Conditions and Effectiveness of Land Use as a Mobility Tool

by

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Abstract

This dissertation examines the potential of land use as a mobility tool to affect travel, a subject of long and ongoing policy debate. Land use strategies such as densification, mixed-use development, and non-driving-oriented design have been recommended by many to reduce vehicle travel. Others argue that land use is an ineffective mobility tool; direct and effectual policies are economic measures such as pricing. This dissertation suggests that either is necessary but not sufficient. To achieve the environmental and social objectives of transportation, the two should act together as complements. The mobility role of land use is to modify transportation supply and to support expansion of travel choices, whereas pricing is to manage and redirect vehicle travel demand. This dissertation presents two case studies: Metropolitan Boston and Hong Kong. Taking a disaggregate approach, the empirical analysis builds on the economic choice theory and focuses on three aspects of travel behavior: mode choice, trip frequency and automobile dependence. Logit models of mode choice and trip frequency are estimated to examine the importance and magnitude of land use affecting travel when travel costs and socio-demographic factors are controlled for. The effects of densification and pricing on mode choice are extrapolated with incremental logit modeling while controlling for the impacts of these policies on individual accessibility, i.e., the utility associated with all available modes. Logit captivity models are estimated to quantify and explain automobile dependence in the process of choice set generation. The analysis shows that densification has significant influence on mode choice and automobile dependence due to the differentiated impacts of land use on modal supply. The influence of street patterns on travel is not much from the geometric difference between gridiron and cul-de-sac, but from the viability of the circulation systems for alternatives to driving. Automobile dependence in the Boston area displays certain patterns in the spatial, social and activity dimensions. The sources of automobile dependence are diverse, often lying beyond the physical environment. The Hong Kong case demonstrates that the presence of economic measures is a precondition for land use to be an effective mobility tool. Hong Kong's non-driving-dominated travel does not come by default from its unique land use pattern, but is accompanied by strong fiscal and regulatory constraints to private transportation.

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Unit and Currency Conversion

Hong Kong (Metric System)	***US (English System)***
1 kilometer	= 0.622 mile
1 square kilometers (sq. km.)	= 0.386 square mile (sq. mi.)
1 hectare	= 2.47 acres
1 liter	= 0.264 gallon (US)
1 Hong Kong dollar (HK$)	= 0.128 US dollar (US$)

Chapter 1

Introduction

1.1 Problem Statement

The growing public concern about the environmental and social problems of transportation has motivated a global search for effective policy strategies to reduce motor vehicle travel (particularly the single-occupant auto travel), to enhance accessibility of all population groups, and to achieve sustainable transportation. Many strategies have been proposed and they can be grouped largely into two approaches. One is the economic approach, that is, to "get the price right" to reflect the full costs of travel and hence to restore transportation market efficiency and to reduce the use of motor vehicles. Recommended measures include increasing vehicle registration fees, imposing higher fuel taxes, pricing road use, and eliminating free parking or parking subsidies. The other is the land-use approach, that is, to "get the land use right" (in terms of development intensity, integration and urban form) to influence individuals' behavior and thus to promote environmentally and socially desirable travel. Suggested strategies include densification through infill-development, land-use mixing, traffic calming, job/housing balancing, and transit-oriented/neo-traditional neighborhood design*.

* A broader context of the pricing vs. land use debate is the evolvement of Travel Demand Management, or TDM as an element of national transportation policy. TDM has been practiced in the US for over 30 years. Its main objective is to enhance mobility and to reduce congestion. The scope of TDM has been evolving and expanding, with the initial focus on improving the efficiency of the urban transportation system through operational improvements before the mid 1970's, and later incorporating concerns such as air quality and energy conservation into the transportation planning process since late 1970's. TDM includes a range of actions such as road system efficiency improvement and management, traffic control in congested areas, and encouragement of alternative travel like transit, walking, biking, and telecommuting. Pricing-based actions have been placed significant weight, although they are among the most difficult to implement. These actions are traditionally assumed to take place in a given land use context. The role of land use in TDM did not receive formal recognition until the early 1990's in the latest legislation such as the Clean Air Act Amendments (1990) and the Intermodal Surface Transportation Efficiency Act (1991) (Meyer 1999).

While there is a general agreement among policy analysts on the necessity to tackle the environmental and social problems associated with the private vehicle-dominated travel, there has been heated debate on the effectiveness of those suggested strategies. In challenging the idea of "getting the land use right," the proponents of "getting the price right" argue that the linkage between land use and transportation is weakening in the U.S. and other developed countries due to decreasing real costs of travel, existence of already well-developed transportation systems, and structural shifts to an information-based economy (Gordon, et al. 1991, Giuliano 1995 and Dunn 1998). Therefore, attempts to alter land use patterns via rezoning or urban design may not have much effect on travel. According to them, the effective remedies to the problems associated with existing travel are to directly price and regulate autos and their use. As long as prices can be set at the proper levels to reflect the real costs of travel, the transportation market would correct by itself to eliminate excessive automobile usage and the associated undesirables. In turn, the land use market would also behave in response to the transportation costs. Researchers in this area pay most attention to finding the *real costs* of travel and to the implementation technologies and strategies of the pricing policies. In the analyses on travelers' response to pricing, land use variables are generally treated as fixed and thus left out of the policy formulation.

The proponents of "getting the land use right," on the other hand, maintain current land use requires and therefore causes current travel. In addition, true market pricing of transportation is unattainable, especially in a pluralistic, democratic society like the US. Land use planning is then the next best thing that can and should be done (e.g. Cervero 1989, 1991, Cervero and Landis 1995, Newman and Kenworthy 1989, 1999). The proponents of this argument believe that land use planning is a viable mobility tool. Reconfiguring urban and regional land use will alter regional travel demand patterns and lead to more desirable outcomes. The majority of the literature along this line has focused on finding the evidence or proving the significance of land use impacts on travel, and on initiating land use-based transportation strategies.

There is an implicit assumption underlying the arguments made by both sides of the debate: economic measures and land use initiatives are substitutable; either approach alone is thought sufficient to correct the transportation and land market failure. This assumption leads the current debate often to a dichotomous mode, and economic measures and land use initiatives have been largely considered and analyzed in separated domain. This leaves a research gap in policy analysis: Few studies have been done to examine the interactive and collective effects of economic and land use-based strategies on travel, although the importance for policy analysis of emphasizing the interactions and complementary effects of these different strategies has been pointed out by a number of scholars (e.g. Crane & Crepeau 1998, Levine 1998).

Another important source of debate comes from the conflicting interpretations of the observed correlation between the built environment and travel outcomes. It has been widely accepted that travel demand (by and large) is derived from the demand to participate in activities such as work, shopping, leisure, etc. (Mitchell and Rapkin 1954, Jones, et al. 1983). Therefore the distribution patterns of activities and residential locations (i.e. land use patterns) basically define the spatial patterns of travel demand. One may thus expect that the characteristics of the built environment in which people live or work explain to a significant extent the way people travel. On the other hand, one may also theorize that the geographical patterns of land use and travel demand are simultaneously determined by exogenous factors such as technological progress and the structure of transportation costs (Pickrell 1999a). A causal relationship between built environment characteristics and people's travel decisions may be indirect or nonexistent.

These mixed interpretations lie in the fact that the relationships between the built environment and travel behavior are very complex. Crane (1999) has warned that our current understanding of the relationships between land use and transportation is not enough to provide sufficient credibility to be the basis for policy. It is therefore imperative to better understand how specific aspects of travel behavior (such as trip making and mode choice) are related to particular attributes of land use (such as density and urban form). Researchers continue to investigate the connections between the built environment and people's travel decisions in order to establish a solid behavioral ground for public policy making.

