p. 830).
2.3.1.5 *Per-Unit Price of Travel*

Per-unit price of travel refers to the time and money cost per mile (Chatman, 2005). Time cost is usually measured by speed, which is the reciprocal of time cost. Chatman (2005) models trip speed as a function of the built environment characteristics and other relevant independent variables. As he articulated, the built environment theoretically influences trip speed in several ways. First and foremost, higher density may increase road congestion, assuming road capacity is constant. Meanwhile, a fine-grained mixing of land uses could decrease congestion and increase the trip speed, by reducing travel distance between activity locations. Second, higher density could influence the share of distance spent on walking for different trips. For auto trips, the share of walking could increase, as parking space in these areas is usually limited in quantity, size and location. On the contrary, for transit trips, the share of walking could decrease if higher-density development is associated with more closely spaced transit stops. Finally, higher density could mean shorter waiting time for transit, as density could influence economies of scale in transit service provision.

In addition, the parking supply can be also understood as a built environment characteristic that directly affects the monetary cost of travel (Chatman, 2005). The cost of parking itself is an important part of the costs of owning and using a car. Moreover, the cost and availability of parking is a critical factor affecting modal choice (Chatman, 2006). Citing the survey results from 1993 of San Francisco Bay Area workers living near heavy-rail stations, Cervero (2004) reported that station-area residents who paid for
parking were much more likely to take transit than drive compared to those who received free parking.

While parking is generally oversupplied and under-priced, it has become the root problem of distorting transportation use, including transit use (Shoup, 2005). Especially, the oversupply of parking in TOD is believed to be a major obstacle to create a vibrant, pedestrian-friendly community near public transit stations (Wilson, 2005). Parking charges at the residence and the workplace are found to have a strong influence on the transit use in TOD. Reforming parking policy, from reducing minimum parking requirements, charging higher meter prices, and cashing out of parking subsidies, can help speed the flow of traffic, encourage denser development, rehabilitate pedestrian environment, and consequently increase transit use (Shoup, 2005).

2.3.1.6 Summary and Discussion

To date, the literature pertaining to the connection between the built environment and travel behavior strikes at several directions and presents very mixed findings about the true nature of this interrelationship. (Guo & Chen, 2007, p.529)

Though a broad literature in this field shows various data, methodologies and results, some common ground can still be identified. In a reduced form, a typical land use-travel behavior regression includes a measure of individual or household travel as the dependent variable, and a vector of land use variables and socio-demographic variables as the independent variables (Boarnet, 2011). In addition, measures of attitudes are also brought into the model to control for self-selection bias.
Past research can also be summarized into three ways to expand this simple regression into “a more structural, and hence more behavioral, understanding of the land use – travel behavior link” (Boarnet, 2011, p. 201). First, land use is understood to influence travel behavior by influencing the cost of travel in terms of travel speed and time. Travel demand is then a function of travel price (travel speed or time), income and socio-demographic factors. However, this approach is not widely adopted, because it is usually difficult to find good instrumental variables for the endogenous measures of travel price.

A more popular approach is to connect residential location choice with travel behavior. As suggested by several studies, people’s choices of where to live in part are based on how they wish to travel (see e.g. Cervero, 1994). In other words, “the association between land use and travel appears to be partly causal and partly due to persons sorting (or choosing) residential locations that match their travel preferences” (Boarnet, 2011, p. 202). Ideally, the relationship between land use and travel should be examined by modeling residential location choice and travel behavior simultaneously.

Last but not least, Boarnet (2011) discusses the endogeneity of policies, plans and urban development patterns, which are rarely focused on in the existing literature. Compared to endogeneity of land use through residential location choice, endogeneity of policy and plan development appear to be “larger” and “more systemic” (Boarnet, 2011, p. 203). Land use policy can be understood as a reflection of current residents’ preference, though whether it is a valid claim remains to be confirmed. Furthermore,

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3 In section 2.3.3 Housing Cost, residential location choice theory is discussed for details.
beyond the relationship between land use and travel behavior, how changes of travel preference can be influenced by changes in the built environment and social network is also under-researched.

2.3.2 Household Transportation Costs and TOD

As Cao et al. (2009a) indicated, “travel cost is a generalized cost including time, out-of-pocket monetary expenditures, and psychological effects such as aesthetics and comfort” (p. 549). They argue that the built environment characteristics may be better predictors of non-motorized travel costs than motorized travel costs. Their capability of predicting transit travel costs is the weakest, especially when the transit takes the flat fare.

In one of Holtzclaw (1994)’s studies, he tests how residential density, transit accessibility, neighborhood shopping and pedestrian accessibility affect household transportation costs in four U.S. cities. The results shows that ignoring the self-selection effects, people live in the denser neighborhoods with better public transportation in these four cities spend less on their transportation budget.

Few studies specifically focus on households’ transportation costs in TOD neighborhoods, and make a direct cost comparison between TODs and their surrounding areas. However, an extensive literature, as the foregoing discussion on the built environment and travel patterns has shown, has shed light on this particular topic. For instance, TODs are found to support more travel by non-automotive modes and reduce auto travel (Cervero et al., 2002). In the same sense, the increased non-automotive travel and reduced auto travel is very likely to translate into out-of-pocket savings in transportation and energy consumption.
Measurement of transportation costs is different in previous studies. Transportation costs are measured in time in Cervero et al. (2006)’s study, in which the authors address that commute times are by far the largest component of any generalized transportation cost expression. Some studies further measure the total time costs of travel as the product of time spent traveling multiplied by unit costs. The unit costs may vary depending on different travel purpose, and travel conditions (Small, Winston, & Yan, 2005). In a study by Haas et al. (2008), household transportation costs are aggregated by three categories of transportation costs – automobile ownership, automobile use in annual household miles, and annual household transit use. These three categories of transportation costs are estimated by three separate multiple regression equations, which combine several built environment and socioeconomic variables, with various weights.

2.3.3 Household Housing Costs

Though this dissertation has its focus on household transportation costs, housing costs, especially its trade-off with transportation costs is a topic that deserves special attention. As indicated in Cervero et al. (2006)’s report, William Alonso’s theory of “bid rents” has framed the understanding of how the trade-off between housing and transportation costs shapes metropolitan spatial structure. William Alonso (1964) extended Von Thunen’s agricultural land use model to urban land use. His model describes the rent as a function of distance from the center of economic activity: the rent a land user is willing to pay will fall with transportation distance at a decreasing rate. The theory was further developed by Mills (1973) and Muth (1969), with a focus on the residential location choice. Specifically,
[Residential location theory identifies] a city form in which the greatest population density and highest land values are at the center and in which these density and land value gradients decline with distance from the city center. (Giuliano, 2004, p.242)

The best residential location for an individual is the point at which the marginal savings of housing are equal to the marginal cost of transport, or the savings in housing are just offset by the increase in transport costs (Giuliano, 2004).

Urban economic theories have pointed out that housing and transportation choices are inextricably linked. In the real world, housing costs is usually the largest and least flexible item in the household budget. To cope with the high housing costs, a major trade-off for most households is in the costs of transportation. In general, if families spend more on housing, they tend to spend less on transportation, and vice versa. Several studies examine the trade-off between households’ housing and transportation costs. Lipman (2006) indicates that for every dollar a working family saves on housing, it spends an average of 77 cents more on transportation. A combined housing + transportation affordability index is developed to measure this trade-off (Center for Transit-Oriented Development & Center for Neighborhood Technology, 2006). This index challenges the traditional measure of affordability, by taking into account not just the costs of housing, but also the costs of transportation, which are often underestimated or ignored. The study claims that the heavier burden of transportation costs is due to higher vehicle ownership and more miles driven each day. Especially,
The combined housing and transportation costs substantially rise as one gets further from the central city and the rise is not due to rising housing costs as a percentage of income, but rising transportation costs. (Haas et al., 2006, p. 44).

Little research has directly tackled the same issue in the context of TOD. Cox and Utt (2004) point out those compact communities may pay less for transportation, but pay much more for housing and food than sprawling communities. However, more in-depth empirical evidence is needed to prove this claim. Furthermore, the concept of TOD is far more complicated than compact development. It’s too early to draw any conclusion about TOD’s role in families’ combined costs of housing and transportation costs.

In addition, affordable housing is a hot topic related to TOD. On the one hand, the housing costs could be even higher after the TOD strategy is implemented, as the neighborhoods become more convenient and desirable (Gordon & Richardson, 1997). Higher land and housing values in TODs may limit housing units affordable for lower-income households. On the other hand, other factors such as local economic conditions, local transit station location decisions, state and local commitment to preserving or developing affordable housing may affect the availability of affordable housing near transit (United States Government Accountability Office, 2009). Obviously, to make TOD more sustainable and more widely accepted, the TOD policy needs to incorporate a series of conscious affordable housing strategies.

Location Efficient Mortgages (LEMs) has been often mentioned in this housing debate. It is designed to combine a low down payment, competitive interest rates, and flexible criteria for financial qualification to allow more people have their own location-
efficient residences (Natural Resources Defense Council, 2009). Potential homebuyers use a model to determine which locations have lower transportation costs, and then can qualify for higher mortgage payments. The program gives many homebuyers an added incentive to choose location efficient residences, and therefore encourages more infill development as opposed to more automobile-dependent development. Fannie Mae sponsored a market test of the LEMs in four metropolitan areas in the U.S. Since its application in 1996, several researchers have argued that its viability as a policy instrument is questionable, especially considering that it may significantly raise default rates (Blackman & Krupnick, 2001). The program is also difficult to generate significant new demand for houses in location efficient areas (Easterbrook, 1999). If TOD fails to provide affordable housing to the residents, its positive role in improving quality of life would be very vague.

Meanwhile, many TOD developers still show a strong preference for luxury-style apartments and condominiums in the TODs, considering that TOD often has a longer, more complex, and more costly approval process for developers compared to greenfield development (Renne, 2005). It has spawned more fierce debate on housing affordability in TOD. To maintain and create affordability, a recent study suggests at least three strategies (Metropolitan Transportation Commission, 2010). First, the inclusion of affordable housing should be a direct requirement that attaches to permits for developers. Second, local agencies should improve affordability through measures that reduce transportation costs. The unbundling of parking costs from housing costs and the provision of free or discounted transit passes and car-share programs are typical examples.
to help reducing neighborhoods’ parking requirements. Finally, local agencies are also suggested to expedite the entitlement process and offer more support to higher-density development to increase the supply of TOD units and reduce the unit price.

2.3.4 Self-Selection Bias

In addition to differences in theoretical frameworks and research settings, self-selection bias is a key reason for the mixed results of models relating the built environment to travel behavior. The role of self-selection in shaping travel behavior is a critical question that has aroused passionate and ongoing debates among researchers. Self-selection refers to the tendency of people to choose where to live is based on their anticipated or current travel patterns and preferences (Chatman, 2006). An abundant literature supports the significance of the built environment on travel behavior (Bhat & Guo, 2007; Cervero, 2002; Chen, Gong, & Paaswell, 2008; Ewing & Cervero, 2001; Handy, Cao, & Mokhtarian, 2005). Most of them conclude that the total effect of the built environment on travel behavior consists of two components – the effect of the built environment itself and the effect of self-selection. It is widely agreed that if self-selection bias is ignored, the influence of the built environment can be overstated. The extent to which self-selection contributes to the relationship between the built environment and travel behavior varies by mode and trip purpose (Cao, Mokhtarian, & Handy, 2009; Mokhtarian & Cao, 2008). Bagley and Mokhtarian (2002) indicate that once attitudinal and lifestyle variables are brought into the models, residential location type shows little impact on travel demand. Zhou and Kockelman (2008) find that at least half of differences in vehicle miles traveled observed between similar households living in
different neighborhood types is due to the location itself, while the effect of self-selection accounts for the remainder. Similarly, Cao (2009) suggests that the effect of the built environment on driving behavior (vehicle miles traveled by car) outweighs that of self-selection, though the self-selection factor accounts for about 25 percent of the total influence of neighborhood type.

Self-selection bias generally results from either attitudes or socio-demographic traits. While socio-demographic characteristics can be easily accounted for in multivariate analysis, attitude-induced self-selection is more difficult to deal with. Various modeling approaches such as structural equation models, sample selection models, propensity score models, longitudinal design, and etc. have been adopted in the existing empirical literature (Mokhtarian & Cao, 2008). Many studies of this kind require additional information about travelers’ attitudes (see e.g. Bagley & Mokhtarian, 2002a; Handy et al., 2005; Khattak & Rodriguez, 2005). However, this information is usually unavailable in most household travel surveys, which imposes new challenges on data collection. Some other studies use an instrumental variable approach to alleviate the self-selection effect (Boarnet & Crane, 2001; Boarnet & Sarmiento, 1998), though models of this kind have their intrinsic limitations (Cao et al., 2009b). Especially, finding suitably uncorrelated variables with which to model built environment can be very difficult.

Despite of preponderance of evidence on the negative role of self-selection in the change of travel behavior, a few studies suggest that residential self-selection may make the impact of built environment underestimated (see discussion in Ewing & Cervero, 2010). Chatman (2009) concludes that the underestimation is because “households
prioritizing travel access – particularly, transit accessibility – may be more set in their ways”, or “households may not find accessible neighborhoods even if they prioritize accessibility” (p. 1087). Lund et al. (2004)’s study cited by Ewing and Cervero (2010a) provides a simple example to explain this point.

[I]f people are simply moving from one transit-accessible location to another (and they use transit regularly at both locations), then there is theoretically no overall increase in ridership levels. If, however, the resident was unable to take advantage of transit service at their prior residence, then moves to a TOD (transit-oriented development) and begins to use the transit service, the TOD is fulfilling a latent demand for transit accessibility and the net effect on ridership is positive. (p. 256)
CHAPTER 3  TOD POLICY IN THE U.S. URBAN AREAS: A DISCRETE EVENT HISTORY ANALYSIS

Jacobs (1993) in her book argues that, “it is futile to plan a city’s appearance, or speculate on how to endow it with a pleasing appearance of order, without knowing what sort of innate, functioning order it has” (p. 14). Similarly, Bogart (2006) addresses, “the ideal city of one time is often a reaction to the existing city, which in turn is the realized version of an earlier ideal” (p. 58). Today’s TOD must take its cue from the existing urban fabrics, using them as backbones for redevelopment and new development (Costello et al., 2003). It therefore provides all the more reason to evaluate the regional factors behind the adoption of TOD policy.

It is not fortuitous that TOD could be brought back to the forefront of many cities’ policy agendas after a long-lasting domination of automobiles in the U.S. What are the underlying forces evoking the local efforts to encourage the adoption of TOD? Scant empirical evidence has been provided to address this question. Yet understanding this relationship is important for planners and policy makers. The answer of this question, on the one hand, will help cities who are interested in TOD evaluate the viability of TOD strategies based on their existing conditions. On the other hand, by exploring factors shaping TOD policy-making process, it helps to take a step toward better understanding the observed patterns of TOD implementations. With these two objectives in mind, this
chapter will examine various urban characteristics from which the concept of TOD regains momentum in the planning and policy world.

3.1 TOD POLICY IN THE UNITED STATES

“[TOD] has gained currency in the United States as a means of promoting smart growth, injecting vitality into declining inner-city settings, and expanding lifestyle choices” (Cervero et al., 2004, p. 3). Since the late 1990s, a number of new guidelines and regulations regarding the development of TOD have been in effect in many areas across the U.S. Various cities have witnessed a considerable amount of TOD projects on the ground. More TODs are in various stages of planning and development. According to Reconnecting America (2011), as of 2010, TOD policy with direct funding or financial incentives has been adopted in eight states, including California, Connecticut, Illinois, Maryland, Massachusetts, New Jersey, Oregon and Pennsylvania.¹ Twelve urban areas (for details, see Table 3-1) have introduced specific regional TOD implementation programs or regional transit, housing and revitalization initiatives with which the idea of TOD has been dovetailed. Local TOD programs that have a comparatively smaller scale than regional programs can also be found at different levels of jurisdictions, including Phoenix, Arizona; San Mateo County, California; Denver, Colorado; Minneapolis, Minnesota; Hennepin County, Minnesota; Charlotte, North Carolina; Portland, Oregon; Seattle, Washington; and Austin, Texas.

¹ In 2010, Reconnecting America conducted a national review of state, regional and local programs that fund TOD plans and projects. Information regarding TOD policy and programs at different levels was collected by web-based research, in-person interviews, and experience learned through Reconnecting America’s technical assistance work in regions and cities across the U.S. Proposed TOD policies that have not yet been adopted or authorized were excluded. Reconnecting America is a national nonprofit that focuses on the challenges for transportation and community development.
Table 3-1 TOD policies/programs at the regional Level.

<table>
<thead>
<tr>
<th>Region</th>
<th>Start Year</th>
<th>Entity</th>
<th>Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin Cities</td>
<td>1995</td>
<td>Twin Cities Metropolitan Council</td>
<td>Livable Communities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Demonstration Account</td>
</tr>
<tr>
<td>Chicago</td>
<td>1998</td>
<td>Chicago Regional Transportation Authority</td>
<td>Community Planning Program &amp; Sub-regional Planning Program</td>
</tr>
<tr>
<td>Portland</td>
<td>1998</td>
<td>METRO Portland</td>
<td>TOD Implementation Program</td>
</tr>
<tr>
<td>San Francisco</td>
<td>1998</td>
<td>Metropolitan Transportation Commission</td>
<td>Transportation for Livable Communities Grant Program</td>
</tr>
<tr>
<td>Seattle</td>
<td>1998</td>
<td>Central Puget Sound Regional Transit Authority</td>
<td>TOD Program</td>
</tr>
<tr>
<td>Atlanta</td>
<td>1999</td>
<td>Atlanta Regional Commission</td>
<td>Livable Centers Initiative</td>
</tr>
<tr>
<td>New York</td>
<td>2000</td>
<td>Capital District Transportation Committee</td>
<td>Linkage Planning Program</td>
</tr>
<tr>
<td>Dallas/Fort Worth</td>
<td>2001</td>
<td>North Central Texas Council of Governments Planning Commission</td>
<td>Sustainable Development Funding Program</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>2002</td>
<td>Delaware Valley Regional Transportation &amp; Community Development Initiative</td>
<td></td>
</tr>
<tr>
<td>Denver</td>
<td>2003</td>
<td>Colorado Housing and Finance Authority</td>
<td>Denver Metro Mayors Caucus TOD Fund</td>
</tr>
<tr>
<td>Cleveland</td>
<td>2005</td>
<td>Northeast Ohio Arcawide Coordinating Agency</td>
<td>Transportation for Livable Communities Initiative</td>
</tr>
<tr>
<td>Washington D.C.</td>
<td>2007</td>
<td>Metropolitan Washington Council of Governments</td>
<td>Transportation/Land Use Connections Program</td>
</tr>
</tbody>
</table>

Note: The table only lists the first TOD program adopted by regions.

It has to be noted that the aforementioned regions have developed TOD-supportive policies that provide direct funding and financial incentives. Other types of policies such as design guidelines and local zoning regulations that support the development of TOD can be found in more regions across the country. However, the scope of the following analysis is limited to TOD policies with direct funding and financial incentives. Compared to other types of TOD-supportive policies, this category of policies provides the strongest incentive for creating powerful momentum for the
development and implementation of TOD. Table 3-1 lists all the TOD policies and programs with direct funding and financial incentives at the regional level, which serve as the basis for the subsequent analysis. Regional TOD policies are usually designed and implemented by regional agencies such as metropolitan planning organizations (MPOs) and transit agencies. They often cover an area crossing several jurisdictional boundaries. Different programs may focus either on planning, implementation, or property acquisition.

3.2 DATA AND METHOD

To explore the key regional characteristics that shape the adoption of TOD policy, a quantitative analysis of the initial regional TOD policy is presented. Following the vast literature on policy innovation in Chapter 2, a discrete event history analysis is employed to examine what makes regions more or less likely to adopt a TOD policy in a given year. According to the standard discrete event history analysis, the first year a TOD policy was adopted by a region is selected as a starting date. Data is then collected on a number of urban areas in the risk set, for a series of discrete time periods. After a region adopts a TOD policy, it is removed from the risk set. Using the data from the Texas Transportation Institute’s Urban Mobility Reports, the Bureau of Economic Analysis, the Census Bureau, and the National Transit Database, the dataset finally consists of several external and internal indicators of 87 urban areas from 1995 to 2007. These factors are the explanatory variables in the prediction models to estimate the adoption of TOD policy. Figure 3-1 shows the list of urban areas included in the following analysis.
3.2.1 Key Variables

The dependent variable TOD is a binary variable, which takes the value of 1 when an urban area’s TOD program is effectively implemented. The data is collected from a TOD inventory report by Reconnecting America (2011), which summarizes existing state, regional and local programs that have been established to promote TOD. As shown in Table 3-1, twelve urban areas have adopted TOD policies and therefore are coded as 1 in the year when the program was initiated. The independent variables include urban form, transportation service, socioeconomic factors and political factors that are expected
to explain the probability of TOD implementation in an urban area (Table 3-2). Summary statistics for these key explanatory variables are reported in Table 3-3. These explanatory variables are further discussed in more detail in the following subsections.

**Table 3-2 List of variables to be included in the models of regional TOD policy adoption.**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Sources</th>
<th>Expected Effects on TOD Policy Adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban area: TOD policy adoption (Dependent variable)</td>
<td>Reconnecting America (2011)</td>
<td></td>
</tr>
<tr>
<td><strong>Urban Form</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central-place population (log)</td>
<td>Census Bureau</td>
<td>+/-</td>
</tr>
<tr>
<td><strong>Transportation Service</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Socioeconomic Factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income per capita (log)</td>
<td>Bureau of Economic Analysis</td>
<td>+</td>
</tr>
<tr>
<td><strong>Political Factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State TOD policy</td>
<td>Reconnecting America (2011)</td>
<td>+</td>
</tr>
<tr>
<td>Traditionalistic political culture</td>
<td>Elazar (1994)</td>
<td>+</td>
</tr>
<tr>
<td>Moralistic political culture</td>
<td>Elazar (1994)</td>
<td>+</td>
</tr>
</tbody>
</table>

**Table 3-3 Summary statistics for key variables.**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population density</td>
<td>2151.0</td>
<td>872.6</td>
<td>989.0</td>
<td>5644.0</td>
</tr>
<tr>
<td>Central-place population (log)</td>
<td>12.7</td>
<td>0.9</td>
<td>10.2</td>
<td>15.8</td>
</tr>
<tr>
<td>Public transit annual passenger miles per capita (log)</td>
<td>4.3</td>
<td>0.8</td>
<td>2.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Roadway congestion index</td>
<td>1.0</td>
<td>0.2</td>
<td>0.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>1.5</td>
<td>0.5</td>
<td>0.9</td>
<td>3.1</td>
</tr>
<tr>
<td>Income per capita (log)</td>
<td>10.3</td>
<td>0.2</td>
<td>9.4</td>
<td>11.2</td>
</tr>
<tr>
<td>State TOD policy (0/1 dummy)</td>
<td>0.1</td>
<td>0.3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Traditionalistic political culture (0/1 dummy)</td>
<td>0.4</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Moralistic political culture (0/1 dummy)</td>
<td>0.2</td>
<td>0.4</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
3.2.1.1 Urban Form

To explore the extent to which the adoption of TOD policy is influenced by the built environment, two variables population density and central-place population are introduced in this analysis. Both of them are indicators of urban density. By re-creating compact and transit-friendly land use patterns, TOD provides an alternative model against urban sprawl, which is closely associated with various negative effects for the social, economic and environmental sustainability in urban areas.

Population density in this analysis is defined as number of persons per square mile in an urban area. Without a doubt, the implementation of TOD is expected to increase the employment and population concentrations. However, the influence of pre-existing population density on the adoption of TOD policy remains ambiguous. Shen and Zhang (2005) suggested that population density might have two potential roles in the change of land use:

[Population density could] either be an indication of high demand for urban land in the area or an indication of having little open space left in the area....[I]n the former case higher population density will increase development possibility, whereas in the latter case higher density will be negatively related to the probability of development. (p. 1464)

The second urban form variable is central-place population. Following the Census Bureau’s definition, an urban area’s central place in this study refers to the most populous incorporated place within this area (Bureau of the Census, Department of Commerce, 2002). A central place usually functions as the dominant center of an urban area. Again,
the impact of central-place population on TOD possibility is unclear. The decreasing central-place population could force a city to find out possible solutions like TOD to generate an urban revival. On the contrary, the increasing central-place population might be an indicator of strong market viability for the implementation of TOD.

3.2.1.2 Transportation Service

The adoption of TOD policy is expected to closely relate to the existing transportation service level. First, congestion level is suspected to positively relate to TOD possibility. More compact and mixed land use patterns may reduce vehicle miles traveled and encourage the use of alternative travel modes (Cervero et al., 2004; Frank et al., 2007; Holtzclaw, 1994). By allowing shorter trips and the use of non-vehicle modes, the concentration of residents, employment, shopping, and other social activities can reduce the automobile dependence and further translate into the reduction of congestion. With this in mind, areas struggling to ease traffic congestion would be more likely to adopt TOD-supportive policies. Second, public transit use is measured by annual transit passenger miles per person in this chapter. Transit service functions as the backbone of the concept of TOD. It is intuitive that a well-developed transit market may provide a favorable environment for the development of TOD.

3.2.1.3 Socioeconomic Factor

The possibility of adopting TOD policy would also be a function of other socioeconomic factors. Foremost among these factors is personal income per capita, which is introduced to measure the living standard and quality of life (Duran & Lahr,
2009). It is expected that income is positively related to the possibility of adopting TOD policy. Second, average fuel cost per gallon is introduced to reflect the cost of automobile use. Automobile associated costs may include the costs of gas, maintenance, repair, depreciation, parking, tax, and insurance. Unfortunately, no data is available to capture all these cost items covering such a long time period. Average fuel cost per gallon is the only variable available. This leaves us with an admittedly crude indicator of auto use costs. The higher fuel cost may discourage the auto use and increase the probability of adopting TOD policy in an urban area.

3.2.1.4 Political Factors

Political culture is usually taken into account when explaining various political developments (Elazar, 2003; Saha, 2011). In his book *The Metropolitan Frontier and American Politics: Cities of the Prairie*, Elazar (2003) wrote:

> Political culture can best be understood in terms of the framework it sets for individual and group behavior – in the political thoughts, attitudes, assumptions, and values of individuals and groups and in the range of permissible or acceptable action that flows from them. (p. 257)

Following Elazar (1994), three different political subcultures – moralistic, individualistic and traditionalistic cultures are identified for all the states in the United States. The moralistic political culture addresses the commonwealth conception as the basis for democratic government. Active government intervention in the economic and social life is encouraged to search for a better society. On the other hand, the individualistic political culture emphasizes the centrality of private concerns. Community
intervention into private activities is largely discouraged. The political culture with three categories is represented in the models by using two dummy variables, one reflecting whether an urban area’s political culture is traditionalistic, and the other reflecting whether an urban area’s political culture is moralistic. The hypothesis here is that TOD policy is more favored among urban areas featuring moralistic political cultures than among individualistic or traditionalistic political cultures. Finally, TOD policy at the state level is also included in the model. Following the diffusion theories for policy innovation, the hypothesis is that urban areas are more likely to adopt TOD policy when their higher level of governments have already adopted a similar policy.

3.2.1.5 Other Variables and Considerations

Other variables tested but not retained in the final model were listed in Table 3-4. Though these variables are tentatively proposed to have an impact on the adoption of TOD policy, none of them yielded significant coefficient or improved the fit of the model.

It should be noted that the list of independent variables discussed above is not exhaustive. There are quite certainly some other possible factors, for instance, the government’s leadership and the local planning tradition, may significantly influence the probability of adopting TOD policies. However, most of these variables are difficult to incorporate with quantitative approaches. Future research might develop a qualitative analysis, which can complement the quantitative analysis. The proposed models will address the most fundamental forces behind the adoption of TOD policy in the U.S. urban areas.
Table 3-4 Variables tested but not retained in the final model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban size</td>
<td>Urban area size in four categories: small, medium, large and very large</td>
<td>Schrank, D. &amp; Lomax, T. (2009)</td>
</tr>
<tr>
<td>Rail service availability</td>
<td>Whether rail service is available in the urban area</td>
<td>National Transit Database</td>
</tr>
<tr>
<td>Unlinked rail passenger trips per capita</td>
<td>Unlinked passenger trips per capita for rail modes</td>
<td>National Transit Database</td>
</tr>
<tr>
<td>Directional rail route miles</td>
<td>The mileage in each direction over which rail service vehicles travel while in revenue service on fixed guideway</td>
<td>National Transit Database</td>
</tr>
<tr>
<td>Neighboring areas who adopted a TOD policy</td>
<td>Number of neighboring areas who adopted a TOD policy (neighboring areas are defined as those areas in the same state or in the geographically adjacent areas)</td>
<td>Author’s calculation</td>
</tr>
</tbody>
</table>

Note: Rail service includes heavy rail, light rail, commuter rail, cable car and monorail/automated guideway.

3.2.2 Functional Forms

The discrete event history analysis can be conducted using different functional forms. Buckley and Westerland (2004) points out that the choice of functional form may substantially affect the results, especially considering that policy adoption is often a rare event. As the most popular model for binary data, the logit function has been widely used in different fields. To illustrate the logit transformation, assume that an urban area $i$ in the year $t$ has a probability of implementing TOD, defined as $P_{i,t}$ as follows.

$$P_{i,t} = \frac{1}{1 + e^{-(\alpha + \beta_1 x_{1,t-1} + \beta_2 x_{2,t-1} + \ldots + \beta_n x_{n,t-1})}} = \frac{e^{(\alpha + \beta_1 x_{1,t-1} + \beta_2 x_{2,t-1} + \ldots + \beta_n x_{n,t-1})}}{1 + e^{(\alpha + \beta_1 x_{1,t-1} + \beta_2 x_{2,t-1} + \ldots + \beta_n x_{n,t-1})}}$$ (3-1)
The probability $P_{i,t}$ increases or decreases as an S-shaped function of $x_1, x_2, \ldots, x_n$ in the previous year $t-1$. The independent variables are lagged by one year, allowing for prior condition to influence future policy decisions.\textsuperscript{5} To express the probability in terms of log odds,

$$\log\left(\frac{P_{i,t}}{1-P_{i,t}}\right) = \alpha + \beta_1 x_{1,t-1} + \beta_2 x_{2,t-1} + \ldots + \beta_n x_{n,t-1}$$

(3-2)

To test the robustness of the model, the estimation is repeated using a probit function and a complementary loglog function. The probit is similar to the logit, except it replaces the logistic function with the normal distribution. These two functional forms are often used interchangeably in many studies. Based on the cumulative standard normal distribution, the cumulative probability of implementing TOD in an urban area $i$ in the year of $t$ associated with any $z$ score equals:

$$P_{i,t} = \Phi(Z_{i,t})$$

(3-3)

The larger the value $Z_{i,t}$ is, the larger the probability. The model can be further presented as:

$$\Phi^{-1}(P_{i,t}) = Z_{i,t} = \alpha + \beta_1 x_{1,t-1} + \beta_2 x_{2,t-1} + \ldots + \beta_n x_{n,t-1}$$

(3-4)

\textsuperscript{5} The equations were also examined using two-year and three-year time lag structures. The results did not differ substantially from those presented below that adopt a one-year lag.
where $Z_{i,t}$ represents the nonlinear transformation of probabilities into z scores using the cumulative standard normal distribution. The independent variables $x_1, x_2, ..., x_n$ are same as in the logit model.

The complementary log-log (cloglog) function represents a third alternative to the logit and probit functions. It is more theoretically appropriate for rare event discrete event history analysis, since this function is asymmetrical – “it has a fat tail as it approaches 0 but it approaches 1 more quickly than either the logit or probit function” (Buckley & Westerland, 2004, p. 102). The probability of adopting TOD policy for a region $i$ in the year $t$ in the complementary log-log model is:

$$P_{i,t} = 1 - \exp[-\exp(\alpha + \beta_1 x_{1,t-1} + \beta_2 x_{2,t-1} + \ldots + \beta_n x_{n,t-1})]$$

(3-5)

The urban area $i$ is the basic unit in all three models. The dependent variable TOD is a binary variable, which takes the value of 1 when $t$ is a year in which the urban area $i$’s TOD program is effectively implemented. The independent variables $x_1, x_2, ..., x_n$ including urban form, transportation service, socioeconomic factors and political factors are expected to explain the probability of TOD implementation in an urban area.

### 3.2.3 Duration Dependence

To test whether the probability of adopting TOD policy changes over time, duration dependence is often taken into account in the discrete event history analysis. Traditional models assume duration independence, *i.e.* a constant hazard rate for the adoption of TOD policy over time. However, duration dependence may arise for two reasons – unobserved heterogeneity in the data and “state dependence” (Zorn, 2000, p.
Unobserved heterogeneity in the data indicates that some observations are more likely to experience the event of interest than others. If this is ignored in the model, negative duration dependence will be observed. Moreover, “state dependence” happens when the value of the hazard depends on previous values or the amount of time that has already passed. Its effect can be positive or negative. Buckley and Westerland (2004) suggest several ways to control for the duration dependence. The most general approach is to include a set of year dummy variables. One problem with this approach is that so many year dummy variables may lose a lot of degrees of freedom. The coefficient of each year dummy variable is also difficult to interpret. Another approach is to introduce a counter variable representing the time of observation or some transformation of time. These two approaches will be tested in the following analysis.