Joining the long and ongoing debate, this dissertation examines the potential of land use as a mobility tool to affect travel. It is aimed to better inform the policy debate by improving understanding of the relationships between the built environment and people's travel behavior, and by investigating the complementarities between land use and economic measures in affecting travel. The dissertation presents two case studies of world cities: Metropolitan Boston and Hong Kong, where there are sharp contrasts in land use, travel patterns, cultural settings, and transportation policy practice (The reasons in selecting these two cities are discussed in Chapter 3). Taking a disaggregate approach, the empirical analysis builds on the economic choice theory and focuses on three aspects of travel behavior: mode choice, trip frequency and automobile dependence. The analysis makes use of a set of choice modeling tools. Logit models of mode choice and trip frequency are estimated to examine the importance and magnitude of land use affecting travel when travel costs and socio-demographic factors are controlled for. The effects of densification and pricing on mode choice are extrapolated with incremental logit modeling while controlling for the impacts of these policies on individual accessibility. Accessibility, measured at the individual level as the utility associated with all available modes, serves to link together household/individual travel decision, transportation and land use policy instruments, and the policy goal (of enhancing accessibility). Automobile dependence is the critical concern to the public and the policy makers and therefore is investigated in greater detail. It is interpreted in this study from the perspective of individuals' travel choice and examine in the process of choice set generation. Logit captivity models are estimated to quantify and explain automobile dependence in relating to transportation, land use, economic, and socio-demographic factors. The main conclusion of this study is that either land use or pricing is necessary but not sufficient policy to achieve the environmental and social objectives of transportation. For them to be effective and practical, the two should act together as complements. The mobility role of land use is to modify transportation supply and to support expansion of travel choices, whereas pricing is to manage and redirect vehicle travel demand.

1.2 Objectives and Research Questions

This dissertation research is aimed to achieve the following objectives:

- To examine the built-environment/travel-behavior relationships in an integrated framework that is built on the economic choice theory and to explicitly quantify and explain automobile dependency with simultaneous consideration of transportation pricing, transit supply, land use and socioeconomic factors;

- To investigate the complementarities between land use and economic measures in affecting travel and consequently to identify the potential that land use constitutes an effective mobility tool to achieve the social and environmental objectives of transportation;

- To contribute to the literature by investigating two special cases of world cities (metropolitan Boston and Hong Kong) at the disaggregate level, and to promote international learning in effective mobility supply and accessibility enhancement and in searching for sustainable transportation strategies.

To achieve these objectives, the following specific questions are addressed:

(1) Are there still significant relationships between the built environment and individuals' travel behavior (i.e. mode choice and travel demand) *after* important behavioral factors (e.g. prices, resources and preferences) are taken into account? A large body of literature has been devoted to the topic of the relationships between the built environment and travel behavior (e.g. Friedman et al. 1994, Cervero and Kockelman 1997, Newman and Kenworthy 1989, 1999). The study approaches range from simple comparisons or bivariate correlation analyses in travel outcomes among neighborhoods or cities with different land use characteristics to sophisticated multivariate analyses. The results reported, however, are rather mixed. Some have concluded that land use variables are strong explainers of travel behavior while others found little of such evidence. One

common problem existing in many of these studies, as they have been criticized by a number of scholars (e.g. Gomez-Ibanez, J.A., 1991, Crane 1999, and Pickrell 1999a), is their omission of important variables such as income, price and/or transportation supply. In this research, we attempt to rigorously control for the effects of these behavioral variables.

(2) How does land use 'cause' changes in people's travel behavior? This is both a theoretical and empirical question concerning individual travel demand. The issue of causation has been a major challenge to researchers in explaining the observed empirical evidence on the built environment/travel behavior connections. Hence, the potential of land use planning as a mobility tool has often been questioned. Many advocates of land use-based mobility strategies themselves are cautious in interpreting their observed land use/travel behavior relationships as associative rather than causal (e.g. Cervero and Kokelman 1997). This is because when cross-sectional data are used to measure the associated effects, the true causality is largely indeterminate. Technically, the direction of causation can be better observed if time-serial models and temporal data are utilized. Unfortunately, such data rarely exist or are too expensive to collect. Furthermore, land use changes generally do not appear in a short period of time. When time goes by, other factors affecting travel behavior such as transportation technologies come into play, masking the true effects of land use. This creates a research dilemma in that the question of whether land use *causes* changes in individuals' travel behavior seems untestable. In this thesis, we attempt to address the question by qualitative reasoning within a behavioral framework of travel demand in combination with empirical modeling of individual trip making.

(3) What is the nature of automobile dependency? How to quantify the degree of automobile dependency for a given population group or in a given geography? What factors do contribute to automobile dependency? The policy concern over automobile dependence relates not only to transportation services but also to the quality of life in general. Automobile dependency has been linked to many undesirable consequences of driving such as congestion, environmental degradation, personal distress and health

problems. Reducing automobile dependency has become one of the main objectives of contemporary transportation planning and policies.

Unfortunately, little is known about the nature of automobile dependency except for such general statements as 'people like their cars' or 'they don't have other alternatives'. Understanding how and to what extent various social, economic, spatial, and idiosyncratic factors contribute to people's automobile dependency is important to public policy making that aims to reduce the undesirable social and environmental consequences associated with auto travel, and to improve the quality of urban and suburban life at large. To those who are captive to automobile due to social or spatial constraints, policy strategies designed to improve alternative travel and social services would be more desirable (than punitive policies such as pricing). On the other hand, to those who depend on automobile for attitudinal reasons, economic approach such as pricing would be necessary and more effective. In this research, we attempt to advance the research on automobile dependence by explicitly modeling and quantifying it.

(4) What are the comparable magnitudes of the effects of economic measures and land use initiatives on travel? Most existing studies have focused on proving that toll and parking charges, land use density, land use mix, or urban form do or do not have impacts on people's travel decision making. It is of course useful to learn the directions of the effects that these factors potentially have on travel. For the purpose of policy making, it is even more important to know the magnitude of the effect, if any, or the extent of changes that policy action would induce.

Despite the disagreements, one thing in common among the advocates of different policy solutions is that they all expect behavioral changes in individuals' travel or location decisions in response to the implementation of the recommended policies. In evaluating the effectiveness of these policy options, it is then fundamental to ask whether or not individuals' behavior adjustments would take place to the extent expected.

(5) How do land use initiatives interact with economic measures in affecting travel? To what extent and under what conditions can land use initiatives effectively affect people's mobility choices and travel decisions? What lessons can be learned from the two case studies (i.e. Metropolitan Boston and Hong Kong) in land use development and transportation policy making? We address these questions by arguing that economic measures and land use initiatives reflect the two sides of one coin--they are inherently complementary.

1.3 Structure of the dissertation

Chapter 1, this chapter, introduces the issues concerned, states research objectives and questions, and describes the structure of the dissertation.

Chapter 2 explains the motivation of the research based on the literature review on topics pertaining to the transportation pricing/land use policy debate, to the built-environment/travel-behavior relationships, and to automobile dependence. From the literature review research needs are identified, which leads to the research design described in the following chapter.

Chapter 3 starts with a summary of the research design. It then provides a review of accessibility models, along with a general description of the concepts of mobility and accessibility. Within that context, the specific accessibility model applied to this research is introduced. Next, it gives a behavioral interpretation and an operational definition of automobile dependence and explains the extension of the mode choice modeling framework for the measurement of automobile dependence. The statistical tools used to analyze individual travel demand, i.e. trip frequency are described subsequently. The reasons why metropolitan Boston and Hong Kong are selected as our empirical study cases are given in the following part. Finally, it describes the ways that data sets are organized and managed using computational tools such as geographic information system (GIS) and database management system (DBMS).

In Chapter 4 we present the study on the Boston case, addressing the research questions stated in Chapter 1. We first provide the basic social, demographic and geographical information about the study area in the Greater Boston. National and regional postwar trends in urban and transportation development are also briefly reviewed. The mobility supply in the study area in terms of road networks and transit services are described in more detail. The major contents of this chapter include three sections on the empirical modeling of the built-environment/travel-behavior relationships focusing on travel mode choice, trip frequency, and automobile dependence. The fourth section is devoted to simulation analysis of the policy effects on travel behavior based on the empirical results. The chapter ends with a chapter conclusion.

Chapter 5 is on the Hong Kong case study. Beginning with the background information on Hong Kong, the Chapter starts presenting a case of success on transit-based mobility supply. It then accounts for factors important to Hong Kong's success in maintaining sufficient mobility and accessibility to its citizens. Parallel to the Boston case, mode choice modeling, automobile dependence measurement, and policy effect simulations are presented next.

Chapter 6 first summarizes the results of the Boston and Hong Kong case studies. It then draws policy implications based on the findings from studying the two cases. Contributions of this dissertation and areas of future research are highlighted next. The chapter ends with concluding remarks.

The appendix includes technical notes and programming codes for data processing and modeling of mode choice and automobile dependence.

Chapter 2

The Premise of Land Use as a Mobility Tool

2.1 The Signs of the Transportation Market Failure

Current travel patterns are generally believed the indication of the transportation market failure in the metropolitan US. Following stylized facts portray such travel patterns.

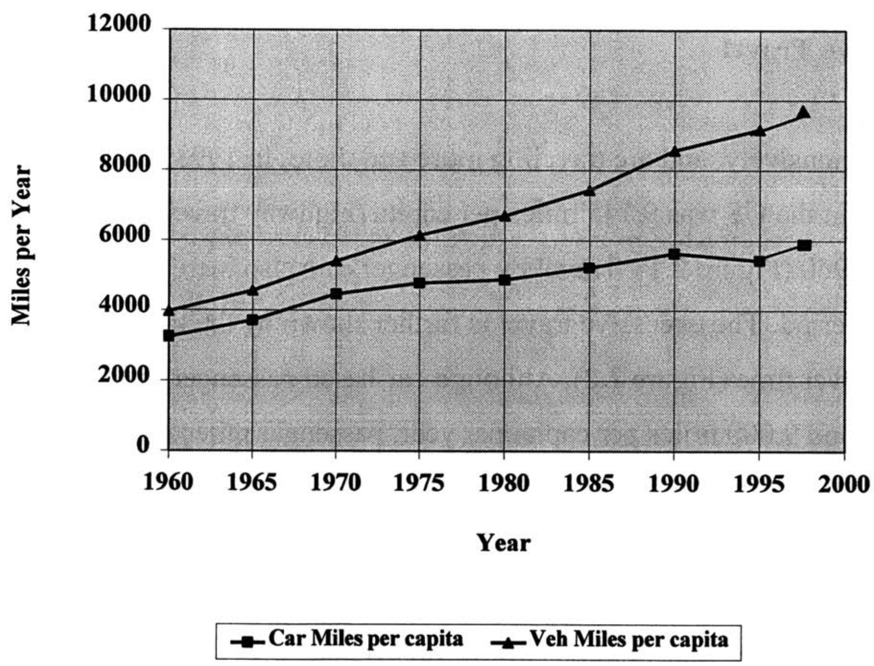
- **Excessive Travel**

People travel extensively, and are traveling more and more. In 1998, annual vehicle miles-traveled in the US was 9,745 miles per capita (highway travel only), a 145% increase from 1960 (Figure 2.1). Travel by passenger cars also increased by 77% during the same time period. The excessive travel is further shown by the trend of passenger-miles traveled over time (Figure 2.2). Although car-based passenger miles traveled have been stable around 9,000 miles per capita per year, passenger miles traveled by all types of vehicles (including passenger cars, light trucks, motorcycles, and buses) have been continuously increasing, reaching 15,715 miles per capita in 1998. If we assume an average travel speed of 45 miles per hour, the annual travel figure translates to a total of 349 hours per person per year. In other words, on average, every American spent about two months traveling around, assuming that they traveled 8 hours per day in the two month period and that they did have weekends off.

The excessive travel is accompanied by the large and growing consumption of energy. In 1999, the transportation sector consumed over 26 trillion BTU of energy, and it accounted for 67% of end-use consumption of petroleum products in the US (US DOE, 2000). The excessive travel also imposes significant impacts on the environment. In the

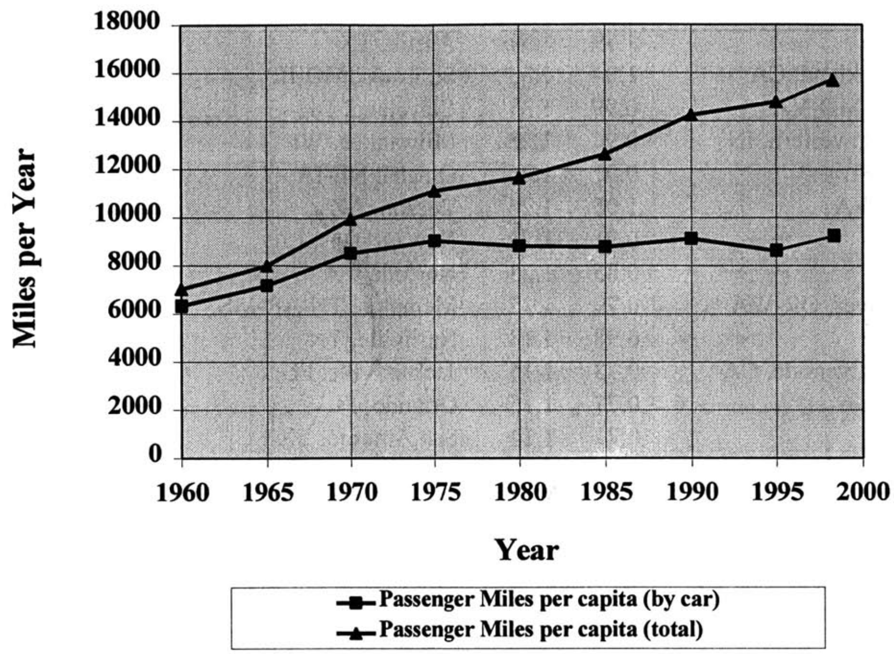
US, transportation accounts for about one third of total greenhouse gas emissions, of which 60% are from cars, 15% from trucks, and the rest from ships, aircraft, etc. (Pickrell 1999). The growing energy consumption by transportation and increasing impacts on the environment have raised serious concerns over the long term sustainability issues that cannot be adequately dealt with by the transportation market itself.

Figure 2.1 Vehicle Miles Traveled in the US, 1960-98



Source: Bureau of Transportation Statistics, 2000

Figure 2.2 Passenger Miles Traveled in the US, 1960-98



Source: Bureau of Transportation Statistics, 2000

- **Road Congestion**

Despite large investments in road infrastructure, road congestion is becoming worse in many major US metropolitan areas. Table 2.1 shows the Road Congestion Index (RCI)* indicating the congestion levels from 1982 to 1997 in selected areas, including 50 largest urban areas in the country. In 1997, 38 out of the 68 selected urban areas have RCI exceeding 1.0, a threshold that indicates the undesirable congestion level. Estimated congestion costs in 1997 for these urban areas were $72,205 million (TTI, 1999).

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* RCI is measured as follows:

$$RCI = \frac{(FreewayVMTperLaneMile) * (FreewayVMT) + (ArterialVMTperLaneMile) * (ArterialVMT)}{13{,}000 * FreeywayVMT + 5{,}000 * ArterialVMT}$$

where 13,000 and 5,000 VMT/lane are the system-wide congestion indicator levels for freeways and for principle arterial roads, respectively. RCI is essentially a measure of average vehicle travel density on major roadways in an urban area. It therefore does not reflect the congestion levels of specific routes or segments of road. When congestion occurs, travel speed decreases, resulting from less flow over the congested segments. When it is too congested, traffic flow becomes close to static. RCI as an aggregate measure does not represent the micro level traffic conditions. Furthermore, it does not consider local roads and streets, which most of the time in a day are free of congestion.

Table 2.1 Roadway Congestion Index in Selected US Metropolitan Areas

Urban area	1982	1997	Urban area	1982	1997
Los Angeles, CA	1.39	1.51	Austin, TX	0.78	1.03
San Francisco-Oakland, CA	1.04	1.33	St. Louis, MO-IL	0.81	1.03
Washington, DC-MD-VA	0.99	1.33	Cleveland, OH	0.75	1.01
Chicago, IL-Northwestern, IN	0.94	1.28	Milwaukee, WI	0.76	1.01
Miami-Hialeah, FL	0.97	1.26	Omaha, NE-IA	0.67	1
Seattle-Everett, WA	1.05	1.26	Tucson, AZ	0.79	1
Boston, MA	0.91	1.24	New Orleans, LA	0.89	0.99
Atlanta, GA	0.85	1.23	Norfolk, VA	0.75	0.97
Portland-Vancouver, OR-WA	0.79	1.22	Memphis, TN-AR-MS	0.76	0.96
Detroit, MI	0.98	1.18	Nashville, TN	0.71	0.96
San Bernardino-Riverside, CA	0.73	1.15	Jacksonville, FL	0.84	0.93
Tacoma, WA	0.77	1.15	Orlando, FL	0.65	0.93
Sacramento, CA	0.71	1.14	San Antonio, TX	0.73	0.92
Minneapolis-St. Paul, MN	0.7	1.13	Fort Worth TX	0.73	0.91
Phoenix, AZ	0.94	1.13	Beaumont, TX	0.67	0.9
San Diego, CA	0.8	1.12	Fresno, CA	0.81	0.9
New York, NY-Northeastern, NJ	0.94	1.11	Hartford-Middletown, CT	0.69	0.9
Cincinnati, OH-KY	0.81	1.08	Providence-Pawtucket, RI-MA	0.79	0.87
Denver, CO	0.77	1.08	El Paso, TX-NM	0.66	0.86
Fort Lauderdale, FL	0.7	1.08	Oklahoma City, OK	0.57	0.85
San Jose, CA	0.76	1.08	Eugene-Springfield, OR	0.54	0.84
Houston, TX	1.09	1.07	Salem, OR	0.57	0.82
Las Vegas, NV	0.67	1.07	Spokane, WA	0.64	0.81
Tampa, FL	0.91	1.07	Boulder, CO	0.64	0.8
Honolulu, HI	0.86	1.06	Rochester, NY	0.53	0.78
Albuquerque, NM	0.69	1.05	Colorado Springs, CO	0.62	0.77
Baltimore, MD	0.78	1.05	Kansas City, MO-KS	0.56	0.76
Indianapolis, IN	0.62	1.05	Pittsburgh, PA	0.72	0.76
Philadelphia, PA-NJ	0.98	1.05	Albany-Schenectady-Troy, NY	0.48	0.75
Charlotte, NC	1.08	1.04	Bakersfield, CA	0.47	0.75
Columbus, OH	0.61	1.04	Buffalo-Niagara Falls, NY	0.6	0.72
Dallas, TX	0.77	1.04	Corpus Christi, TX	0.67	0.72
Louisville, KY-IN	0.72	1.04	Brownsville, TX	0.53	0.71
Salt Lake City, UT	0.68	1.04	Laredo, TX	0.52	0.61