3.3 EMPIRICAL FINDINGS

The results of all three models using different functional forms are presented in Table 3-5. The variance inflation factors (VIF) for the independent variables used in each model were examined. None of the variables has a VIF that exceeds 10, which is often regarded as an indicator of problematic multicollinearity (Gujarati, 2009). Durbin-Watson tests show that there is no first-order autocorrelation, which biases the standard errors and makes the estimation less efficient. To account for heteroskedasticity across observations, the regression models take the option of robust cluster by region in STATA. These three models yield very similar results.

All models in Table 3-5 show that both population density and central-place population are significant in explaining the possibility of adopting TOD policy in urban
areas. This finding suggests that urban areas’ TOD policy-making is closely responsive to the emerging problems of sprawl. Urban areas with a declining population density are more likely to engage in adopting TOD-supportive policies. When the overall population density becomes lower because of a greater degree of sprawl, TOD is considered as a strategy to regain former levels of population density and limit urban sprawl. On the other hand, increased central-place population is an indicator of strong market viability for the implementation of TOD.

From the perspective of transportation service, annual public transit passenger miles per capita is significant and positive in all three models, reinforcing the evidence that TOD policy is more favored by urban areas that have been already conducive to transit use. Intuitively, the transit use level reflects the community readiness to accept the idea of TOD. More importantly, the positive relationship between the possibility of adopting TOD policy and the local transit use level tells that TOD is largely developed as a service improvement for the already relatively well-used transit systems, rather than launching the new transit market or reversing the shrinking transit market. In other words, TOD policy does not aim to create a market itself. Rather, the existing transit market decides and creates opportunities for TOD.

It is also worth mentioning that a two-way relationship can exist between the adoption of TOD and the level of transit use. While a good transit market gives the developer an additional incentive to build TOD, the presence of TOD then supports higher levels of transit use. The analysis in this chapter has used the lagged explanatory variables to help controlling for endogeneity bias. However, future studies should
consider more nuanced examination of such a two-way relationship and measure its impact more thoroughly.

Table 3-5 Regression results for the adoption of TOD policy at the U.S. urban areas.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Logit</th>
<th>Probit</th>
<th>Complementary Log-Log (Cloglog)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urban Form</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density, t-1</td>
<td>-0.001**</td>
<td>-0.001*</td>
<td>-0.001**</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>Central city population (log), t-1</td>
<td>1.33***</td>
<td>0.58***</td>
<td>1.21***</td>
</tr>
<tr>
<td></td>
<td>(0.47)</td>
<td>(0.22)</td>
<td>(0.44)</td>
</tr>
<tr>
<td><strong>Transportation Service</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public transit annual passenger miles per capita (log), t-1</td>
<td>0.75*</td>
<td>0.36*</td>
<td>0.81*</td>
</tr>
<tr>
<td></td>
<td>(0.38)</td>
<td>(0.16)</td>
<td>(0.40)</td>
</tr>
<tr>
<td>Roadway congestion index, t-1</td>
<td>2.59**</td>
<td>1.29*</td>
<td>3.35**</td>
</tr>
<tr>
<td></td>
<td>(2.19)</td>
<td>(0.89)</td>
<td>(2.08)</td>
</tr>
<tr>
<td><strong>Socioeconomic Factors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel cost, t-1</td>
<td>-1.84</td>
<td>-0.86</td>
<td>-1.66</td>
</tr>
<tr>
<td></td>
<td>(1.29)</td>
<td>(0.54)</td>
<td>(1.22)</td>
</tr>
<tr>
<td>Income per capita (log), t-1</td>
<td>4.38**</td>
<td>2.20**</td>
<td>4.18**</td>
</tr>
<tr>
<td></td>
<td>(2.22)</td>
<td>(0.85)</td>
<td>(1.96)</td>
</tr>
<tr>
<td><strong>Political Factors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditionalistic political culture, t-1</td>
<td>.07</td>
<td>0.11</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>(0.91)</td>
<td>(0.36)</td>
<td>(0.92)</td>
</tr>
<tr>
<td>Moralistic political culture, t-1</td>
<td>1.76**</td>
<td>0.90***</td>
<td>1.82***</td>
</tr>
<tr>
<td></td>
<td>(0.77)</td>
<td>(-.35)</td>
<td>(0.71)</td>
</tr>
<tr>
<td>State TOD policy, t-1</td>
<td>-0.75</td>
<td>-0.43</td>
<td>-0.70</td>
</tr>
<tr>
<td></td>
<td>(0.84)</td>
<td>(0.41)</td>
<td>(0.83)</td>
</tr>
<tr>
<td><strong>Duration Dependence</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time spline</td>
<td>2.93</td>
<td>4.28</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>(101.41)</td>
<td>(44.86)</td>
<td>(97.17)</td>
</tr>
<tr>
<td>Intercept</td>
<td>-68.52***</td>
<td>-33.10***</td>
<td>-66.25***</td>
</tr>
<tr>
<td></td>
<td>(9.39)</td>
<td>(8.75)</td>
<td>(18.45)</td>
</tr>
<tr>
<td>N</td>
<td>1030</td>
<td>1030</td>
<td>1030</td>
</tr>
<tr>
<td>Log pseudolikelihood</td>
<td>-55.01</td>
<td>-54.77</td>
<td>-55.59</td>
</tr>
<tr>
<td>Wald chi2</td>
<td>81.14</td>
<td>80.73</td>
<td>83.87</td>
</tr>
<tr>
<td>Prob. &gt; chi2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*p < 0.10; **p < 0.05; ***p < 0.01 (two-tailed)

Note: All models estimated with robust standard errors clustered by urban area. Estimated coefficients with standard errors in parentheses. Time spline reported is the linear time counter variable.
The results also support the hypothesis that one of the most significant forces behind the adoption of TOD at urban areas is to reduce congestion. All three models consistently show that an area’s congestion level has a strong positive impact on the likelihood of adopting TOD policy, suggesting that for many policy makers, they believe TOD holds a lot of promise to ease traffic congestion. Traffic congestion has put a huge stranglehold on many cities’ social and economic development, significantly increasing the likelihood of adopting TOD policy.

In addition, income per capita is significantly related to the possibility of adopting TOD policy. TOD policy is more favored by areas that are economically better off. This finding is along the same line of earlier studies on personal income and policy innovation in general. From the government’s perspective, the availability of economic resources may increase the motivation of policy makers to initiate a new policy alternative. At the individual level, this positive relationship may imply strong support for TOD policy from higher-income people. According to a recent report, many transit-oriented communities increase property values and attract wealthy people, while low-income households are crowded out (Pollack et al., 2010). TOD in this way increase the wealth of higher-income people, whereas lower-income people, who are more likely to be renters, have to pay more on the housing than they otherwise could afford. Without the proper planning, it can lead to stratified neighborhoods and higher rates of car ownership. This unintended consequence reinforces serious equity concerns in the TOD policy-making process. It is not surprising that people usually support policies that benefit them, and TOD policy
adds another example here. Beyond the personal benefit, another explanation to such a positive relationship is that as people’s income increases, they may place a higher value on quality of life, which may further translate into a stronger willingness to support policies that aim to solve urban problems such as traffic congestion and environmental pollution.

Elazar’s political cultural categorization stands out as the last significant factor in these models. As expected, TOD policy is more acceptable among urban areas featuring moralistic political culture compared to their counterparts with individualistic or traditionalistic political cultures. The dummy variable for traditionalistic political culture is positively associated with the possibility of adopting TOD, though its impact is insignificant. Though this political cultural classification has been criticized for being unable to account for sub-cultures within sub-state regions and cultural changes across time (Paterson & Saha, 2010), it still performs well in terms of predicting the adoption of TOD policy in this chapter. Urban areas in moralistic states led in the development of TOD programs.

Fuel cost, the existing state TOD policy, and the time spline appear to be insignificant in these models in explaining the possibility of adopting TOD policy in urban areas. The insignificance of fuel cost in the model could because average state fuel cost per gallon is a too crude measure for auto use costs. Also, the data is at the state level, which is too general to capture any significant differences among urban areas. Although the impact of auto use costs has been postulated in these models discussed above, its role is certainly not settled at this point and deserves further investigation.
Furthermore, the signs of time spline are consistently positive across models, though insignificant, which suggests that there is no duration dependence in our models. There is not any strong evidence to support regional diffusion theory either. In addition to the existing state TOD policy, another variable – the number of neighboring regions adopting TOD policy is also tested and found being insignificant. The decision on regional TOD adoption is not driven by policy choices in state level or neighboring regions. Considering TOD’s high cost and long-term consequences, regions generally make related policy decisions based on their practical internal needs rather than external conditions.

Finally, it is worth commenting on some of the variables that have been dropped out in the model specification process (Table 3-4 provides a description of each of these variables). The size of urban area had the expected positive sign but turned out to be insignificant after the congestion level was added into the model. Furthermore, since TOD is often envisioned as an infill solution that corresponds with the resurgence of rail transit system construction in many cities, an additional set of variables – the availability of rail service, unlinked rail passenger trips per capita, and directional rail route miles were used to reflect the rail transit service level in these urban areas. They all had a positive sign, though statistically insignificant. The coefficient for the number of neighboring urban areas who adopted a TOD policy was negative and insignificant. Again, this result shows that internal factors are stronger predictors of the TOD policy adoption than are diffusion effects from neighboring areas.
3.4 CONCLUSIONS

This chapter is an effort to better understand the conditions under which urban areas are willing to adopt TOD policy. Although TOD and its impact has been widely discussed, only rarely have researchers empirically investigated the factors that influence regional governments to adopt TOD policy. To address this deficiency, this chapter conducts a discrete event history analysis to examine the patterns of existing TOD policy in different urban areas.

In summary, the results indicate that the probability of adopting TOD policy increases with central-place population, personal income per capita, traffic congestion level and moralistic political culture. The possibility is also higher for areas with better-used transit systems. The probability of TOD adoption decreases with population density. TOD can be understood as the land use and economic development version of transportation demand management, favored by areas suffering comparatively greater pain from urban sprawl and traffic congestion. Adequate public transit infrastructure and well-developed transit market appears to be a perquisite for the commitment to TOD. It is less clear how TOD policy plays a role in launching new transit markets. Cities considering TOD policy should carefully evaluate their strength and quality of the current public transit service.

While TOD for many people remains as a promising idea to deliver various social and economic benefits, undesirable consequences such as neighborhood gentrification can still happen. Therefore, carefully designing good policy instruments to support TOD
is important and necessary. For instance, how to make TOD goes hand in hand with housing affordability is a big challenge.

As TOD and its policy adoptions are continuing evolving, continued efforts to monitor its causes and effects are important (Knaap & Talen, 2005). Although these regional characteristics are necessary to create an environment that helps to breed TOD policies and strategies, an exclusive focus on these characteristics cannot guarantee the success of TOD. The purpose of TOD is not to create a particular physical form but to create desirable functional outcomes such as more affordable housing, more balanced transportation choices, and more accessibility to jobs and services. Understanding these regional characteristics is just the very first step to initiate a successful TOD policy.
CHAPTER 4  TRANSIT ORIENTED DEVELOPMENT AND HOUSEHOLD TRANSPORTATION COSTS: A TRANSIT STATION LEVEL ANALYSIS

The debate over whether TOD is a more affordable way of life continues unabated. While designed to accomplish several key social and economic objectives, TOD is also blamed as the cause of gentrification and displacement (Pollack et al., 2010). Furthermore, when land and housing values skyrocket near transit, the policy commitment to meeting the affordable housing needs lags far behind in many cities. This chapter will provide some additional insight into this debate, by exploring the relationship between TOD and household transportation costs in the San Francisco Bay Area. The interaction between household transportation and housing costs is also examined.

This dissertation is pursued under the basic conceptual understanding that the built environment has an impact on transportation spending by influencing people’s travel decisions. Many studies have found evidence of statistically significant associations between the built environment and travel (Ewing & Cervero, 2010a). Travelers’ spending on transportation in different land use patterns has also been examined. Nevertheless, few address this topic in the context of TOD. The trade-off between transportation costs and housing costs makes the relationship between TOD and
household transportation costs even more complex. Many families face a choice between paying a greater share of their income for housing or bearing longer commutes and higher transportation costs. For those spend more on housing, they tend to spend less on transportation, and vice versa. However, over certain distance, generally 12 to 15 miles, the increase in transportation costs may outweigh the savings on the housing side (Lipman, 2006).

As suggested in the literature, a real TOD must be marked by some common traits, for instance, mixed use development; development that is close to and well served by transit; development that is conducive to transit riding; compactness; pedestrian- and cycle-friendly environments; public and civic spaces near stations; and stations as community hubs (Cervero et al., 2002). TOD obviously has various traits that may add value. How these TOD characteristics influence different aspects of people’s travel and in turn influence people’s expenditure on transportation is generally under-researched. To fill this gap, this chapter obtains the related data at the transit station area level in the San Francisco Bay Area and addresses the following questions: how and to what extent the distinct features of TOD influences household transportation burdens.

4.1 DATA AND METHOD

4.1.1 Methodological Framework

The literature has shown that there is a complex nature of relationships between the built environment, travel behavior and other factors. Therefore, structural equation modeling (SEM) is employed to estimate a path model, which allows the examination of
multi-stage relationships among a set of variables. In particular, this modeling approach can specify the direct and indirect effects of variables on each other. Potential endogeneity biases such as the self-selection due to household socioeconomic characteristics can also be adjusted (Cao, Mokhtarian, & Handy, 2009). Structural equation modeling is very useful to visualize and analyze travelers’ decisions as a process. It has been widely used in travel behavior research (Golob, 2003). For instance, Golob (1996) adopted SEM method to model travel time, vehicle miles of travel and auto ownership together, using Portland, Oregon as a case study. Cao et al. (2007) developed a structural equation model to explore the connection among built environment, auto ownership and travel behavior.

Following Cao et al. (2007), the matrix notation for the structural model is in the form:

\[ Y = BY + \Gamma X + \zeta \]  

(4-1)

where \( Y \) is the \((N_Y*1)\) column vector of endogenous variables, \( X \) is the \((N_X*1)\) column vector of exogenous variables, \( B \) is the \((N_Y*N_X)\) matrix of coefficients representing the direct effects of endogenous variables on other endogenous variables, \( \Gamma \) is the \((N_Y*N_X)\) matrix of coefficients representing the direct effects of exogenous variables, and \( \zeta \) is the \((N_Y*1)\) column vector of errors.

Structural equation models are performed using maximum likelihood estimation in SPSS AMOS 18.0, using a data sample of 326 fixed guideway transit stations in the
San Francisco Bay Area in the year 2000. The data is collected from the National TOD Database by the Center for Transit Oriented Development. All variables represent the average condition in a given half mile radius around each transit station. One point deserves further clarification. The subsequent analysis will not equate all fixed guideway transit stations under examination with TOD. Many transit station areas could be very automobile-oriented. Some stations could even be located literally in the middle of nowhere. Therefore, distinct built environment characteristics associated with TOD will be defined and discussed in the following subsection.

A major practical drawback to this approach is the use of cross-sectional data, which limits the ability to draw any causal conclusions. Travel behavior is a dynamic process. The cross-sectional data is too simple to capture the impact completely (Cao, Mokhtarian, & Handy, 2009b). Further studies are warranted to replicate and extend these findings when longitudinal data becomes available. Despite this limitation, the successful estimation of the following structural equation models enables us to test some interesting hypotheses and determine their general veracity. The findings are expected to enrich the understanding of TOD’s impact on household transportation spending.

As discussed earlier, the key research question is how and to what extent the features of transit oriented development influences household transportation costs. Several measures of neighborhood characteristics are first defined to distinguish those

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6 According to the Public Transportation Fact Book by American Public Transportation Association (2006),

A fixed guideway is a mass transit facility using and occupying a separate right-of-way or rail for the exclusive use of mass transportation and other high-occupancy vehicles; or using a fixed catenary system usable by other forms of transportation…[A]lthough almost exclusively located on the surface, short stretches of some of these roadways are in tunnels or elevated. (p. 48)
TODs from non-TODs. In addition, a number of other factors are introduced as control variables in the model. Figure 4-1 presents the conceptual diagram for the structural equation models. The dependent variable average household transportation costs is at the bottom in Figure 4-1. To test the trade-off between household transportation and housing costs, average housing costs is further incorporated into the conceptual model, and its relationships to other dimensions are shown with dashed lines.

Figure 4-1 The conceptual diagram for the structural equation models.
4.1.2 Data Specification

4.1.2.1 Household Transportation Costs and Housing Costs

Household transportation costs is a key variable in the model shown above. There are many ways to define transportation costs. Lee (1995) provides a simple example in this regard.