NOTES: The roadway congestion index (RCI) is a measure of vehicle travel density on major roadways in an urban area. An RCI exceeding 1.0 indicates an undesirable congestion level, on average, on the freeways and principal arterial street system during the peak period.

SOURCE: 1982-97: Texas Transportation Institute, The 1999 Annual Urban Mobility Report (College Station, TX: 1999), Appendix A-4.

- **Modal Mismatch of Demand and Supply**

While highway travel demand continues to grow, transit ridership has been declining. In 1998, national transit ridership was only slightly over half of the 1920 level (Table 2.2). From 1960 to 1998, the US population increased by 49%. The transit ridership, however, was down by 7%. In spite of growing share of public spending on transit since the 1950's (Table 2.3), transit share of total urban passenger miles keeps declining (Table 2.3). In 1997, transit share of total urban passenger miles was merely 2%, a result of long term decrease since World War II (Table 2.4).

Table 2.2 Transit Ridership by Mode in the US (millions), 1920-1998

Year	Bus	Heavy Rail	Light Rail	Commuter Rail	Other	Total
1920	--	1,792	13,770	--	--	15,562
1930	2,481	2,559	10,530	--	16	15,586
1940	4,255	2,382	5,951	--	542	13,130
1950	9,447	2,264	3,904	--	1,686	17,301
1960	6,425	1,850	463	--	657	9,395
1970	5,037	1,881	235	--	182	7,332
1980	5,837	2,108	133	280	209	8,567
1990	5,677	2,346	175	328	273	8,799
1998	5,387	2,393	275	382	309	8,746

Source: Luberoff and Altshuler, 1999

Table 2.3 Modal Share of Public Spending on Highways and Transit, in the US, 1956-94

Year	Total Spending (billions, in 1997$)	Highways	Transit
1956	$44.60	92%	8%
1960	$55.80	93%	7%
1964	$66.50	93%	7%
1968	$74.40	91%	9%
1972	$74.90	90%	10%
1976	$67.00	85%	15%
1980	$74.30	81%	19%
1984	$77.50	76%	24%
1988	$92.50	78%	22%
1992	$104.00	77%	23%
1994	$109.70	75%	25%

Source: Luberoff and Altshuler, 1999

Table 2.4 Urban Transit and Urban Automobile Passenger Miles (billions) in the US, 1945-1997

Year	Transit	Auto	Transit Share
1945	130	240	35%
1950	90	403	18%
1955	60	515	10%
1960	48	627	7%
1965	43	786	5%
1970	41	1,089	4%
1975	38	1,341	3%
1980	40	1,288	3%
1985	40	1,400	3%
1990	41	1,533	3%
1995	38	2,024	2%
1997	42	2,106	2%

Source: Luberoff and Altshuler, 1999

- **Automobile Dependence**

Most North American communities are believed automobile dependent (Newman and Kenworthy 1999, Litman 1999). In these communities, the use of automobile is not so much a choice but a necessity. According to Newman and Kenworthy, US cities (along with Australian cities) are the most extensive in their dependence on the automobile, three to four times more than the European cities. American's dependence on automobile is characterized by the high per capita transportation use of energy (2.5 times higher than that in the Europe), the dominant role of cars among travel modes, generous road and parking supply, and low density suburban sprawl that support and require car use. The 1995 Nationwide Personal Transportation Survey shows that in the US, 86% of total person trips were made by private vehicles. Private mode of transportation served for over 90% of all commute and personal business trips (Table 2.5).

Table 2.5 Total Person Trips by Mode and Trip Purpose (millions) in the US, 1995

	Private	Transit	Other	Total
Total	327,400	6,638	32,424	366,462
	89%	*2%*	*9%*	*100%*
To or From Work	60,740	2,328	2,397	65,465
	93%	*4%*	*4%*	*100%*
Work Related Business	8,835	123	658	9,616
	92%	*1%*	*7%*	*100%*
Family/Personal Business	156,065	2,000	10,524	168,589
	93%	*1%*	*6%*	*100%*
School/Church	22,436	826	8,960	32,222
	70%	*3%*	*28%*	*100%*
Social & Recreational	78,809	1,350	9,799	89,958
	88%	*2%*	*11%*	*100%*
Other	470	11	84	565
	83%	*2%*	*15%*	*100%*

Source: Nationwide Personal Transportation Survey, 1995

2.2 Land Use-Based Mobility Strategies

It is generally agreed that one of the main causes of current Transportation market failure is the mis-pricing of private vehicle use. Charging motorists prices that reflect the long-run social costs of driving is therefore considered the most direct, effective measure to correct the market failure. However, political barriers make such measure unfeasible to implement, at least in the near future.

Many have thus argued that land use should play the role, because the transportation market failure is closely related to the land use practice prevailing in the urban and suburban communities. It is believed that people are traveling long distances because jobs, stores, shops, and other services are located far away from where they live; they make frequent trips because these service facilities are segregated and isolated, which generate more single-purpose trips than the case with mixed-use development; they rely on automobiles too much because there are no other viable options such as transit, which is not efficiently supported by existing land use patterns. Accordingly, many land use initiatives have been recommended, and some are being practiced nation-wide, aiming to alter current travel patterns. Following four are believed the most effective, land use-based mobility initiatives. They are closely related and, in practice, are often jointly implemented.

- **Densification**

Density is considered the single most important land use factor that affects travel (Newman and Kenworthy 1989, 1999). Suggested desirable density is 18 units per acre (or FAR of 2.0), which is necessary to achieving mode splits in the 15 to 20 percent transit share. Densification is recommended at both ends of the commute trip.

- **Mixed-Use Developments**

Mixed-use places compatible activities side-by-side so that they mutually benefit from one another. The transportation benefits of mixed-use developments are believed to include: increased walk trips; evenly distributed trip-making throughout the day and week; higher likelihood of carpool or vanpool (Duany, et al. 1991).

- **Job-Housing Balance**

The idea of job-housing balancing is to provide opportunities for people to live reasonably close to their workplaces. It requires balanced distribution and diversified housing and job opportunities in a given area. Job-housing balance reduces cross-zone commuting that has been currently spreading out in many metropolitan areas (Cervero 1991).

- **Site Planning and Design Practices**

Design-based strategies include neotraditional neighborhood design, transit-oriented development, and traffic calming (Duany, et al. 1991, Calthorpe 1993, Ewing 1999). The basic idea is to design the built environment that is more pleasant for walking, biking, which helps create a sense of place and promotes human interactions. Expected transportation benefits are that more pedestrian-friendly work environments could attract larger numbers of suburban employees to vanpools, carpools, and transit.

2.3 Conflicting Evidence of Land Use's Mobility Role

How effective are these land use-based mobility tools? There have been heated debates among policy analysts. Mixed evidence is reported in the literature. Below we review related literature and design our research with detailed examination of previous studies and findings.