The economist’s notion of cost – which is used here – is the value of resources (used for a given input) in their best alternative use….If less time were used in travel, how valuable would the time be for whatever purpose travelers chose to use it? If clean air where less consumed in dispersing vehicle pollutants, how much would society benefit from using the air to disperse non-highway pollutants or from breathing cleaner air? This concept of costs depends, then, on benefits foregone; there is no separate measure of cost that is distinct from valuation of benefits. (p. 7)

In short, transportation costs could involve money, time, or even social costs regarding clean air, crash risk, and quiet environment. However, this chapter will primarily focus on the monetary (out-of-pocket) costs related to household transportation activities, which are the direct expenditures paid by end users (i.e. travelers) in the transportation systems. According to the National TOD Database, average household transportation costs represent the aggregation of annual household costs on auto ownership, auto use and transit use. Auto ownership costs are defined as the costs of depreciation, finance charges, insurance, license, registration and taxes (state fees). Auto
use costs include costs on gas, maintenance and repairs. All the results are based on the estimates from multidimensional regression analyses. The data is originally from the Housing + Transportation Affordability Index developed by the Center for Neighborhood Technology (CNT) with the support of the Brookings Institutions’ Urban Markets Initiative.

The Housing + Transportation Affordability Index also provides information on average household housing costs. Annual average household housing costs are calculated as an average of Selected Monthly Owner Costs (SMOC) for house owners with a mortgage and Gross Rent (GR) for renters paying cash obtained from the U.S. Census 2000 (Center for Neighborhood Technology, 2009). In summary, for these 326 fixed guideway transit stations in the San Francisco Bay Area, the average annual household transportation costs and housing costs are 10,557 and 22,124 dollars respectively.

4.1.2.2 TOD Characteristics

TOD characteristics are of particular interest in this chapter. There is no single definition of TOD. As shown in the literature in Chapter 2, three dimensions of the built environment are addressed when measuring TOD – density, diversity, and design (Cervero & Kockelman, 1997). More recent research also expands the so-called “three Ds” to “seven Ds”, consisting of density, diversity, design, destination accessibility, distance to transit, demand management, and demographics (Ewing & Cervero, 2010). Without a focus on “Ds” aforementioned, Bernick and Cervero (1997) define the

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7 A complete discussion of the methodology used for estimating household transportation costs can be found on CNT’s website: http://htaindex.cnt.org/method.php
essential elements of TOD, including enhanced mobility and environment, pedestrian friendliness, alternative suburban living and working environments, neighborhood revitalization, public safety, and public celebration. Portland uses “five Ps” – people, places, performance, physical forms and pedestrian/bicycle connectivity to measure TOD (Center for Transit-Oriented Development & Nelson/Nygaard, 2011).

Based on the data available, seven built environment characteristics associated with TOD are identified in this chapter. The summary statistics for these variables, together with other explanatory variables of interest, are provided in Table 4-1.

Table 4-1 Summary statistics for key variables in the structural equation models.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>S.D.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOD (Built Environment) Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>3.10</td>
<td>1.48</td>
<td>-4.61</td>
<td>4.65</td>
</tr>
<tr>
<td>Employment density</td>
<td>2.38</td>
<td>1.40</td>
<td>-2.08</td>
<td>5.92</td>
</tr>
<tr>
<td>Retail employment density</td>
<td>1.02</td>
<td>1.38</td>
<td>-3.74</td>
<td>4.34</td>
</tr>
<tr>
<td>Average block size</td>
<td>1.83</td>
<td>0.66</td>
<td>0.85</td>
<td>4.93</td>
</tr>
<tr>
<td>Land use mix</td>
<td>0.78</td>
<td>0.14</td>
<td>0.38</td>
<td>1.00</td>
</tr>
<tr>
<td>Betweenness</td>
<td>7.22</td>
<td>1.25</td>
<td>0.00</td>
<td>9.00</td>
</tr>
<tr>
<td>Degree</td>
<td>0.68</td>
<td>0.25</td>
<td>0.00</td>
<td>1.79</td>
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<tr>
<td><strong>Socioeconomic Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of households having elderly over 60</td>
<td>28.50</td>
<td>11.04</td>
<td>0.00</td>
<td>49.18</td>
</tr>
<tr>
<td>% of households having children</td>
<td>40.24</td>
<td>24.52</td>
<td>4.02</td>
<td>83.50</td>
</tr>
<tr>
<td>Average household income</td>
<td>11.20</td>
<td>0.34</td>
<td>10.08</td>
<td>12.09</td>
</tr>
<tr>
<td>Household size</td>
<td>2.49</td>
<td>0.67</td>
<td>1.39</td>
<td>4.49</td>
</tr>
<tr>
<td><strong>Transportation Behavior</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of commute to work by public transit</td>
<td>20.22</td>
<td>12.18</td>
<td>0.82</td>
<td>45.03</td>
</tr>
<tr>
<td>% of commute to work by non-auto transport</td>
<td>31.06</td>
<td>20.42</td>
<td>1.17</td>
<td>77.65</td>
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<tr>
<td>Average distance to work</td>
<td>1.35</td>
<td>0.70</td>
<td>-0.30</td>
<td>3.21</td>
</tr>
<tr>
<td><strong>Automobile Ownership</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of vehicle per household</td>
<td>1.37</td>
<td>0.47</td>
<td>0.23</td>
<td>2.40</td>
</tr>
</tbody>
</table>

Note: Variables degree, betweenness, average block size, population density, employment density, retail employment density, average household income and average distance to work are in logarithmic form.
Population density represents the number of residents per square mile in the transit station area. Two other density measures are employment density and retail employment density, which respectively measure the number of jobs per square mile and the number of shopping and entertainment jobs per square mile. The density for retail employment can be considered as a proxy for the intensity of commercial activities. The dimension of design is expressed in terms of average block size, which measures the pedestrian friendliness in the neighborhood. Moreover, diversity is captured by land use mix, which is an adaptation of an entropy index measuring the diversity of a component (Frank & Pivo, 1994; Messenger & Ewing, 1996). It ranges from 0 to 1 and captures the evenness of distribution of different land use types within a spatial unit. For each neighborhood, level of land use mix is defined as:

\[ LUMix = -\sum_{i=1}^{n} p_i (\ln p_i / \ln n) \]  

(4-2)

where \( p_i \) is the proportion of housing units or jobs in land use type \( i \), and \( n \) is the number of land use types present.

In addition to these commonly used measures for neighborhood characteristics, centrality measures in social network analysis are brought forward and adapted to this chapter.\(^8\) The underlying transit network has not been explicitly taken into account in the

---

8 Social network analysis is the mapping and measuring of relationships among interacting entities (Wasserman, 1998). A network usually consists of a number of actors, some of which are connected by a set of relations. The actors in the network are people, corporation, nation-states, or other collective social units. They are linked to each another by social ties, which are channels for “flow” of resources. As Knoke and Kuklinski (1982) addressed in their book, “the structure of relations among actors and the location of individual actors in the network have important behavioral, perceptual, and attitudinal consequences for the individual units and for the system as a whole” (p. 34). By conceptualizing such relationships and structures among actors, network analysis investigates emergent dimensions of complex systems that
research on the relationship between TOD and travel behavior. However, the arrangement and connectivity of each station area in the transit network may provide a broader framework to understand people’s travel decisions. Kennedy and Derrible (2009) find that transit network design is important to attract people to use public transit. Another study by Sohn and Shim (2010) uses centrality indices to account for the efficiency of each transit station’s external connectivity with metro and highway network, concluding that these centrality measures do have a significant influence on transit ridership. Following these studies, the hypothesis here is that the structural position of each station area in the transit network can affect people’s perceptions and choices on travel mode and travel distance, which in turn change people’s expenditures on transportation.

The spatial information of transit network design is collected from the National TOD Database. Again, only fixed guideway transit stations are included. It should be noted that every transportation system has a number of different sub-networks. There are intricate interactions among these sub-networks. The overall network properties that take into account all sub-networks available would be ideal, though difficult to implement due to its complexity. Limited data availability does not support such a comprehensive calculation either. Hence, the focus is narrowed down to the transit system consisting of fixed guideway stations in the Bay Area. This network is then translated into a graph, in which stations become nodes and links become edges. Accordingly, a connectivity matrix is created to represent the transit network, by assigning 1 for all pairs of stations have a

cannot be captured by simply analyzing the attributes of actors (Knoke, 2008). All the social network measures are generated using UCINET 6 in this chapter.
direct connection (*i.e.* non-stop transit service) between each other, and 0 to all others without a direct connection (see a simple example in Figure 4-2). It should be pointed out that, this binary matrix only represents the presence of the direct connection between stations, but does not taken into account real service frequency or distance.

Transit line 1 consists of transit station A, B, C, and D; transit line 2 consists of transit station A, B, C, and E.

**Figure 4-2 A pictorial representation of mapping a graph to a matrix.**

Using this connectivity matrix, two centrality measures are identified. Degree centrality and betweenness centrality are two of the most basic and frequently used measures. Compared to other centrality measures, they are easy to understand, while still providing great insights to the topic. First, degree centrality is defined as the number of direct connections that a node establishes with the others (Freeman, 1978). A higher degree implies less dependence in relation to others and more connectivity in the network. The node’s importance or centrality in this network increases when it has more direct interactions with others. Stated as a formula, degree centrality of a node *i* is:
where element $a(P_i, P_k) = 1$ if a direct connection exists between nodes $P_i$ and $P_k$ and $a(P_i, P_k) = 0$ otherwise. The formula here represents the first-order degree for a particular node, which means how many other nodes have direct connection with this node. Degree can be calculated at higher orders and enable more indirect connection with this node being captured. The degree higher than first-order could be reserved for future research to expand and improve the findings. The analysis shown here will start from a first-order degree, in which only the number of other stations that can be reached by a transfer-free trip is taken into account for each transit station.

Betweenness centrality counts the extent to which a node lies between other nonadjacent nodes on the shortest path connecting them in a network. It can be understood as a measure of the degree to which a node serves as a bridge to connect other nodes. A node with a higher betweenness can influence the network by facilitating, withholding or altering the movement of flows, and is thus important (Freeman, 1978). The betweenness of a node $i$ can be expressed as:

$$C_B(P_k) = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{g_{ij}(P_k)}{g_{ij}}$$

(4-4)

where $g_{ij}(P_k)$ is the sum of all shortest paths between nodes $P_i$ and $P_j$ that pass through $P_k$. $g_{ij}$ is the number of shortest paths that link nodes $P_i$ and $P_j$. In a transit network, stations with a high betweenness and/or degree usually are hubs that connect isolated areas in the
network. Note that distance is measured in number of links, not the Cartesian distance between transit stations.

4.1.2.3 Household Socioeconomic Characteristics

Four socioeconomic characteristics that are considered include the percentage of households having elderly over sixty years, the percentage of households having children under eighteen years, average household income and household size. Together with TOD characteristics, these factors are expected to influence household travel patterns, including auto ownership in terms of the average number of vehicles available per household, and other travel patterns such as the percentage of people who commute by transit, the percentage of people who commute by non-auto modes including walking and bicycling, and the median distance to work. The list of variables mentioned above is by no means exhaustive but is expected to capture some important effects of different TOD dimensions that pertain to household transportation costs.

4.2 EMPIRICAL RESULTS AND INTERPRETATIONS

Two structural equation models are estimated. The first model estimates the relationship between average household transportation costs and factors in four dimensions – TOD characteristics, household socioeconomic characteristics, auto ownership, and travel behavior. The second model further takes average household housing costs into consideration. Table 4-2 and Table 4-3 present the results of the first model. Table 4-2 shows the direct, indirect and total effect of each independent variable.
on household transportation costs. Table 4-3 further explains the impact of each independent variable on the key endogenous variables respectively in the model.

Table 4-2 Model 1 (household housing costs excluded): model summaries.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Direct coefficient</th>
<th>Indirect coefficient</th>
<th>Total coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOD (Built Environment) Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-.003</td>
<td>-.007</td>
<td>-.010</td>
</tr>
<tr>
<td>Employment density</td>
<td>-.007</td>
<td>-.029</td>
<td>-.036</td>
</tr>
<tr>
<td>Retail employment density</td>
<td>-.006</td>
<td>-.042</td>
<td>-.048</td>
</tr>
<tr>
<td>Average block size</td>
<td>.022</td>
<td>.085</td>
<td>.107</td>
</tr>
<tr>
<td>Land use mix</td>
<td>.083</td>
<td>-.154</td>
<td>-.071</td>
</tr>
<tr>
<td>Betweenness</td>
<td>-.001</td>
<td>-.003</td>
<td>-.004</td>
</tr>
<tr>
<td>Degree</td>
<td>-.044</td>
<td>.024</td>
<td>-.020</td>
</tr>
<tr>
<td><strong>Socioeconomic Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of households having elderly over 60</td>
<td>.004</td>
<td>-.001</td>
<td>.003</td>
</tr>
<tr>
<td>% of households having children</td>
<td>.003</td>
<td>.002</td>
<td>.005</td>
</tr>
<tr>
<td>Average household income</td>
<td>.904</td>
<td>.047</td>
<td>.951</td>
</tr>
<tr>
<td>Household size</td>
<td>.112</td>
<td>.028</td>
<td>.140</td>
</tr>
<tr>
<td><strong>Transportation Behavior</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of commute to work by public transit</td>
<td>.002</td>
<td>-.028</td>
<td>-.026</td>
</tr>
<tr>
<td>% of commute to work by non-auto transport</td>
<td>.000</td>
<td>-.018</td>
<td>-.0180</td>
</tr>
<tr>
<td>Average distance to work</td>
<td>.067</td>
<td>.008</td>
<td>.075</td>
</tr>
<tr>
<td><strong>Automobile Ownership</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of vehicle per household</td>
<td>.098</td>
<td>.086</td>
<td>.184</td>
</tr>
<tr>
<td><strong>Goodness of fit in model development</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>326</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>203</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degrees of freedom (df)</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparative fit index (CFI)</td>
<td>.904</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normed fit index (NFI)</td>
<td>.931</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root Mean Square Error of Approximation (RMSEA)</td>
<td>.084</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: (1) CFI > .9, NFI > .9 and RMSEA = .05 indicate acceptable model fits; (2) Variables household transportation costs, degree, betweenness, average block size, population density employment density, retail employment density, average household income and average distance to work are in logarithmic form.
The overall findings reported in Table 4-2 and Table 4-3 are generally in line with the common expectations. The increase of population density, employment density, retail employment density, betweenness, and degree has a direct effect of reducing household transportation costs. Average block size and land use mix level have a direct and positive effect on household transportation costs, though mixed land use’s impact is insignificant. Furthermore, these TOD characteristics are also found to significantly affect household travel patterns in terms of auto ownership, mode choice for daily commute, and distance to work, which in turn affect household expenditures on transportation. While population density, employment density, retail employment density, land use mix, and betweenness are negatively related to household transportation costs, average block size tends to have a positive relationship to household transportation costs (see Table 4-2). Among all density measures, population density has the most positive and significant impact on everyday commute to work by public transit. Employment density and retail employment density show stronger impact on commuting to work by non-auto modes, distance to work, and auto ownership, though insignificant in affecting commuting on public transit (see Table 4-3). This finding is largely consistent with the earlier literature discussed in Chapter 2. In short, as density goes up, more commute by public transit and non-auto modes are encouraged, distance to work is shortened, and the rate of household vehicle ownership also drops. All these lead to a decrease in household transportation costs. Retail employment density and employment density appear to be more significant than population density to directly influence average household transportation costs (see Table 4-2).
As expected, larger block size discourages non-automobile commute, especially the use of public transit, which then translates into higher household transportation costs (see Table 4-3). Block size does not only imply the length of block, but more importantly, the street connectivity and walkability (Ewing, Pendall, & Chen, 2003). On the contrary, a higher level of land use mix positively contributes to daily commute trips by non-automobile modes. Its impact on auto ownership is negative, though insignificant. Household transportation costs are thereupon reduced.

Two centrality measures – betweenness and degree also show some interesting results. Higher betweenness centrality encourages more commute by public transit (see Table 4-3). Shorter distance to work also occurs when betweenness centrality is higher, though the impact remains statistically minor. By this way, its total effect on household transportation costs is negative (see Table 4-2).

Degree centrality, on the other hand, shows an indirect and positive impact on household transportation costs (see Table 4-2). Nevertheless, its negative direct impact on transportation costs outweighs the positive indirect impact, supporting the hypothesis that a higher degree centrality decreases household transportation costs.

First, degree centrality is positively and significantly related to distance to work (see Table 4-3). It turns out that people living near transit stations with a high degree centrality may have access to a geographically larger employment market. A quick look into the transit planning theory may provide some additional insights and offer another possible explanation for such a relationship between the variable of degree centrality and commute trips by public transit identified in the model. As Scheurer et al. (2007) pointed
out, a complex multimodal transportation network allows a large number of alternative routes to exist between more than one pair of nodes. A transfer trip does not necessarily mean inefficiency. Instead, it may result in shorter travel time or the use of modes with better service quality for a segment of the trip than a transfer-free connection. Especially, there is always a trade-off between maximum covering and shortest path in transit planning (Matisziw, Murray, & Kim, 2006). Transit routes are usually not the shortest path, but with the great ability to access to the maximum potential ridership. Hence, a higher first-order degree in the transit network may indicate longer trips to work, because of the compromise between service coverage and shortest distance in the transit network.

Second, degree centrality’s impact on commute by public transit is positive and insignificant (see Table 4-3). Although not exciting, this finding has to be interpreted with caution. The weak association between degree centrality and commute by public transit may be due to the complexity of transportation network system, which has not been fully captured in this analysis. As addressed in the section of data and method, only fixed guideway stations are included in the analysis, while other transportation modes are completely ignored due to the data limitation. Also, the analysis is limited to the first-order degree of a particular transit station area, which indicates the number of other stations that can be reached by a transfer-free trip. Both of these limitations could weaken the capability of degree centrality explaining the transit use level in daily commute. For instance, neighborhoods having a high degree centrality for fixed guideway transit systems may have even more convenience and greater accessibility in a highway
network. In this case, its central position in the fixed guideway transit network then tends to be unimportant when households making travel decisions.

Socioeconomic characteristics among households are a group of variables that cannot be ignored. They play important roles in explaining household transportation costs, as shown in the model (see Table 4-3). Average household income stand out as a very strong predictor in explaining household transportation spending level. As average household income increases, household transportation costs go up. Additionally, transportation costs are positively associated with the percentage of households having children. Households with children are less likely to take non-automobile commute, and are more inclined to own vehicles. The underlined reason is their higher mobility requirement due to the presence of children, as explained by Hocherman et al. (1983). On the other hand, more aging population indicates a lower transportation cost, though the impact is very modest. Finally, household size increases household transportation costs in total. Larger household size also raises the possibility of owning more vehicles.

With respect to travel patterns’ impact on household transportation costs, the findings largely follow expectations. In general, household transportation costs become lower as more commute trips are taken by non-automobile modes. Savings from public transit rely on transit’s positive role in encouraging non-auto mode use, shorter distance to work, and lower automobile ownership. In a direct way, the percentages of commute to work by public transit and non-auto modes are positively associated with household transportation costs. Travelers have responded to high transportation costs by using alternative transportation modes other than automobiles. Nevertheless, the total impact is
very limited. Non-auto commute’s role is more inconsequential. Not surprisingly, the longer the distance to work, the higher transportation costs households have to face. The same relationship is found in vehicle ownership and household transportation costs.

When average household housing costs are further introduced into the model, the results are very similar as in the previous model (see Table 4-4 and Table 4-5). The direction of the relationship between each pair of variables remains the same. The impact of some variables such as household income, distance to work and auto ownership is reinforced. An important finding is that household housing costs and transportation costs are negatively and significantly associated to each other. The impact of housing costs on transportation costs is much more profound, as shown by its larger coefficient in the model (see Table 4-4). The negative relationship tells that households actively make trade-offs between these two largest expenditure items.

It is worth noting that while density measures slightly decrease average household housing costs, the structural position of a station area in the transit network shows a different impact (see Table 4-5). In contrast to the density measures, both degree and betweenness centrality measures are positively related to household housing costs. There is no doubt that households pay for location advantage. This is very true for the development of TOD, especially those TODs located in central places in the transit network. The integration of affordable housing goals into TOD then tends to be extremely critical. Otherwise, high spending on housing will quickly offset the savings on transportation, and force people move out of TOD neighborhoods to relocate to more affordable places.
Table 4-3 Model 1 (household housing costs excluded): SEM estimates.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Household Transportation Costs</th>
<th>% of commute to work by public transit</th>
<th>% of commute to work by non-auto transport</th>
<th>Average distance to work</th>
<th>Average number of vehicle per household</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOD (Built Environment) Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-.003***</td>
<td>2.241***</td>
<td>.058</td>
<td>-.008*</td>
<td>-.005</td>
</tr>
<tr>
<td>Employment density</td>
<td>-.007**</td>
<td>2.114</td>
<td>1.458</td>
<td>-.231***</td>
<td>-.148</td>
</tr>
<tr>
<td>Retail employment density</td>
<td>-.006**</td>
<td>1.295</td>
<td>.654</td>
<td>-.122*</td>
<td>-.207*</td>
</tr>
<tr>
<td>Average block size</td>
<td>.022*</td>
<td>-3.170*</td>
<td>-1.831</td>
<td>-</td>
<td>.092</td>
</tr>
<tr>
<td>Land use mix</td>
<td>.083</td>
<td>10.593*</td>
<td>14.556***</td>
<td>-</td>
<td>.630</td>
</tr>
<tr>
<td>Betweenness</td>
<td>-.001*</td>
<td>1.001*</td>
<td>-</td>
<td>-1.022*</td>
<td>-</td>
</tr>
<tr>
<td>Degree</td>
<td>-.044**</td>
<td>.210</td>
<td>-</td>
<td>.031***</td>
<td>-</td>
</tr>
<tr>
<td><strong>Socioeconomic Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of households having elderly over 60</td>
<td>.004**</td>
<td>.002</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>% of households having children</td>
<td>.003***</td>
<td>-.205***</td>
<td>-.101**</td>
<td>-</td>
<td>.007*</td>
</tr>
<tr>
<td>Average household income</td>
<td>.904***</td>
<td>-6.306</td>
<td>-12.298**</td>
<td>.222***</td>
<td>.424***</td>
</tr>
<tr>
<td>Household size</td>
<td>.112***</td>
<td>9.495***</td>
<td>5.569**</td>
<td>-</td>
<td>.029***</td>
</tr>
<tr>
<td><strong>Transportation Behavior</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of commute to work by public transit</td>
<td>.002**</td>
<td>-</td>
<td>.661***</td>
<td>-.007***</td>
<td>-.023</td>
</tr>
<tr>
<td>% of commute to work by non-auto transport</td>
<td>.000</td>
<td>.036</td>
<td>-</td>
<td>-</td>
<td>-.031</td>
</tr>
<tr>
<td>Average distance to work</td>
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<td>-1.917*</td>
<td>-.150</td>
<td>-</td>
<td>.241***</td>
</tr>
<tr>
<td><strong>Automobile Ownership</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of vehicle per household</td>
<td>.098**</td>
<td>-22.705**</td>
<td>-38.371**</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*p < 0.10; **p < 0.05; ***p < 0.01
Table 4-4 Model 2 (household housing costs included): model summaries.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Direct coefficient</th>
<th>Indirect coefficient</th>
<th>Total coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOD (Built Environment) Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-.003</td>
<td>-.008</td>
<td>-.011</td>
</tr>
<tr>
<td>Employment density</td>
<td>-.005</td>
<td>-1.634</td>
<td>-1.639</td>
</tr>
<tr>
<td>Retail employment density</td>
<td>-.006</td>
<td>-.289</td>
<td>-.295</td>
</tr>
<tr>
<td>Average block size</td>
<td>.003</td>
<td>.096</td>
<td>.099</td>
</tr>
<tr>
<td>Land use mix</td>
<td>.043</td>
<td>-.572</td>
<td>-.529</td>
</tr>
<tr>
<td>Betweenness</td>
<td>-.024</td>
<td>-.099</td>
<td>-.123</td>
</tr>
<tr>
<td>Degree</td>
<td>-.068</td>
<td>.055</td>
<td>-.013</td>
</tr>
<tr>
<td><strong>Socioeconomic Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of households having elderly over 60</td>
<td>.004</td>
<td>-.005</td>
<td>-.001</td>
</tr>
<tr>
<td>% of households having children</td>
<td>.004</td>
<td>.003</td>
<td>.007</td>
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<tr>
<td>Average household income</td>
<td>2.211</td>
<td>1.257</td>
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</tr>
<tr>
<td>Household size</td>
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<td>1.057</td>
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<tr>
<td><strong>Transportation Behavior</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of commute to work by public transit</td>
<td>.006</td>
<td>-.009</td>
<td>-.003</td>
</tr>
<tr>
<td>% of commute to work by non-auto transport</td>
<td>.003</td>
<td>-.006</td>
<td>-.003</td>
</tr>
<tr>
<td>Average distance to work</td>
<td>.094</td>
<td>4.029</td>
<td>4.123</td>
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<tr>
<td><strong>Automobile Ownership</strong></td>
<td></td>
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<tr>
<td>Average number of vehicle per household</td>
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<tr>
<td><strong>Goodness of fit in model development</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>326</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>214</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degrees of freedom (df)</td>
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<tr>
<td>Comparative fit index (CFI)</td>
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<tr>
<td>Normed fit index (NFI)</td>
<td>.962</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root Mean Square Error of Approximation (RMSEA)</td>
<td>.091</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: (1) CFI > .9, NFI > .9 and RMSEA = .05 indicate acceptable model fits; (2) Variables household transportation costs, degree, betweenness, average block size, population density employment density, retail employment density, average household income and average distance to work are in logarithmic form.
Table 4-5 Model 2 (household housing costs included): SEM estimates.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Household Transportation Costs</th>
<th>% of commute to work by public transit</th>
<th>% of commute to work by non-auto transport</th>
<th>Average distance to work</th>
<th>Average number of vehicle per household</th>
<th>Average Household Housing Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOD (Built Environment) Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>-.003***</td>
<td>.419***</td>
<td>.033</td>
<td>-.009</td>
<td></td>
<td>-.004***</td>
</tr>
<tr>
<td>Employment density</td>
<td>-.005**</td>
<td>.795</td>
<td>3.198***</td>
<td>-.349***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail employment density</td>
<td>-.006**</td>
<td>1.146</td>
<td>2.665***</td>
<td>-.222</td>
<td>-.073***</td>
<td>-.068***</td>
</tr>
<tr>
<td>Average block size</td>
<td>-.003***</td>
<td>-5.724***</td>
<td>-3.022**</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use mix</td>
<td>.043</td>
<td>21.805**</td>
<td>17.032*</td>
<td>-</td>
<td>-.182</td>
<td>-.024</td>
</tr>
<tr>
<td>Betweenness</td>
<td>-.024</td>
<td>1.001***</td>
<td>-</td>
<td>-1.043</td>
<td></td>
<td>.025***</td>
</tr>
<tr>
<td>Degree</td>
<td>-.068**</td>
<td>-2.935</td>
<td>-</td>
<td>.323***</td>
<td></td>
<td>.037***</td>
</tr>
<tr>
<td><strong>Socioeconomic Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of households having elderly over 60</td>
<td>.004***</td>
<td>.045</td>
<td>-</td>
<td>-</td>
<td></td>
<td>.005***</td>
</tr>
<tr>
<td>% of households having children</td>
<td>.004***</td>
<td>-.228***</td>
<td>-.071</td>
<td>-</td>
<td>.025***</td>
<td>.004***</td>
</tr>
<tr>
<td>Average household income</td>
<td>2.211***</td>
<td>.139</td>
<td>.565</td>
<td>.275***</td>
<td>.336***</td>
<td>2.897***</td>
</tr>
<tr>
<td>Household size</td>
<td>.197***</td>
<td>4.958*</td>
<td>3.242</td>
<td>-</td>
<td>.163***</td>
<td>.120***</td>
</tr>
<tr>
<td><strong>Transportation Behavior</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of commute to work by public transit</td>
<td>.006***</td>
<td>-</td>
<td>.941***</td>
<td>-.021***</td>
<td>-.003*</td>
<td>-</td>
</tr>
<tr>
<td>% of commute to work by non-auto transport</td>
<td>.003***</td>
<td>.230</td>
<td>-</td>
<td>-</td>
<td>-.009***</td>
<td>-</td>
</tr>
<tr>
<td>Average distance to work</td>
<td>.094***</td>
<td>-.5.079***</td>
<td>-.3.909***</td>
<td>-</td>
<td>.066***</td>
<td>-</td>
</tr>
<tr>
<td><strong>Automobile Ownership</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average number of vehicle per household</td>
<td>.403**</td>
<td>-4.031</td>
<td>-5.632*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Household Housing Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average household housing costs</td>
<td>-.789***</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Household Transportation Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average household transportation costs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-1.230***</td>
</tr>
</tbody>
</table>

*p < 0.10; **p < 0.05; ***p < 0.01
4.3 CONCLUSIONS

This chapter employs a structural equation modeling approach to investigate the relationships among TOD characteristics, auto ownership, travel behavior in terms of commute mode choice and distance to work, household housing costs and household transportation costs. In general, transit-oriented environment characterized by moderate to high density, mixed land use, smaller block size can increase overall household transportation affordability. Population density has the most significantly positive association with commute by public transit, which in turn reduces household transportation costs. Employment density and retail employment density appear to have similar but more critical role than population density to explain commute by non-auto mode, distance to work, and auto ownership. Their total effects on household transportation costs are larger than population density. The desired functional outcome of TOD, rather than physical characteristics, seems to shape people’s travel and costs in a more important way. Average block size and land use mix level show significant relationship with commute by non-automobile modes, but hardly affect distance to work and auto ownership.

Evidence from this chapter also provides strong arguments for adapting network structure measures into the model. The embedded transportation network structure facilitates a useful framework to examine people’s travel. A higher betweenness indicates a higher capacity of a station area to be an intermediary between any other transit stations. It is positively related to commute by public transit, but negatively to distance to work. In total, it places a negative impact on household transportation costs. On the other
hand, degree centrality and average distance to work have a positive association, implying that more direct connections to other transit stations do not necessarily mean efficiency in terms of travel time and quality. Degree in higher orders should be introduced in the future study to capture more indirect connectivity. A multimodal transportation network, instead of a fixed guideway transit network, may also suggest more meaningful findings.

Furthermore, the relative position of a particular station area in the urban network has a great impact on average household housing costs. The trade-off between housing costs and transportation costs at the household level is also clear. This finding is consistent with many other studies that claim land near a transit station has an added value due to its proximity to the station, especially when the station provides good service to the city center and other areas (Armstrong, 1994; Benjamin & Sirmans, 1996). As the transit station is more central in the transit network, its average housing costs become higher. As such, housing affordability will remain as a prominent concern in an efficient TOD policy adoption. If the savings on transportation is offset by the higher costs of housing, TOD will lose its inherent attractiveness as an affordable pattern of development.
CHAPTER 5  TRANSIT ORIENTED DEVELOPMENT AND HOUSEHOLD TRANSPORTATION COSTS: A HOUSEHOLD LEVEL ANALYSIS

This chapter examines the same research question in the previous chapter, albeit from a different angle. In Chapter 4, the key question is how TOD influences average household transportation spending. Relationships among different TOD characteristics, household characteristics and travel behavior including transportation costs are explored, using structural equations models. The analysis at the transit station area level concluded that a number of TOD characteristics did significantly affect household transportation costs to varying degrees. Bear in mind that the existing literature on the built environment and travel behavior is mixed and inconclusive. The discussion in Chapter 2 has shown that many studies use different data and focus on different aspects of travel behavior at different geographic scales. The findings are also very different. It would thus be of interest to learn whether different models and data types for the same study area can produce consistent results on the impact of TOD on household transportation costs. If different methods and data types produce similar results, our confidence in the findings is increased.

Therefore, the first purpose of the present chapter is to test reliability and validity of the results in the previous chapter. Unlike the structural equation models in the
previous chapter, this chapter adopts another method – Heckman’s sample selection model, which specifically underscores the importance of modeling the self-selection effect. In addition, the analysis relies on a different data source – the 2000 San Francisco Bay Area Household Travel Survey (BATS). With a more disaggregated dataset, the new models are able to move a step further to tell the impact of the TOD characteristics on people’s transportation spending in a relative sense. The impacts of the TOD characteristics themselves and the impact from self-selection can be disentangled and quantified respectively. Hence, the results are not merely for validating the relationship between TOD and household transportation costs, but also deepening and widening our understanding from different viewpoints. This serves as the second purpose of this chapter.

5.1 HECKMAN’S SAMPLE SELECTION MODEL

Self-selection is recognized as an important concern in the built environment and transportation behavior studies. Heckman’s sample selection model is one of the nine possible modeling approaches to investigate the relationship between the built environment and travel behavior, controlling for residential self-selection (Mokhtarian & Cao, 2008). Zhou and Kockelman (2008) first adopted such a methodology to investigate the role of built environment and self-selection respectively in shaping household driving distance. Cao (2009) used the same method to explore a similar research question, though introducing more attitudinal factors to obtain more robust results. Using the same modeling approach, this chapter focuses on the impact of TOD attributes on household
transportation costs as well as the role of self-selection bias in this process, which has been little discussed so far.