- **The 'Transportation/Land-Use Connection' Debate**

An important issue pertaining to the effectiveness of land use as a mobility tool is whether the evolving land-use and transportation connections offer any significant potential for land use to play a role in influencing people's mobility choice and in modifying urban accessibility. Historically, land-use and transportation developments have been closely related. Frequently cited example is the strip-type land use development patterns in the street-car era. In the automobile era, however, such close connections between land use and transportation development are no longer as obvious since automobile has provided almost ubiquitous access. If the connections between land-use and transportation become weakening, the role of land use as a mobility tool would be diminishing.

Giuliano and Small (1995) suggest that this is what's happening to contemporary cities, particularly in urban America. They list a number of reasons. First, transportation costs are low relative to housing costs and the real cost of commuting has dropped dramatically over time. Rising income increases demand for more space (lower density) and cleaner air (farther away from central city). Transportation is of declining importance in the locational decisions of households and firms. Second, American cities are already built up with highly developed transportation systems, which have long life. The relative impact of even major transportation investments is minor. Studies in Los Angeles and Oregon show that land use policies (e.g. densification) and transportation policies have to be truly extreme to have significant impact on mode shares, trip lengths and urban form.

Third, structural economic shifts to information-based activities engender decentralization. It allows more flexible work arrangements (temporal and spatially) and less clustering among firms. This implies more spatial dispersion.

Cervero and Landis (1995) take a contrary position. They argue that the existing land use and travel patterns are the outcomes in a distorted market of cheap auto usage, not representing the true land use-transportation relationships. They challenge that Giuliano and Small's findings and conclusions are based on questionable information or examples, i.e. modeling results with unrealistic assumptions, stated-preference survey, and incomplete trip data. In contrast, they cite studies in which strong capitalization effects are found for proximity to San Francisco's BART and San Diego's light rail system. In the case of freeway accessibility, the opposite effect is observed. They conclude that the land-use/transportation connection still matters and public policy plays a vital role in shaping the connection. True market pricing of transportation is more unattainable than strengthening transportation-land use linkages in a pluralistic, democratic society. In the absence of true market-based pricing of travel, land use policies are among the next best things.

Pickrell (1999) tells a more detailed story on transportation/land-use relationships. He observes that urban development represents the *cumulative* effect of incremental improvements to the transportation technologies. In this cumulative development process, the effect of innovations in transportation technology on development pattern is exerted primarily within the expanded portion of growing urban areas. Since technological improvements eventually translate to reduction of the time or monetary costs of travel, each successive innovation in passenger transportation, including urban transit and automobile, contributes in turn to metropolitan decentralization and lower development densities than in preceding eras.

Another feature related to the cumulative effect is that, because of the durability of the urban (infra)structures, even massive investments in the capital infrastructure represent comparatively modest additions to the cumulative value of investments that are already in place. Therefore, the role of transportation in location and land use decisions is likely to have weakened over time. Changes in travel costs fostered by technological innovation and investment are likely to be much smaller than was historically the case.

Pickrell thus concludes that, although the historical effect of transportation on land use has been pronounced, current and foreseeable technological innovations and investment levels are unlikely to have comparably large effects. Consequently, the influence of land use patterns on the volume and geographic pattern of urban travel is modest. "Land use planning as a means to mitigate externalities such as traffic congestion and air pollution generated by urban transportation thus seems unlikely to be *an effective substitute* [emphasis added] for rationalizing investment levels and pricing policies in urban transportation." (p.432)

- **Evidence of Land Use Having/Having No Influence on Travel: Regional Scale**

Many empirical and simulation studies have been done searching for evidence of land use having or having no influence on travel. One approach is to examine, at the regional scale, whether travel patterns are attributable to urban spatial structure.

Cervero (1989a, 1989b) and Downs (1989) have hypothesized that imbalances and mismatches between jobs and housing cause long commutes and increase highway congestion. Imbalances occur when the number of workers who can be housed in an area differs substantially from the number of jobs located in the area. Mismatches occur when prices or other characteristics make housing in the area unsuitable for the works who hold jobs there. Both make inter-area commutes necessary and longer than the balanced and matched case. They contend that the continuing lengthening of commuter trips and the marked deterioration of traffic conditions is partly due to a widening job-housing imbalance in many metropolitan areas across the country. The spatial mismatch between the location of jobs and the location of affordable housing is forcing growing numbers of

Americans to reside farther from their workplaces than they would otherwise choose and, consequently, is intensifying congestion. They then identifies at least five economic and demographic forces that have contributed to the job-housing imbalance: (1) Fiscal and exclusionary zoning; (2) Growth moratoria, including capping the number of building permits, increasing minimum lot sizes; (3) Worker earnings/housing cost mismatches; (4) Increasing two wage-earner households; and (5) Increasing job turnover rates and high cost of financing new home mortgages. Therefore, various zoning, taxation, and transportation pricing initiatives should be taken to encourage a balanced job-housing pattern in metropolitan areas.

Giuliano and Small (1993) test this job-housing imbalance hypothesis by applying the concepts of *required commute* and *excess commuting*. Required commute is the minimum average commute required by the actual spatial patterns of housing units and jobs sites. It is measured using the linear programming technique employed by Hamburg et al (1965) and White (1988). They use data for the urbanized portion of the five-county Los Angeles region. The data include 1980 journey-to-work information for 1146 zones and estimated inter- and intra-zonal distances and peak-period travel times on the highway network. Their results show that the average commuting time to each sub-area of LA region is at least twice as large as it would be in the cost-minimizing pattern (i.e. required commute). Overall, required commutes are more than three times longer to the sub-urban centers than elsewhere, whereas actual commutes are just 23 percent longer to the centers than elsewhere. The polycentric pattern of employment centers in the region, along with the dispersal of many jobs outside centers altogether, creates the potential for shorter commutes than those required of people working in downtown Los Angeles. However, commuters are taking little advantage of this potential, choosing instead to commute only a few minutes less than downtown workers.

The mismatch effects are further analyzed by applying occupational constraints in calculating the required commutes. The results show that mismatches could lengthen commutes to some extent, but more than half of the average commute time remains unexplained.

In addition, the intra-regional variation in commuting time was examined by applying regression techniques. Regression analyses are run at different spatial aggregation levels with the proposed job-housing balance indicators as the independent variables. The results show that jobs-housing balance, whether measured by the ratio of resident workers per job in a broad sub-area or by the required commuting time, has a statistically significant but not very large influence on actual commuting times. They then conclude that attempts to alter the metropolitan-wide structure of urban land use via policy intervention are likely to have disappointing impacts on commuting patterns, even if successful in changing the degree of jobs-housing balance. Such policies do not address the main sources of dispersion in location patterns.

In another study, Waches et al. (1993) examined a number of commute outcomes for 30000 hospital employees over a six-year period. They concluded that little evidence sustains the purported commute-increasing effects of jobs-housing imbalances.

A fundamental issue left unexplained in the job-housing balance debate is at what spatial scale that job-housing balance is to be maintained. While talking about job-housing balance at the level as small as traffic analysis zonal is of no any practical importance, talking about job-housing balance at the metropolitan level is of little meaning, too. This conceptual vagueness leads to confusions of interpreting the empirical results.

For example, Levine (1998) points out that, Giuliano and Small's findings, if interpreted from a more positive perspective, may be used to demonstrate the importance of the job-housing balance argument. For instance, their calculation shows that 36.6 percent of actual commute may be attributed to the patterns of job and housing locations. When controlled for the mismatch effects, the explained portion of actual commute increases to 44.7 percent. Metropolitan travel outcomes are affected by many social, economic, and regulatory factors. An independent variable with such explanatory power to the dependent variable can be considered a strong predictor.

Another widely cited yet controversial study along this line is by Gordon et al. (1991). Using travel data from the standard sources such as the Census, the American Housing Survey (AHS), and Nationwide Personal Transportation Study (NTPS), Gordon, et al compare and examine the average commuting times for the twenty largest Metropolitan Statistical Areas in the US. In spite of the widespread reports of congestion, they find that changes in work trip times and distance during the study periods were modest and generally insignificant. They attribute the observed stability of average commuting to adoptability of commuters in the given urban structure. Individuals and firms have the capacity to adjust rationally to potentially adverse changes in physical and economic conditions so as to keep commuting times within tolerable limits. Therefore, one would not expect significant changes in average commuting times in major US metropolitan areas.