In short, Heckman’s approach to sample selection consists of two steps. It first specifies the decision on whether to live in the TOD neighborhood (residential location selection equation), and second the decision on how much to spend on transportation (transportation costs equation). Since the group has been selected at the first stage, the selection bias would be introduced if a standard regression were used at the second stage. A selection correction factor is therefore computed at the first stage and brought into the second-stage estimation.

A simple example may help to understand the rationale behind this approach. Suppose the decision to live in a TOD neighborhood depends on household income and on the pro-transit attitude. When only the variable of household income is entered into the model of residential location choice, the estimation may yield biased results because the omitted variable – the pro-transit attitude may be correlated with household income. At the second stage, sample households in each group (i.e. TOD and non-TOD) are the result of an underling selection process. For instance, because of the financial concerns, low-income households may choose to live in the TOD neighborhood, regardless of their attitude toward transit. However, high-income households with a strong pro-transit attitude may also live in the TOD neighborhood. The latter situation introduces biases into the estimation. To correct this bias, a selection correction factor is computed from the first-stage estimation. It measures the degree of correlation between the explanatory variables in the model and the ones omitted (i.e. income and pro-transit attitude for each
household in the above illustration). The second-stage estimation then includes this
selection correction factor and other explanatory variables, which make the estimates of
the parameters consistent.

The following equations can be considered to model each step depicted above.

The model is adapted from Heckman et al.’s (2001) study, in which they consider a
model of potential outcomes:

\[
\begin{align*}
Y^1 &= X\beta^1 + U^1 \\
Y^0 &= X\beta^0 + U^0
\end{align*}
\] (5-1)

In this chapter, \(Y\) indicates the log of household transportation costs; \(X\) represents a group
of explanatory variables, while \(\beta\) is their corresponding coefficient, respectively. \(U\) stands
for the unobserved random variables. Each household belongs to either the non-TOD (or
untreated, \textit{i.e.} control group) group or the TOD (or treated) group – not both. The control
group and treatment group are represented by the superscript 0 and 1 respectively.

Ignoring the issue of self-selection, the expected treatment effect of TOD on household
transportation costs is \(E(Y^1 - Y^0 | X)\).\(^9\) However, residential self-selection cannot be simply
ignored, as residents are hardly assigned randomly to neighborhood with TOD or non-
TOD features.

To correct the self-selection bias, a binary probit model is first developed to
predict households’ residential choices as follows.

\(^9\) In general, the term “treatment effect” refers to the causal effect of a binary (0/1) variable on an outcome
variable of policy interest.
\[ D^* = Z\theta + U^D \]  \hspace{1cm} (5-2)

\( D \) denotes the observed treatment decision. \( D = 1 \) denotes the receipt of treatment – living in TOD neighborhood, while \( D = 0 \) denotes nonreceipt – living in non-TOD neighborhood. \( Z \) is a group of observed explanatory variables that predict the binary choice of a household’s residential choice. \( U^D \), again, represents unobserved random variables. The corresponding coefficient for the treatment decision \( \hat{\theta} \) then is used to compute the selection correction factor. For a household \( i \), the selection correction factor is computed as:

\[ \frac{\phi(Z_i\hat{\theta})}{\Phi(Z_i\hat{\theta})} \text{ when } D_i=1, \]

\[ \frac{\phi(Z_i\hat{\theta})}{[1 − \Phi(Z_i\hat{\theta})]} \text{ when } D_i=0 \]  \hspace{1cm} (5-3)

in which \( \phi \) and \( \Phi \) are the probability density function and cumulative density function of a standard normal distribution, respectively.

After the estimation of each household’s residential choice, a second equation is then estimated, relating each household’s transportation costs to another group of explanatory variables. The appropriate selection correction factor is also brought into the model to control the self-selection bias. On the whole, a household’s transportation costs can be given as follows:

\[ Y = DY^1 + (1 − D)Y^0 \]  \hspace{1cm} (5-4)
Unlike the classic sample selection model, the model shown here observes both the treatment and control group (Cao, 2009).

To understand the role of self-selection bias in the model, two concepts are further introduced – average treatment effect (ATE) and the effect of treatment on the treated (TT). As suggested by Cao (2009), ATE “represents the causal influence of the built environment on travel behavior”, while TT is “the total influence of the built environment on travel behavior”, in which self-selection bias is included (p. 211). In other words, ATE in the following analysis represents the average change in household transportation costs of moving a randomly selected household from a non-TOD neighborhood to a TOD neighborhood. TT is the average change in household transportation costs for a randomly selected TOD household from a non-TOD neighborhood to a TOD neighborhood. Stated as a formula, the conditional estimate\(^{10}\) for ATE and TT, respectively, is:

\[
\text{ATE}(x) = E[\Delta \mid X = x] = x\beta^1 - x\beta^0
\]

\[
\text{TT}(x,z,D(z) = 1) = E[\Delta \mid X = x,Z = z,D(z) = 1] = x(\beta^1 - \beta^0) + E(U^1 - U^0 \mid U^0 \geq -z\theta) = x(\beta^1 - \beta^0) + E(U^1 - U^0 \mid U^0 \geq -z\theta)
\]

The integration of relevant samples leads to the unconditional estimates as follows.

\[
\text{ATE}(x) = E(\Delta) = \int \text{ATE}(X)dF(X) = \frac{1}{n} \sum_{i=1}^{n} \text{ATE}(x_i) = \bar{x}(\beta^1 - \beta^0)
\]

\(^{10}\) ATE shown in Equation 4 is conditional on the distribution of X. Similarly, TT in Equation 5 is conditional on the joint distribution of X and Z.
\[ TT = E(\Delta \mid D(Z) = 1) = \int TT(X,Z,D(Z) = 1)dF(X,Z \mid D(Z) = 1) = \frac{1}{m} \sum_{i=1}^{n} D_i TT(x_i,z_i,D(z_i) = 1) \]

(5-8)

\[ TT(x_i,z_i,D(z_i) = 1) = x_i(\beta^1 - \beta^0) + (\rho_1 \sigma_1 - \rho_0 \sigma_0) \frac{\phi(z_i,\theta)}{\Phi(z_i,\theta)} \]  

(5-9)

In the above equations, \( n \) is the sample size, and \( m \) is the sample size of the treatment group. \( \rho_1 \sigma_1 \) and \( \rho_0 \sigma_0 \) are the coefficients for selection correction factors in Equation 5-4. Since the household transportation costs in this chapter has been log-transformed, ATE and TT then are expressed in an exponential form:

\[ ATE(x) = E(\Delta) \frac{1}{n} \sum_{i=1}^{n} [\exp(x_i\beta^1) - \exp(x_i\beta^0)] \]  

(5-10)

\[ TT(x_i,z_i,D(z_i) = 1) = \exp[x_i\beta^1 + \rho_1 \sigma_1 \frac{\phi(z_i,\theta)}{\Phi(z_i,\theta)}] - \exp[x_i\beta^0 + \rho_0 \sigma_0 \frac{\phi(z_i,\theta)}{\Phi(z_i,\theta)}] \]  

(5-11)

One limitation for this model is that only one treatment type is allowed in its modeling framework. While neighborhood environments are diverse and dynamic, such a model may not be capable of capturing the full range of relations between the built environment characteristics and transportation costs. Despite this limitation, the sample selection model has a distinct advantage over other approaches, in that the effect of the built environment and the effect of self-selection on travel behavior can be specified separately, as shown in Equation 5-10 and 5-11. In addition, as Cao (2009) pointed out, unlike instrumental variables models,
In sample selection models it is not only permissible but customary for the residential choice equation and the travel behavior equations to share some explanatory variables. That is, the exogeneity is not a concern for sample selection models. This contributes to the attractiveness of the sample selection model. (p.210)

5.2 DATA SPECIFICATION

5.2.1 Measuring Household Transportation Costs

Household transportation costs are calculated based on data drawn from the 2000 San Francisco Bay Area Household Travel Survey (BATS). This comprehensive activity-travel survey offers very detailed demographic, socioeconomic, and travel diary data for a sample of about 15,000 households in the Bay Area. In addition to eliminating households with incomplete information on household weight, household characteristics, and all transportation cost components, four types of households are excluded from the analysis, including households reporting more than 1,000 daily vehicle miles traveled (VMT), households reporting the travel on weekend (Saturday and Sunday), households who carpooled, and households reporting zero transportation expenditure. The final sample includes 6,526 households.

Daily transportation costs for each household include the monetary costs on driving, parking, public transit and taxis. The aggregation of costs for parking, public transit and taxis is straightforward – by adding up all the out-of-pocket expenses together. The calculation of driving costs is a little more complicated, as the survey does not
provide the driving expenses directly. In addition, the costs vary widely across different vehicle types. The vehicle miles traveled (VMT) for each vehicle in each household is obtained from the reported odometer readings before and after the two days of the survey. While the VMT is collected directly from the survey, the cost per mile for driving alone is estimated based the AAA Your Driving Costs Estimates (2000) in the year of 2000, which includes both auto ownership costs and operating costs. Auto ownership costs refer to fixed costs in depreciation, insurance, motor vehicle taxes, license and registration and finance charges, regardless of whether or not the vehicle itself is used. Operating costs refer to the costs associated with the actual usage of automobiles. The value is calculated from the miles driven per vehicle, gasoline price per gallon, maintenance and tire expenditures. For auto ownership cost and operating cost, automobiles are categorized by size. Small sedan, medium sedan, large sedan, vans and trucks and sports utility vehicles (SUV) have different cost estimates.\textsuperscript{11}

Table 5-1 summarizes the estimated cost per mile of each vehicle category. All the estimates are then aggregated across all vehicles in a household to obtain a two-day household driving cost. Finally, this two-day household driving cost is averaged across the two survey days to obtain an average daily household driving cost.

Based on this estimation method, the obtained average household transportation cost is 39.7 dollars per day in the year of 2000, based on household weights. It leads to an annual household transportation cost $14,491. According to a report by the Urban Land

\textsuperscript{11} The classification of vehicle types in this analysis follows the United States Environmental Protection Agency’s set of classification rules based on interior passenger and cargo volumes. More details can be found on its website: \url{http://www.fueleconomy.gov/feg/info.shtml/#sizeclasses}
Institute, the average annual household transportation cost in the San Francisco Bay Area is $13,375 in the same year (Terwilliger Center for Workforce Housing, 2009). The differences are not very large. The sample also shows that about 93 percent of daily household transportation costs are on automobiles related items. The expenditures on public transit and taxis only account for 7 percent of the total transportation costs.

Table 5-1 Driving cost estimation.

<table>
<thead>
<tr>
<th>Category</th>
<th>Vehicle Type</th>
<th>Ownership Costs (Cents/Day)</th>
<th>Operating Costs (1) (Cents/Mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small Sedan</td>
<td>14.6</td>
<td>12.1</td>
</tr>
<tr>
<td>2</td>
<td>Medium Sedan</td>
<td>17.3</td>
<td>15.0</td>
</tr>
<tr>
<td>3</td>
<td>Large Sedan</td>
<td>19.8</td>
<td>15.2</td>
</tr>
<tr>
<td>4</td>
<td>SUV</td>
<td>19.9</td>
<td>15.1</td>
</tr>
<tr>
<td>5</td>
<td>Van and truck</td>
<td>17.3</td>
<td>15.0</td>
</tr>
<tr>
<td>6</td>
<td>Average (2)</td>
<td>17.3</td>
<td>14.1</td>
</tr>
</tbody>
</table>

Notes (1) Estimates on operating cost per mile is based on an annual driving distance 10,000 miles. AAA also provides different estimates based on the annual driving distance of 15,000 miles and 20,000 miles, respectively. (2) Average indicates the average of small, medium and large sedan. If a vehicle does not belong to any of these categories 1-5, it is grouped into category 6 – average.

At the county level, average household transportation costs per day range from $26 in San Francisco County to $50 in Marin County (Figure 5-1). Costs for automobiles and parking dominate total transportation costs, though households in counties with better public transit service usually have a greater share of costs on the non-automobile related part.
5.2.2 Defining a TOD Area with Census Data

TOD typically happens in the half-mile radius area around a transit station. However, it is difficult to find a proper data source to precisely measure each half-mile radius of a TOD area. In Renne’s study (2005), TOD is defined using U.S. Census data at the census tract level. Most tracts do not exactly overlap with a TOD area, hence those tracts with 50 percent or more area overlapping the half-mile area are identified. As shown in the example in Figure 5-2, tracts 2, 4 and 5 are chosen to represent the case of TOD. In this study, the same method aforementioned is adopted, but the census tract level data is replaced by the census block group level data.
Figure 5-2 Selecting Census Tracts to define a TOD area.

Existing TODs in the San Francisco Bay Area are identified based on a number of sources, including California Transit Oriented Development Searchable Database (California Department of Transportation, 2000) and two reports Transit Oriented Development in the United States: Experiences, Challenges, and Prospects by the Transit Cooperative Research Program (TCRP) (Cervero et al., 2004) and New Places, New Choices: Transit-Oriented Development in the San Francisco Bay Area by Metropolitan Transportation Commission (MTC) (Association of Bay Area Governments, Bay Area Air Quality Management District, San Francisco Bay Conservation and Development Commission, & Metropolitan Transportation Commission, 2006). While California Transit Oriented Development Searchable Database has information on various existing transit oriented developments in California, MTC’s report provides a closer overview of TOD projects in the Bay Area. The report by TCRP relies on surveys to stakeholders and case studies documented in the TOD literature to track existing TODs. These sources
complement each other and provide the most complete list of available TOD profiles in the San Francisco Bay Area (shown in Table 5-2).

**Table 5-2 Existing TODs in the San Francisco Bay Area identified in the study (2000).**

<table>
<thead>
<tr>
<th>Region/Agency</th>
<th>TODs</th>
</tr>
</thead>
</table>
| Bay Area Rapid Transit (BART) | Concord BART  
Pleasant Hill BART  
Walnut Creek BART  
Rockridge BART  
Daly City BART  
El Cerrito del Norte BART  
Downtown Berkeley BART  
Lake Merritt BART  
Fruitvale BART  
Hayward BART  
Fremont BART  
Balboa Park BART  
City Center – 12th Street BART  
Richmond BART  
Embarcadero BART  
16th / Mission BART  
24th / Mission BART  
Colma BART |
| San Francisco/San Mateo/Santa Clara County Axis: Caltrain, Peninsula Corridor Joint Powers Board, San Francisco Municipal Railway, San Mateo County Transit District | Mission Bay (UCSF)  
South Beach King and 4th MUNI  
Bay Meadows (San Mateo)  
The Crossings (Mountain View)  
Redwood City  
San Mateo downtown |
| Santa Clara County: Santa Clara Valley Transportation Authority (VTA) | Moffett Park (Sunnyvale)  
Ohlone-Chynoweth (San Jose)  
Almaden Lake Village (San Jose)  
Fair Oaks  
Whisman |
| San Jose-Oakland-Sacramento: Capital Corridor Joint Authority (Sacramento area excluded) | Martinez  
Almaden Lake Village  
Moffett Park (Sunnyvale) |
| Amtrak | Emeryville |
5.2.3 Measuring Built Environment Characteristics associated with TOD

Though the aforementioned Heckman’s sample selection model only relies on a 0/1 dummy variable to define TOD, built environment characteristics associated with TOD are respectively quantified and compared before running the sample selection model. A yes-or-no indication of whether a particular neighborhood is a TOD may be too highly aggregated to offer some helpful insights into the difference between TOD and non-TOD neighborhoods in detail.

Unlike the measures of TOD in the previous chapter, TOD attributes are all measured at the census block group level. The key data is drawn from the Center of Neighborhood Technology (CNT) and Census Transportation Planning Package (CTPP) in the year of 2000. It should be kept in mind that the components of TOD are more complex and dynamic than the built environment characteristics summarized here. For instance, aesthetic value in the TOD design is often hard to quantify and measure. Due to the limitations of data availability, it would be very difficult to appropriately quantify every single TOD feature. A set of key built environment characteristics associated with TOD is identified as follows.

5.2.3.1 Gross Household Density

Gross household density is defined as the total households per total land acre.

5.2.3.2 Employment Access Index

Employment access index is used as a measure to estimate the quantity of and residents’ access to the jobs in an area (Center for Neighborhood Technology, 2009). According to the Center for Neighborhood Technology, it is calculated using an inverse-
square law to model total access to jobs by using the sum of the number of jobs divided by the square of the distance to those jobs. Higher values in employment access index indicate higher employment accessibility.

### 5.2.3.3 Transit Connectivity Index

Transit connectivity index accounts for “the number of bus routes and train stations within walking distance for households in a given block group scaled by the frequency of service” (Center for Neighborhood Technology, 2009). It is a measure of the transit service level. A higher value here indicates a higher transit service level.

### 5.2.3.4 Average Block Size

Average block size is the average size of all the blocks in a given block group. Smaller blocks make a neighborhood more walkable.

### 5.2.3.5 Land Use Mix

Land use mix, again, adopts an entropy index measuring the diversity of a component. As defined in the previous chapter, for each neighborhood, level of land use mix is:

$$LUMix = -\sum_{i=1}^{n} p_i (\ln p_i / \ln n)$$

(5-12)

where $p_i$ is the proportion of housing units or jobs in land use type $i$, and $n$ is the number of land use types present. It ranges from 0 to 1 and captures the evenness of distribution of different land use types within a spatial unit.
5.2.3.6 The Comparison

In the San Francisco Bay area, there are 4,422 Census block groups in nine counties. After combining with the travel diary data from the San Francisco Bay Area Household Travel Survey (BATS) and removing block groups with missing data and outliers, 2,726 census block groups remained in the analysis. Table 5-3 displays the average level for the list of TOD measures described above. The difference for each measure between TOD and non-TOD neighborhood is significant. Overall, TODs in the list are a group of neighborhoods that can be clearly distinguished from other neighborhoods, based on the built environment features listed above.

Table 5-3 Average built environment characteristics associated with TOD.

<table>
<thead>
<tr>
<th>Built Environment Characteristics (Mean)</th>
<th>TOD Neighborhood</th>
<th>Non-TOD Neighborhood</th>
<th>p-value in t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Household Density</td>
<td>12.60</td>
<td>6.22</td>
<td>.000</td>
</tr>
<tr>
<td>Employment Accessibility Index</td>
<td>82535.72</td>
<td>45074.95</td>
<td>.000</td>
</tr>
<tr>
<td>Transit Connectivity Index</td>
<td>10923.50</td>
<td>3106.92</td>
<td>.000</td>
</tr>
<tr>
<td>Average Block Size</td>
<td>6.26</td>
<td>32.95</td>
<td>.000</td>
</tr>
<tr>
<td>Land Use Mix</td>
<td>.49</td>
<td>.40</td>
<td>.000</td>
</tr>
<tr>
<td>Number of census block groups</td>
<td>121</td>
<td>2,605</td>
<td></td>
</tr>
</tbody>
</table>

However, TODs are diverse in design and quality. An individual TOD neighborhood is not necessarily strong in every single dimension. Furthermore, the overall strength of TOD is also different. Four typical TOD neighborhoods are displayed in Figure 5-3, represented by different line styles. Each built environment dimension has

---

12 A large number of households are removed because in the San Francisco Bay Area Household Travel Survey (BATS), some key information is missing or unknown, especially the mileage of car used, and the cost of parking, transit, and taxi.
been standardized to the uniform scale 0 to 100. A line is drawn connecting the value for each dimension. TOD 4 represents the neighborhood having the highest employment accessibility among these four TODs. Its transit connectivity and land use mix level are also high, though its gross density is low. In contrast, TOD 2 is stronger in the dimension of gross density, while TOD 3 is especially strong in the dimension of land use mix level. TOD 1 tends to be more balanced in every dimension. Though more detailed discussion on these differences between different TODs goes beyond the scope of this chapter, it certainly deserves further research.

Figure 5-3 The strength of TOD in six built environment dimensions: four examples.

13 The dimension of block size is not clearly visualized in this chart. Standardized values for block size in TODs tend to be small, very close to zero. Furthermore, unlike other variables, a smaller value for block size indicates a stronger TOD presence.
5.2.4 Household Characteristics

The models also include other explanatory variables to measure household characteristics that might affect household travel. All variables are obtained from the San Francisco Bay Area Household Travel Survey 2000. A full description for each variable is listed in Table 5-4. Ideally, attitudinal variables such as pro-transit and car dependent should be included as well. However, these attitudinal variables are usually not collected in standard travel surveys. The available household characteristics can at least partially reflect households’ tastes when making residential choices.

Table 5-4 Description of variables for household characteristics.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household size</td>
<td>Number of people in a household</td>
</tr>
<tr>
<td>Household income*</td>
<td>Household annual income level (categorical variable)</td>
</tr>
<tr>
<td>Household vehicle ownership</td>
<td>Number of vehicles owned by a household</td>
</tr>
<tr>
<td>Household employed</td>
<td>Number of household members employed</td>
</tr>
<tr>
<td>Number of licensed drivers</td>
<td>Number of licensed drivers in a household</td>
</tr>
<tr>
<td>Number of children</td>
<td>Number of children (under 18 years old) in a household</td>
</tr>
<tr>
<td>Number of elderly</td>
<td>Number of elderly (over 60 years old) in a household</td>
</tr>
<tr>
<td>Dummy of owning the house</td>
<td>Household tenure status: 1=own, 0=rent</td>
</tr>
<tr>
<td>Dummy of living in single house</td>
<td>Whether house type is single house: 1=yes, 0=no</td>
</tr>
<tr>
<td>Dummy of married household head</td>
<td>Whether household head is married: 1=married, 0=otherwise</td>
</tr>
<tr>
<td>Age of household head</td>
<td>Household head’s age</td>
</tr>
<tr>
<td>Squared age of household head</td>
<td>Squared term of household head’s age</td>
</tr>
<tr>
<td>Dummy of male household head</td>
<td>Household head’s gender: 1=male, 0=female</td>
</tr>
<tr>
<td>Dummy of white household head</td>
<td>Whether household head is white: 1=white, 0=other</td>
</tr>
</tbody>
</table>

*Note: Income groups are classified into 15 categories: 1-below $10,000; 2-$10,000 to below $15,000; 3-$15,000 to below $20,000; 4-$20,000 to below $25,000; 5-$25,000 to below $30,000; 6-$30,000 to below $35,000; 7-$35,000 to below $40,000; 8-$40,000 to below $45,000; 9-$45,000 to below $50,000; 10-$50,000 to below $60,000; 11-$60,000 to below $75,000; 12-$75,000 to below $100,000; 13-$100,000 to below $125,000; 14-$125,000 to below $150,000; 15-$150,000 or more.
5.3 EMPIRICAL RESULTS

5.3.1 Residential Location Choice Model Results

As explained earlier, Heckman’s sample selection model involves a two-step procedure: first, to estimate the probit equation for residential location choice, and second, to estimate the household transportation spending by two ordinary least squares (OLS) regressions, in which the selection correction factor is included: one for the treatment group, and the other for the control group.

Households living in the TOD neighborhood are expected to have different characteristics from those living in the non-TOD neighborhood. A binary probit model is first employed to control for this self-selection problem. As shown in Table 5-5, a number of household characteristics are statistically significant in explaining people’s residential location choices in the San Francisco Bay Area. Household size is negatively related to TOD selection. The layout of TOD is often more compact, with fewer single-family houses and smaller lots, which is usually favored by smaller households. Similarly, households with more children or elderly members are more likely to stay away from TOD neighborhoods.

Household income level is negatively associated with the selection of TOD. As people get richer, they are less likely to live in the TOD neighborhood. This is consistent with the existing literature. As pointed out by Renne (2005), for many metropolitan areas such as Atlanta, Chicago, Miami, and Washington D.C., income levels were substantially higher in the TOD areas compared to the metropolitan area as a whole. TODs in these areas have become “expensive and upscale communities” (p. 68). However, this was not
the case in San Francisco. Per capita income in TODs in San Francisco was about 22 percent lower, compared to the whole metropolitan area in the year of 2000. A future research could focus on the comparison among these different areas.

Table 5-5 Probit model for the residential location choices (TOD vs. non-TOD).

| Variables                          | Coefficient | Standard Error | z    | P>|z| |
|------------------------------------|-------------|----------------|------|-----|
| Household size                     | -.007       | .003           | -2.30| .022|
| Household income level             | -.041       | .001           | -67.74| .000|
| Dummy for white household head     | -.084       | .005           | -17.77| .000|
| Age of household head              | -.023       | .001           | -25.31| .000|
| Squared age of household head      | .0001       | .000           | 15.16| .000|
| Dummy for male household head      | .043        | .005           | 10.59| .000|
| Number of children in a household  | -.010       | .004           | -2.52| .012|
| Number of elderly in a household   | -.201       | .006           | -33.03| .000|
| Dummy for married household head   | -.119       | .005           | -22.50| .000|
| Constant                           | -.292       | .020           | -14.40| .000|
| Number of observation              | 6,526       |                |      |     |
| Pseudo R-squared                   | .092        |                |      |     |

Note: Household sampling weights are applied to make the estimates representative of the population as a whole.

A clear association between residential location choice and selected characteristics of the head of household can be observed in the results. If the head of household is white, female and married, the probability of living in the TOD neighborhood is significantly lower. The negative and positive coefficients for the age and age-squared terms, respectively, suggest that the overall probability of living in the TOD neighborhood falls with age, but show a gradual incline after the head of household reaching a certain age. It is worth noting that an elderly head of household and a household containing elderly members would have different impact on residential location choice. These two types of households represent different forms of family.
formation. The empirical findings here support the assertion that households with more elderly members are less likely to live in the TOD neighborhood. On the contrary, households with an elderly head of household prefer TODs.

5.3.2 Household Transportation Costs Model

Based on the probit model in the first step, sample correction factors are computed. The sample correction factor is used as an additional regressor in the regression equation for household transportation costs. Two separate regressions are estimated for the treatment group – households in the TOD neighborhoods, and the control group – households in the non-TOD neighborhoods. Explanatory variables that are statistically insignificant in either of the regression equations are retained, since the point estimates of the treatment effect require the same set of variables in both models. Specifically, built environment variables associated with TOD are not included as explanatory variables in this stage. Following Cao (2009), “these variables could still be correlated with unobserved characteristics influencing travel behavior, in violation of the model’s assumption” (p. 218). Table 5-6 and Table 5-7, respectively, show the summary statistics and model results.

As show in Table 5-7, for those households living in the non-TOD neighborhood, number of household members employed, number of licensed drivers and vehicles owned in a household, and number of children in a household show positive impacts on daily household transportation costs. Number of household members employed reflects the commute needs in a household. The presence of children in a household indicates the additional travel needs to school and other social activities. In addition, when the head of
household is married, household transportation costs also go up. More licensed drivers and vehicles in a household lead to more driving, and increase transportation spending accordingly. Those asset-rich households, for instance, who own their house, or live in a single house appear to have higher transportation costs. In the same vein, higher household income levels are associated with higher transportation costs.

Table 5-6 Summary statistics for household transportation costs model.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOD Neighborhood (Number of observation: 286)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily household transportation cost (ln)</td>
<td>3.35</td>
<td>.46</td>
<td>2.69</td>
<td>4.94</td>
</tr>
<tr>
<td>Dummy of owning the house</td>
<td>.50</td>
<td>.50</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dummy of living in single house</td>
<td>.37</td>
<td>.48</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Number of household members employed</td>
<td>1.28</td>
<td>.71</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Number of licensed drivers</td>
<td>1.57</td>
<td>.64</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Number of vehicles owned</td>
<td>1.48</td>
<td>.67</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Household income</td>
<td>9.99</td>
<td>3.62</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Number of children in a household</td>
<td>.25</td>
<td>.67</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Dummy of married head of household</td>
<td>.42</td>
<td>.50</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Non-TOD Neighborhood (Number of observation: 6,240)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily household transportation cost (ln)</td>
<td>3.62</td>
<td>.50</td>
<td>2.69</td>
<td>5.36</td>
</tr>
<tr>
<td>Dummy of owning the house</td>
<td>.73</td>
<td>.44</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Dummy of living in single house</td>
<td>.69</td>
<td>.46</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Number of household members employed</td>
<td>1.33</td>
<td>.83</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Number of licensed drivers</td>
<td>1.76</td>
<td>.68</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Number of vehicles owned</td>
<td>1.89</td>
<td>.87</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Household income</td>
<td>10.56</td>
<td>3.25</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Number of children in a household</td>
<td>.50</td>
<td>.91</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Dummy of married head of household</td>
<td>.60</td>
<td>.49</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 5-7 Regression results for the household transportation costs model.

<table>
<thead>
<tr>
<th>Variables</th>
<th>TOD Neighborhood</th>
<th></th>
<th>Non-TOD Neighborhood</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coef.</td>
<td>p-value</td>
<td>Coef.</td>
<td>p-value</td>
</tr>
<tr>
<td>Dummy of owning the house</td>
<td>.018</td>
<td>.852</td>
<td>.060</td>
<td>.002</td>
</tr>
<tr>
<td>Dummy of living in single house</td>
<td>.035</td>
<td>.703</td>
<td>.039</td>
<td>.042</td>
</tr>
<tr>
<td>Number of household members employed</td>
<td>.054</td>
<td>.405</td>
<td>.050</td>
<td>.000</td>
</tr>
<tr>
<td>Number of licensed drivers</td>
<td>.007</td>
<td>.930</td>
<td>.089</td>
<td>.000</td>
</tr>
<tr>
<td>Number of vehicles owned</td>
<td>.857</td>
<td>.000</td>
<td>.564</td>
<td>.000</td>
</tr>
<tr>
<td>Household income</td>
<td>.061</td>
<td>.001</td>
<td>.039</td>
<td>.000</td>
</tr>
<tr>
<td>Number of children in a household</td>
<td>.094</td>
<td>.007</td>
<td>.050</td>
<td>.000</td>
</tr>
<tr>
<td>Dummy of married head of household</td>
<td>.211</td>
<td>.060</td>
<td>.058</td>
<td>.005</td>
</tr>
<tr>
<td>Selection correction factor</td>
<td>-.466</td>
<td>.096</td>
<td>.228</td>
<td>.223</td>
</tr>
<tr>
<td>Constant</td>
<td>2.194</td>
<td>.000</td>
<td>1.795</td>
<td>.000</td>
</tr>
<tr>
<td>Number of observations</td>
<td>286</td>
<td></td>
<td>6,240</td>
<td></td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>.62</td>
<td></td>
<td>.71</td>
<td></td>
</tr>
</tbody>
</table>

Note: Household sampling weights are applied to make the estimates representative of the population as a whole.

On the other hand, fewer explanatory variables show significant impacts on household transportation costs for those living in the TOD neighborhood. Only number of vehicles owned, household income level, number of children in a household, dummy of married head of household are significant in the model.

Finally, it has to note that attitudinal factors toward travel may have significant impacts on household transportation costs, though they are not included in the above two-stage model due to the data unavailability. The role of attitudinal factors toward travel will be readily observable once data becomes available.

5.3.3 Self-Selection Effects

As discussed earlier, the inclusion of a selection correction factor serves to control for the self-selection bias that could otherwise arise from the unobservable variables. The
model suggests that the selection correction factor is marginally significant in the model for households in the TOD neighborhood, while it becomes insignificant in the model for households living in the non-TODs. This subsection will further discuss the self-selection effect.

As discussed earlier, self-selection effects can be quantified using two measures – average treatment effect (ATE) and the effect of treatment on the treated (TT). ATE is estimated to be 96 cents per day, which indicates that a randomly selected household would save 96 cents per day on transportation, if moving from a non-TOD neighborhood to a TOD neighborhood. ATE represents the real impact of TOD itself on household transportation costs, controlling for self-selection bias. The average household transportation costs in the survey sample is 39.7 dollars per day. The savings from TOD is only about 2.4 percent (=0.96/39.7) of the daily transportation costs. However, on average, TOD still helps to save about 350 dollars on transportation costs annually at the household level. If this saving is simply because of less driving, it means a typical household would consume about half gallon less gasoline per day. In turn, it could translate into a reduction about 11-mile daily household driving. The dataset used in this analysis tells that a typical household in the Bay Area drives about 66 miles per day. A reduction of 11-mile per day therefore indicates about 16.7 percent of a household’s overall driving. In this regard, the impact of TOD on people’s travel behavior is not

\[\text{14 The gasoline consumption estimation is based on the average gasoline (all types) price 183 cents per gallon in the San Francisco Bay Area in 2000. See more details about the gasoline price in the Bay Area, go to } \text{http://www.mtc.ca.gov/maps_and_data/datamart/stats/gasprice.htm. The driving distance estimation is based on the average values of 22 miles per gallon (mpg) for passenger cars in 2000. This value is obtained by dividing vehicle miles traveled by fuel use for all passenger cars in the U.S., using the data of Highway Statistics 2000 by the Federal Highway Administration (FHWA).}\]
negligible, not to mention other possible benefits such as congestion and pollution reduction beyond the monetary savings.