However, they do find that there is a striking difference in auto commuting times between dense and dispersed cities. Dense cities result in much longer automobile commuting times than spread-out, dispersed cities. Commuting times tend to be shorter in rapidly growing cities and growth per se does not lead to ubiquitous congestion.

They thus conclude that the appropriate role for planning agencies and local jurisdictions should be to facilitate the decentralization of jobs by relaxing zoning restrictions to help the market to work rather than attempt to strangle it. With such an approach, economic agents (both firms and individuals) will be able to continue to make rational decisions, hold commuting times in check, and mitigate congestion.

Bourne (1993) challenges the viewpoint of Gordon, et al. He agrees that traffic congestion may be self-regulating, resulting in the average commuting time below a certain threshold (about 30 minutes). However, he maintains that the explanations or interpretations offered by Gordon, et al. are not well justified, leaving the hypotheses untested. Therefore, arguments based on the untested hypotheses are weak and policy recommendations may be misleading.

He argues that economic efficiency cannot be well evaluated without reference to prices or to the distribution of costs involved. Extremely rapid decentralization and a dispersed form of urban development often lead to massive inefficiencies in other sectors and locations. These are most commonly reflected in the misuse of land, in the underutilization of existing infrastructure, in the diseconomies of overextended social service provision, and in the downstream costs of maintaining even reasonably uniform access to those services, as well as through their negative impacts on local environmental and ecological systems.

He further contests that Gordon, et al., ignore the pervasive role of the governments. New suburban areas are as much as a product of their institutional context and of specific public sector actions (or inactions) as are planned communities, although the instruments of design and implementation obviously differ. The market in fact differs less from place to place than do the institutions, political agencies, and policy instruments that regulate urban development. Governments are integral parts of the urban development process.

According to Bourne, there is no simple answer to the question of which, mono-centric or poly-centric cities, are better or more efficient, due to our limited understanding about the urban structure. The transforming industrial structure, the widespread of telecommunications and information technologies, and the changing roles of governments, NGO's or other public/private sectors in the economy all place challenges to urban researchers. There is still much to be learned about the complexity of contemporary metropolis.

- **Evidence of Land Use Having/Having No Influence on Travel: Local Scale**

Another line of empirical analysis of land use/transportation connections is to examine, at the micro scale, the interactions between the built environment characteristics and people's travel behavior. The work by Kockelman and Cervero is perhaps the most representative of the kind.

To model the built environment/travel behavior relationships, Kockelman (1997) proposes four measures to quantify the essence of the basic characteristics of relatively local urban form. These four measures are: density, accessibility, entropy index (land use balance), and dissimilarity index (mix).

The accessibility index is constructed in the form of gravity model. Land use balance is evaluated based on a measure of entropy, originally defined for the energy state of a system and commonly used to quantify the uniformity of gaseous mixture. The measure has been extended to gauge the uncertainty represented by probability distribution function, and more recently, in the regional-science literature to index sectoral balance across distinct industries. The Dissimilarity Index measures the integration of land use, i.e. the degree to which they come into contact with one another. All else being equal (e.g., population and retail space), one would expect the average distance between origins and destinations to be longer when uses are segregated, even if they are in relative balance.

Using these measures Kockelman estimates five pairs of models of mode choices and travel demand, with each pair containing a base model without including land use variables and a final model including them, in addition to other socio-economic variables.

Kockelman's estimation results show that the inclusion of built environment variables strengthens each of the models, reducing unexplained variation in the dependent variables substantially (a range between 22 and 55 percent). Accessibility to opportunities is very strongly linked to travel behavior. It is a far better predictor of vehicle miles-traveled (VMT) and mode choice than density, although in auto ownership model population densities prove highly useful.

Land use balance (entropy) and mix (dissimlarity) do appear to matter, with both affecting VMT and with entropy influencing walking-biking probabilities substantially. Automobile ownership appears to be more significantly influenced by local attributes of the built environment such as population density whereas trip distances and VMT are influenced at more of a community and regional level.

Applying the same measures proposed in Kockelman (1997), Cervero and Kockelman (1997) present a similar study based on more carefully selected 50 neighborhoods in the San Francisco Bay Area. The technique of factor analysis is also applied to gauge the relative influence of land use density, diversity and design as well as their collective impacts on travel demand after controlling for other explainers, like travelers' demographic characteristics. The results are consistent to those in Kockelman (1997).

In both studies, the authors raise the issue of causation. Attributing to the limitation of cross-sectional statistical analysis, they acknowledge that it is unclear whether land use causes travel behavior changes. They therefore warn that their results must be interpreted as being associative rather than causal. The unresolved issue of causation has remained in most of past and current empirical analysis, challenging the potential of land use as an effective mobility tool.

Using a sample of 11 US metropolitan areas and data from the 1985 American Housing Survey, Cervero and Wu (1997) model commuting mode choice probabilities as functions of the characteristics of trip origins and destinations. They find that mixed uses in one's immediate neighborhood encourage commuting by foot or transit, assuming home-to-work distance are not too long. Vehicle ownership levels decline with the increase of neighborhood density and the presence of non-residential land uses in the area. Relative to a neighborhood with single-family detached units, households in high-rise apartments are likely to own 0.47 fewer vehicles, all else being equal. Commuting distances tend to be shorter for those living in dense, mixed-use neighborhoods. Neighborhood densities have a stronger influence than mixed land uses on all commuting mode choices except for walking and bicycling. For non-motorized commuting, the presence or absence of neighborhood shops is a better predictor of mode choice than residential densities. If retail shops are within 300 feet, or several city blocks, of a dwelling unit, workers are more likely to commute by transit, foot, or bicycle. Beyond this distance, however, mixed use activities appear to induce auto-commuting.

Neighborhood density and mixed land uses tend to reduce vehicle ownership rates and are associated with shorter commutes, controlling for income and other factors. In combination, the effects of reducing auto-commuting, commute distance, and vehicle ownership rates suggest that moderate-to-high density, mixed-use neighborhoods average less VMT per capita than lower density, exclusively residential ones.

One limitation of the study is that it does not control for the effect of monetary costs of travel on mode choice. Omission of the important behavioral variables tends to cause their modeling results being statistically biased.

The study by Kitamura, Mokhtarian and Laidet (1997) is another example demonstrating the continuing interest in the topic of built-environment and travel behavior. The uniqueness of this study is that data on personal attitudes are combined with the commonly used explanatory variables. Trip frequency and proportion of trips by modes are regressed on social and demographic variables, land use variables for the neighborhoods, and attitude variables that are obtained from a survey designed to extract residents' opinions on driving, the environment, and related questions. They find parking availability to be negatively associated with total person trips and positively associated with the proportion of automobile trips. High residential density is positively related to the share of non-motorized trips. Similarly, the distance to the nearest rail station and having a backyard are negatively correlated with the number and fraction of transit trips. They suggest that attitudinal factors have stronger explanatory power than neighborhood characteristics.

In a series of studies by Crane (1996), Crane and Crepeau (1998), and Boarnet and Crane (2000), the authors emphasize the importance of having a sound theoretical underpinning to support empirical analysis on the built-environment/travel behavior relationships. In a rather theoretical reasoning, Crane (1996) demonstrates that the demand for trips by any mode, and overall travel, can be linked to the built environment by an explicit characterization of trip costs. Different urban forms and features, such as the street layout and land use mixing, should be directly reflected in trip time and distance. The demand for trips in each mode, like for any commodity, is expected to be downward sloping in cost.

Adopting this framework, Crane and Crepeau (1998) estimate models of number of non-work trips and mode choice as functions of prices, income, taste variables, and other controls including land use measures. Trip speed and distance are used as proxies of prices. Land use variables include the neighborhood circulation pattern, the density of the street network, the residential, commercial, and vacant shares of the census tract, and distance from downtown, all measured at the trip origin. Household socio-economic variables include income, age, gender, employment status, and housing tenure. The modeling results show that the trip cost variables are highly significant for all models estimated. If trip length and time are longer, they tend to be fewer in number. The higher the commercial share of the census tract, the higher the number of trips for adults only. A more dense street network is associated with fewer trips. However, whether the streets are configured as a grid had no significant effect.