On the other hand, TT which represents the total impact of TOD on household transportation costs, is estimated to be 1.22 dollar per day, the self-selection effect included. Hence, the self-selection bias is 26 cents (=1.22-0.96) per day. It accounts for about 21 percent (=0.26/1.22) of the total influence of TOD. In other words, 79 percent of the household transportation costs difference between households living in the TOD and non-TOD neighborhoods is due to the “pure” effects from those built environment characteristics associated with TOD.

Last but not least, the estimation for self-selection bias discussed above is based on the Heckman’s sample selection approach only. Other estimation methods may produce largely different results. As Cao et al. (2008) suggest, nine categories of methods can be used to address residential self-selection issue: direct questioning, statistical control, instrumental variables models, sample selection models, propensity score, joint discrete choice models, structural equations models, mutually-dependent discrete choice models, and longitudinal designs. They specifically recommend usage of longitudinal structural equations modeling with control groups. These methods provide a rich foundation for further exploration in this area in the future.

5.4 SUMMARY AND DISCUSSION

This chapter represents an attempt to examine the impact of TOD on household transportation costs while controlling for residential self-selection bias. In particular, the magnitude of self-selection impact is quantified based on a Heckman’s sample selection
model. Accordingly, the “pure” contribution of TOD to household transportation savings is specified. Using a sample of 6,526 households in the San Francisco Bay Area in 2000, the model tells that the total effect of TOD on household transportation costs is a saving of 1.22 dollar per day, in which 96 cents relies on the effect of TOD itself and the remaining 26 cents is due to the self-selection bias. Annually, this would mean an average saving about 350 dollars on transportation. It only accounts for 2.4 percent of the total household transportation costs. The impact is comparatively small. However, if such a saving is all because of less driving for a typical household in the Bay Area, it could mean about 16.7 percent reduction in its daily driving distance. The impact of TOD is still considerable with this regard. The self-selection effect accounts for about 21 percent of the total influence of TOD. The built environment features associated with TOD dominate the influences on household transportation costs. Nevertheless, the results confirm that the self-selection effect does exist and therefore should be addressed properly.

The study effort presented in this chapter is among the first to directly investigate household transportation costs in a context of TOD. It offers some interesting insights into the relationship between TOD and household transportation costs. The most fundamental result emerging from the foregoing analysis is that TOD in general help households save on transportation spending. This finding is consistent with the results in the previous chapter. However, the monetary savings for households are moderate. More importantly, noticing that the transportation benefits in terms of monetary savings are not huge, housing affordability has to be more vigorously addressed for the development of
TOD. Otherwise, the monetary benefits for living in the TODs could quickly fade away, considering that most TODs having a higher housing cost.

Several limitations deserve mention. First, this study relies on the standard travel survey data, without considering any attitudinal factors that are usually used to further control for self-selection bias. If attitudinal factors can be included in the model, they certainly will help to obtain a more robust result.

Second, the sample selection model introduces TOD as a yes-or-no indication in the selection equation, largely ignoring the differences among TODs. A 0/1 dummy variable is far from perfect to fully characterize the various nature and potential of TOD. Intuitively, higher quality TODs may be more capable of reducing families’ transportation burdens. As Zhou and Kockelman (2008) suggested, Heckman’s method could be extended to take multinomial model for location choices or neighborhood attributes into consideration. It requires more research effort on how to properly classify different TODs based on a number of key characteristics. The quality of TOD should also be carefully evaluated and specified. Furthermore, the methodology extension also requires extra data collection effort to provide more detailed information for the TOD areas.

Finally, the findings are based on the data of the San Francisco Bay Area in the year of 2000. Regional variations may exist or even tend to be significant. The analysis therefore could cover more regions and see whether distinct regional contexts matter. These limitations in the foregoing discussion also suggest future research directions.
CHAPTER 6 CONCLUSIONS

The objective of this dissertation is to provide a more complete picture about TOD by dealing with two major questions – first, what regional characteristics makes regions more or less likely to adopt a TOD policy; and second, whether, how and to what extent does TOD influence household transportation spending. The policy innovation and diffusion theory underlying the first research question addresses that both internal and external regional characteristics affect TOD policy adoption. A number of regional characteristics are tested in Chapter 3. The second research question heavily relies on a rich literature on the built environment and travel behavior. Chapter 4 adopts structural equations modeling approach to examine the relationship between the built environment characteristics associated with TOD and household transportation costs, using a dataset of 326 fixed guideway transit station areas in the San Francisco Bay Area in 2000. This is followed by an independent but closely related analysis on the same research question in Chapter 5. Though the data and methods used are completely different in these two chapters, the finding of the moderately positive role of TOD in reducing household transportation costs remains the same. This chapter provides concluding remarks regarding this dissertation research. The following sections summarize the major contributions, key findings, policy implications, and areas of future research.
6.1 CONTRIBUTIONS OF THIS RESEARCH

The main contributions of this dissertation are two-fold.

First, this dissertation provides an original understanding of the regional
determinants of TOD implementations at the urban area level. TOD is such a long-term
endeavor that involves consideration of many factors from different levels. Although
TOD has attracted great attention for recent years, little research systematically and
empirically frames various regional determinants of TOD implementations. Therefore,
the analysis of this research question will bring forth policy implications on identifying
proper conditions for regional TOD growth. By exploring factors shaping TOD policy-
making process, it also helps to take a step toward better understanding the observed
patterns of TOD implementations in the United States.

Moreover, this dissertation provides instructive answers to the impacts of TOD
on household transportation costs. Few studies analyze travelers’ transportation costs in a
TOD context. This dissertation aims to bridge this gap. Especially, the analysis is
conducted at two levels, using different methods and data. To answer this research
question, the analysis first focus on the fixed guideway transit station areas in the San
Francisco Bay Area. By taking various TOD characteristics into account at the same
time, the analysis provides additional evidence to explain the individual TOD
characteristics respectively in shaping households’ travel budget. The findings also have
important implications for policy makers in the recent surge of interest in developing
TOD policy, by investigating what particular built environment characteristic associated
with TOD can yield the biggest transportation benefits. Next, the research turns to
emphasize the impact of TOD on household transportation costs at a more disaggregated level, while controlling for residential self-selection bias. The empirical findings are important when recommending possible TOD strategies to the general public, by developing a better understanding of whether or not TOD brings more affordable choices for transportation and housing. After all, the spending on transportation and housing is always a principal concern for hundreds and thousands households.

6.2 MAJOR FINDINGS

The major findings in this research consist of two distinct but related parts. First and foremost, the discrete event history analysis in Chapter 3 empirically tests and highlights the external and internal regional characteristics that affect the adoption of TOD policy. Numerous variables have been tested using the discrete event history analysis with three different functional forms, including a probit model, a logit model, and a complementary loglog model. Three models invariably show that external influences appear to be weak in the policy decision regarding the TOD adoption, while internal characteristics have more powerful impact. At the regional level, the probability of adopting the TOD policy increases with central-place population, personal income, traffic congestion level, transit use level and moralistic political culture. The possibility of TOD policy adoption decreases with the overall population density. Variables of gasoline price, TOD policy adoption at the state level and time spline that represents the time duration are insignificant in these models.

In short, the first part of the research provides an investigation of various regional characteristics that facilitate TOD policy adoption at the regional level. It deepens the
understanding of the broad context within which TOD policy is initiated and implemented across many U.S. urban areas in the past two decades.

The research then moves forward to explore the second key question – whether, how and to what extent does TOD influence household transportation costs. The basic hypothesis is that TOD helps reducing household transportation costs. Chapter 4 and Chapter 5 explore research evidences to support this hypothesis from different angles, taking the advantage of distinct merits embedded in different models.

Chapter 4 employs a structural equation modeling approach to investigate the relationships among TOD characteristics, auto ownership, travel behavior in terms of commute mode choice and distance to work, household housing costs and household transportation costs. This method allows for a close examination of mediating processes, which are responsible for the final outcome – household transportation costs. As expected, the built environment characteristics associated with TOD increase overall household transportation affordability to varying degrees. Looking at these TOD characteristics separately, the effect of population density on household transportation costs is not as strong as the effects from employment density and retail density. Furthermore, average block size and land use mix level show significant relationship with commute by non-automobile modes, but hardly affect distance to work and auto ownership. Larger average block size indicates higher household transportation costs, while these costs on average are lower when land use patterns become more mixed.

Another key finding in Chapter 4 is the potential strong capability of transit network measures to explain household transportation costs. Adapted from social
network analysis, two centrality measures are introduced into the model to represent the structural position of a transit station in the embedded transportation network. Higher betweenness centrality implies a higher capacity of a transit station to be an intermediary between any other transit stations. While positively related to commute by public transit, this measure is negatively associated with average distance to work. In total, it places a negative impact on household transportation costs. On the other hand, degree centrality is positively related to average distance to work. The positive relationship indicates a better access to a larger job market for a transit station area with a higher degree centrality. Another possible explanation is the complexity of the multimodal transportation system. More transfer-free connections to other fixed guideway transit stations do not necessarily guarantee efficiency in terms of travel time and quality in a more complicated transportation network in which all modes are taken into account. The benefit of such a central position in a fixed guideway transit system may be quickly diminished in a multimodal transportation network. Unfortunately, this point cannot be tested in this research, due to the data limitation and complexity. The measure for a multimodal transportation network, rather than a fixed guideway transit network, may suggest more meaningful findings.

Furthermore, there is a clear trade-off between housing costs and transportation costs at the household level, as shown in the last model in Chapter 4. The relative position of each transit station in the transit network is positive and significant to explain household housing costs, while other characteristics associated with TOD slightly decrease housing costs.
Chapter 5 represents another effort that casts light upon the same research question in Chapter 4, though the emphasis shifts. Unlike the previous chapter, the analysis covers a larger geographical area in the San Francisco Bay Area, which is not limited to the half-mile radius area around each fixed guideway transit station. Moreover, the analysis is at a more disaggregated level – the household level. All the neighborhoods at the Census Block Group level are dichotomized as 1 if it is a TOD, or 0 if it is not. The focus therefore is not to compare the impacts of different TOD characteristics respectively to household transportation costs, but to understand the role of TOD as a distinct planning tool in shaping household transportation costs, while controlling for residential self-selection bias at the same time.

The final sample consists of 6,526 households in the San Francisco Bay Area in 2000. The results confirm that TOD has a positive role in reducing household transportation costs, as what have been identified in the previous chapter. Specifically, the Heckman’s sample selection model shows that the total effect of TOD on household transportation costs is a daily saving of 1.22 dollar, in which 96 cents rely on the effect of TOD itself and the remaining 26 cents are due to the self-selection bias. Excluding the self-selection bias, living in the TOD neighborhood would bring an average saving about 350 dollars on transportation annually, which accounts for 2.4 percent of the total household transportation costs. Behind such amount of savings, it could mean a reduction of 16.7 percent of driving distance for a typical household. Though the monetary impact is comparatively small, it is undeniable that TOD is capable of changing people’s travel behavior and their transportation costs accordingly.
In particular, the magnitude of self-selection impact is about 21 percent of the total influence of TOD. In other words, the built environment features associated with TOD still dominate the influences on household transportation costs. The existence of self-selection effects, again, indicates that such a bias considerably affects the estimation results and needs to be addressed properly.

6.3 POLICY IMPLICATIONS

The above empirical findings shed light on key regional characteristics that influence the existing TOD policy adoption. These regional characteristics underlying the patterns of existing TOD policy in different U.S. urban areas tell that a TOD-supportive policy is favored by regions with great pressure of sprawl and congestion. A well-developed transit market is a prerequisite for the TOD policy to come into play. In some sense, the existing TOD policy in those regions is not established for the purpose of creating a market. Instead, such a policy is a response to the emerging market demand that favors TOD. Policy makers who consider TOD as a tool to launch new market should have serious second thoughts.

In addition, the model identifies a positive relationship between the possibility of TOD policy adoption and personal income level. It underlines the importance of equity concerns in designing TOD related policies. Recall that TOD has the potential to increase the value of surrounding properties, and therefore is easier to gain support from high-income people who always own these properties. It poses affordability challenges to low-income and transit-dependent people who are usually renters. In the absence of sufficient policy support such as maintaining or creating affordable housing, this type of new
development will most likely reduce the supply of reasonably priced locations and gentrify low-income neighborhoods. This would be the last thing policy makers would like to obtain from TOD. Hence, to properly account for equity in the TOD planning and implementation should become a necessity for a successful TOD policy that goes far in providing a sustainable and affordable environment for many people.

On the transportation costs side, TOD does reduce household spending on transportation related activities, though the monetary saving is not huge. Also, a clear trade-off between transportation costs and housing costs is also identified in the model. These findings have brought a few weaknesses of the existing TOD practices into the open. For many TODs, it is very likely that the savings on the transportation side is offset by the faster-growing costs on the housing side. Therefore, affordable housing is a critical issue that deserves careful attention in developing TOD.

Looking at the built environment characteristics separately, the findings tell that while transit station areas are more functionally integrated into social activities, representing by a higher employment density or retail density in the model, they tend to affect household transportation costs more significantly. It reinforces the statement by Belzer and Autler (2002) that TOD should “focuses primarily on functions and outcomes rather than on physical form and project configuration” (p. 2). The label of TOD itself is not important, but the way it brings together people, services, and jobs is the key.

Finally, a regional scope is important for a successful TOD implementation. As shown in the analysis, the relative position of a neighborhood in the transit network has provided additional insights into the role of TOD in shaping household transportation
costs. TODs that are located very central in the transit system obviously should have more concerns on housing affordability issues. In general, the optimization of the potential for a TOD at each individual station requires a careful evaluation of each station’s position relative to other stations in the system. This is important for both the planning and evaluation of TOD.

6.4 AREAS OF FUTURE RESEARCH

While there have been many lessons for TOD going forward, as summarized above, there remain many areas, to some degree, unknown or unclear, where further research would be useful.

One direction of future research is to explore the impact of TOD beyond the monetary functions. Household transportation costs in this dissertation refer to the out-of-pocket expenditures on transportation related activities. However, transportation costs could be measured in time, environmental quality or any other item of value. The influences of TOD may also vary according to these different perspectives. Personal needs and preference can vary widely. For instance, a businessman would place a high cost on time spending on travel, while monetary cost is not his or her priority concern. In contrast, a college student may have a completely opposite choice in this aspect. Hence, it makes the most sense when transportation costs can be evaluated from different perspectives, which allow a better understanding of TOD from certain vantage points.

Furthermore, future research should look more closely at TOD’s quality. The purpose is two-fold. On the one hand, it helps to differentiate TODs and their impacts case by case. It is not the label of TOD, but its quality underlined, affects people’s travel.
Therefore, the quality of TOD needs to be identified in a comprehensive and integrative manner. On the other hand, this is also an important step to extend the current methodological framework and explore the same research topic in more depth. As shown earlier, the sample selection model in Chapter 5 introduces TOD as a yes-or-no indication in the selection equation, ignoring the quality differences among TODs. Nevertheless, under the same label “transit oriented development”, the quality of each neighborhood may differ substantially. To specify such differences, a possible extension of the current methodological framework may unveil some interesting findings. Existing literature has suggested that rather than a binary probit model, a multinomial model for location choices or neighborhood attributes tends to be a suitable and promising extension for the current methodological framework.

Another area that holds great potential for future research is the integration of social network analysis into the TOD related study. This dissertation has introduced two basic centrality measures into the analysis. The results revealed interesting insights into the models for estimating the impact of TOD on household transportation costs. Though the findings are far from conclusive yet, they suggest that further exploratory efforts in this aspect would yield additional useful information. The network perspective allows new leverage for the TOD analysis. At a disaggregate level, it can explore the relationships between individual elements in a network, and identifies their contribution to network performance respectively. At an aggregate level, it measures the overall structure of an entire network. As more areas adopt TOD as a regional policy, TOD does not only exist as an isolated occurrence, but spread throughout the transportation
network. The TOD network itself and the relative position of a typical TOD in a transportation network will have important implications.

Last but not least, more research effort should be spent on data collection. The concept of TOD is still young in the planning literature. Accordingly, related data in this field is not sufficient to perform diverse research analyses involved. Especially, land use and travel behavior studies usually require information for a number of variables, such as land use types, demographics, socioeconomic characteristics, and activity-travel diary data, just to name a few. To control for residential self-selection bias that has been widely recognized, additional attitudinal factors influencing the travel decisions become more critical in the analysis. However, these attitudinal factors are often beyond the scope of most standard travel surveys. In addition to incorporating more variables into the analysis, longitudinal data collection is another area that deserves further effort. This tends to be extremely important, as more TODs are emerging and become increasingly mature. Travel survey data and land use data are often cross-sectional, which limit the ability to draw any causal conclusions. Future studies should replicate and extend these findings when longitudinal data becomes available. Once more data becomes available, studies could also cover more regions in addition the San Francisco Bay Area. TOD impacts across regions could be examined and compared. This appears to be a particularly fruitful direction for future research.
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