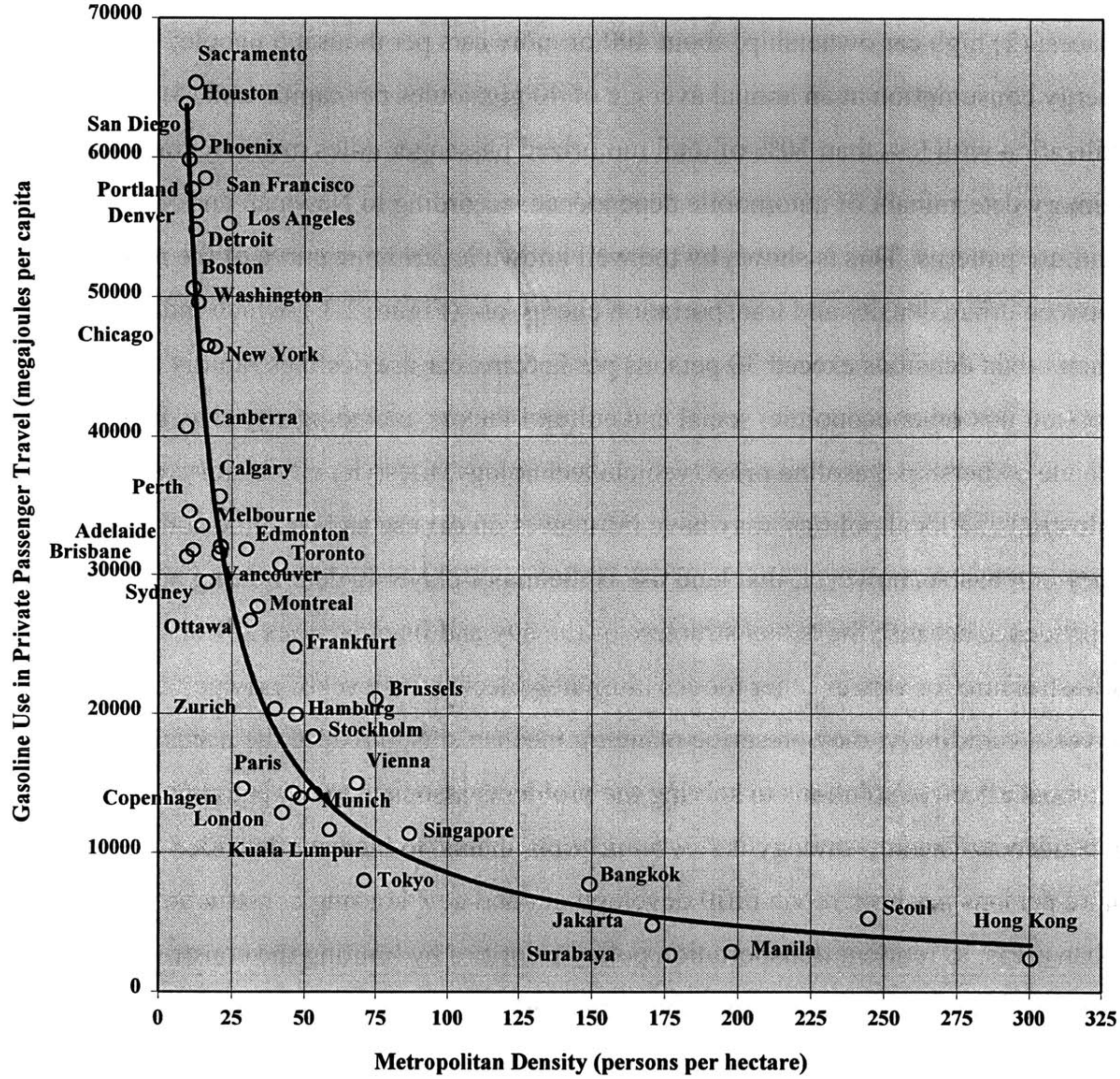
- **Land Use, the Causes and Consequences of Automobile Dependence**

Of the few empirical studies devoted to the subject of automobile dependence and its relationships to the built environment, the work by Newman and Kenworthy (Newman and Kenworthy 1989, 1999, Kenworthy and Laube, 1999, and Kenworthy, et al. 2000) generates a great deal of influence and debate on transportation and land use planning and policy analysis. The work is unique in its international scope, studying the patterns of and prescribing policy solutions to automobile dependence based on a sample of initially 32 and later on an expanded sample of 46 world cities that spread out North America, Europe, Austria, and Asia.

Automobile dependence is characterized by Newman and Kenworthy as (1) low land use density (averaging 20 persons or less per hectare) and large supply of road and parking spaces; (2) high car ownership, about 400 or more cars per thousand people; (3) large energy consumption at an annual average of 40 gigajoules per capita; and (4) low transit utilization with less than 10% of total motorized passenger miles made by transit. The primary determinant of automobile dependence, according to Newman and Kenworthy, is land use patterns. This is shown by the well known logarithmic curve of the relationship between urban density and transportation energy use (Figure 2.3), which indicates that, when urban densities exceed 30 persons per hectare, car use declines rapidly. They mention that other economic, social and cultural factors, including city size, income, vehicle ownership, gasoline price, vehicle technology, lifestyle, city history, and industrial and local politics, may have influences on car use and gasoline consumption. They emphasize, however, that land use is the major player in determining automobile dependence because the actual structure of the city and its provisions of transportation infrastructure for cars or other modes ultimately decide the level of private vehicle-based travel. Accordingly, they prescribe planning mechanisms to reduce the needs for cars as the most effective solutions to solving the problems associated with automobile dependence. The key strategy is *reurbanization*, that is, to increase densities to 30 or more persons per hectare via infill development and new housing construction in central urban areas; to reorient transportation policy priorities by limiting the construction of new roadways and downtown parking, and promoting transit, particularly rail, walking and biking.

The work by Newman and Kenworthy is echoed by a number of other scholars (e.g. Holtzclaw 1994, Pivo, 1995, and Litman 1999). Litman focuses on the consequences of automobile dependence. He stresses that automobile dependence is costly and inequitable. His estimates suggest that average motorist spends about $4,000 directly on each automobile, and that businesses and governments must spend a comparable amount on facilities and traffic services, or a total of about $8,000 per vehicle. These estimates do not include non-market external costs of motor vehicle use, such as uncompensated accident and environmental damages, or the opportunity cost of land used for public

Figure 2.3
Energy Consumption vs. Urban Density in Global Cities



Source: Created based on the data from Newman and Kenworthy, 1999 roads. Automobile dependency provides direct benefits to motorists. However, it imposes a variety of economic, social and environmental costs. Increased driving is not necessarily beneficial to society when all incremental benefits and costs are considered. Because automobile use imposes external costs, people who drive less than average bear more than their share of costs, while those who drive more than average receive a subsidy. Disadvantaged people (low income, disabled, children and seniors) bear a large share of such costs. People who for any reason cannot own or drive a motor vehicle are worse off. Automobile dependency does not reflect true consumer choice due to market distortions that encourage excessive motor vehicle use. Only if such distortions are eliminated can society be sure that automobile use actually provides net benefits. Litman believes that land use is one of the key strategies that reduce automobile dependence and associated costs.

Newman and Kenworthy's observations and conclusions on land use and automobile dependence have also invited criticism. Direct counter arguments are made by Gomez-Ibanez (1991), mostly on the methodological grounds. Gomez-Ibanez contends that Newman and Kenworthy's accounts on the causes of automobile dependence is one-sided and incomplete. He doubts that per-capita gasoline consumption used by Newman and Kenworthy is an appropriate measure of automobile dependence, since gasoline consumption varies with different energy efficiencies of the auto fleets, average travel speeds, and variations in auto use. Newman and Kenworthy's use of partial correlation method for their analysis is considered by Gomez-Ibanez as fundamentally problematic. He maintains that auto dependence is caused not only by low land use density but by other factors such as incomes, gasoline prices, and public policies to subsidize public transportation or highway use. Therefore, to estimate the independent effects of urban density on auto dependence, one should simultaneously control for the effects of income, gas prices, and other variables.

Gomez-Ibanez further points out that separating cause from effect is a difficulty in any analysis of auto dependence due to the interactive relationships between land use and auto use. He believes that Newman and Kenworthy fail to make significant efforts in their research design to separate other causal factors such as incomes and prices from land use. Consequently, Newman and Kenworthy's results of land use effects on automobile dependence are overstated. Asserting that Newman and Kenworthy's analysis is methodologically fundamentally flawed, Gomez-Ibanez challenges the efficacy and validity of Newman and Kenworthy's land use-based policy prescriptions to reducing automobile dependence.

Lave (1992) believes that the true causes of increased automobile dependence lie in the changes in the composition of the work force, the age structure of the population, and the growth of income. Plotting out the national demographic and motorization figures from 1965 to 1987 in both the US and Western Europe, he observes the unstoppable trends towards increasing automobile ownership and its use. For example, in spite of Europe's high gasoline prices, expensive parking, efficient transit supply, pleasant walking environment and inadequate roads, auto ownership still grew rapidly in Western Europe, faster than in the US; auto use (in terms of car miles driven per year) was only marginally less than the US. Stating that the desire for personal mobility is the Irresistible Force, Lave offers his policy recommends just the opposite to Newman and Kenworthy's, that is, to improve auto technology with higher fuel-efficiency and less emission, and to expand highway networks. This view is also shared by Dunn (1998).

Several other studies focus on the understanding of the nature of automobile dependence and stress the challenges facing the policy makers to overcome automobile dependence. For example, Goodwin (1995) emphasizes that automobile dependence should be distinguished from auto use, and reducing automobile dependence should be achieved with the minimum of destructive side effects on quality of life. Dupuy (1999) points out that the widespread of automobile dependence is due to the fact that the automobile has created positive network effects to auto-owning individuals. Policies aiming to overcoming automobile should minimize these network effects by providing better and diversified services to the auto-less populations. In sum, the issue of automobile dependence remains a focus of the transportation policy debate (TRB, 1999; TQ, 2000).

2.4 Research Needs

- **A Research Gap in Policy Analysis**

From above literature review we see that there is an implicit assumption underlying the arguments made by both sides of the debate: economic measures and land use initiatives are substitutable; either approach alone is thought sufficient to correct the transportation and land market failure. This assumption leads the current debate often to a dichotomous mode, and economic measures and land use initiatives have been largely considered and analyzed in separated domain. It leaves a research gap in policy analysis: Few analyses have been done to examine the interactive and collective effects of economic and land use-based strategies on travel, although the importance for policy analysis of emphasizing the interactions and complementary effects of these different strategies has been pointed out by a number of scholars (e.g. Crane & Crepeau 1998, Levine 1998).

- **Measuring Automobile Dependence**

Automobile dependence warrants detailed analysis, given the relevance of the issue to the social and environmental concerns of travel, and to the quality of life of urban and suburban families at large. To what extent do people depend on the automobile in their daily activities? What are the causes of individuals' automobile dependent travel behavior? These are two fundamental yet not fully addressed questions in the policy debate on overcoming automobile dependence. As shown in previous literature review, most commonly, automobile dependence is treated as synonymous to auto use and characterized as the high levels of motorization and vehicle miles-traveled (VMT), low land use density, marginal modal shares of non-driving, and high rate of energy consumption (e.g. Kenworthy and Laube, 1999; Newman and Kenworthy, 1989, 1999; Litman, 1999; Kenworthy, et al. 2000). With this characterization, policy analysts often face two difficulties in recommending strategies to overcome automobile dependence. Firstly, it is difficult to define based on these performance measures what amount of auto use is auto dependent and what is not. Some predefined figures have been suggested, for example, an annual VMT of 5,000 miles or more per capita, a density of 20 people or less per hectare, a vehicle ownership of 400 vehicles per thousand people, and a transit share of 10% or less. However, applying these normative figures to evaluate automobile dependence tends to ignore the local variations in income and economic development, in social and spatial characteristics, and in vehicle and fuel technologies, which are important factors affecting the demand and supply of mobility and vehicle use (Gomez-Ibanez, 1991).

Secondly, polices recommended to overcome automobile dependence tend to be perceived as anti-auto, and therefore likely to be suspected or dismissed by auto users, producers, and consequently by the policy makers. The automobile as a means of transportation offers convenience, flexibility, comfort and privacy. It provides a great deal of personal mobility and accessibility and enables people to enjoy flexibilities in residential locations, in time use, and in other consumption choices (Goodwin, 1997). Through many decades development, the automobile has deeply rooted into American's daily life and become part of the American culture (Lewis and Goldstein, 1983). Equalizing automobile dependence to the auto use tends to create fear to the users that reducing automobile dependence would reduce their personal mobility and jeopardize their basic value and culture systems. This is something they are not willing to do even though they agree that it is necessary to reduce vehicle travel-associated undesirables such as road congestion, emissions and pollutions.

Overcoming these two difficulties requires a policy strategy focusing on the dependent portion, not the total amount of auto use. In fact, many advocates of reducing automobile dependence have emphasized that the issue of concern on automobile dependence is "not the automobile in itself but an overuse of and dependence on it." (Newman and Kenworthy, 1999, p.60). Identifying the overuse of the automobile needs a proper measure of automobile dependence. This research attempts to complement the existing studies by addressing the issue of automobile dependence from the perspective of individuals' travel choices and by quantifying and explaining the variations of automobile dependence among individuals.

- **Better Understanding the Built-Environment/Travel-Behavior Relationships**

The literature has also shown that the relationships between built environment and travel behavior are complex. Table 2.6 cross-tabulates the commonly used indicators of the built environment and travel behavior, and highlights commonly perceived or expected relationships. Also shown in the table cells, where applicable, are representative studies (either support or counter the common expectations) on the relationships between the specific pair of the built environment and travel behavior indicators. A general observation is that the reported results are not all consistent, and are often conflicting. This is because (i) one land use attribute may affect various aspects of travel behavior in reverse directions, (ii) there are more than one land-use attributes affecting each aspect of travel, and (iii) there are still many aspects of the relationships that remain to be investigated. Hence, the aggregate travel outcome, with which policy making is concerned, is not all clear as a result of changing land use characteristics. Crane (1999) has warned that our current understanding of the relationships is not enough to provide sufficient credibility to be the basis for policy.

Nevertheless, past studies have shed light on various aspects of disentangling the complex relationships between the built-environment and travel behavior, and have indicated at least three areas in which research can be further improved.

(1) Control for other important factors related to people's travel decisions

Lack of methodological rigor is a common weakness of many existing studies. Some studies are simple comparisons or bivariate correlation analyses in travel outcomes among neighborhoods or cities with different land use characteristics in terms of density, land-use mix and urban form (e.g. Friedman et al. 1994, Newman and Kenworthy 1989, 1999). Such analytical approaches often invite criticism since it is difficult to link the observed behavior with land-use attributes without simultaneous control for factors such as income, age, etc. Other studies do consider the social-demographic factors with applications of multivariate statistical techniques. Still, variables such as the quality of alternative transportation supply are often omitted in model specifications. In the analysis of land-use impacts on mode choice, such an omission is very likely to produce biased results. Also quite common is the exclusion or oversimplified treatment of price factors. As one of the most important behavioral and policy variables, transportation prices, or generalized costs of travel, rarely enter the equations of existing studies of land use effects on travel, with very few exceptions (e.g. Crane & Crepeau 1998).

(2) Quantifying the magnitude of the effects of the built environment on travel

Most studies dwell on proving that density, land use mix, or urban form do or do not have impacts on people's travel decision making. It is of course useful to learn the directions of the effects that these factors potentially have on travel. For the purpose of policy making, it is even more important to know the magnitude of the effect, if any, or the extent of changes that policy action would have. Despite the disagreements, one thing in common among the advocates of different policy solutions is that they all expect behavioral changes in individuals' travel or location decisions in response to the implementation of the recommended policies. In evaluating the effectiveness of these policy options, it is then fundamental to ask whether or not individuals' behavior adjustments will take place to the extent expected and to quantify the possible changes in meaningful terms.

(3) Building systematic behavioral frameworks to sustain empirical work

Crane (1996, 1998, 1999) has strongly voiced the need to build systematic behavioral frameworks for empirical analyses and testing on land-use/travel-behavior connections. Current studies are designed and conducted largely on an *ad hoc* basis, "making both supportive and contrary empirical results difficult to compare or interpret" (Crane 1999, p.7). For example, a number of researchers have studied the effects of built environment on travel by analyzing the travel outcomes of representative neighborhoods, namely the traditional in contrast to the modern neighborhoods. (The traditional neighborhoods are characterized with grid network patterns and higher land-use density and mix, whereas the modern neighborhoods are characterized with curve-linear networks and functionally separated land use and lower density). While some found that auto trip share, vehicle miles traveled (VMT), and frequency were higher in modern neighborhoods than in traditional ones (e.g. McNally and Ryan 1993, Cervero and Gorham 1995), others found results inconclusive or even just the opposite, for instance, higher trip frequency associated with higher density or accessibility (e.g. Handy 1996, Crane 1996). A systematic behavioral framework would help better understand the discrepancies among the studies.

In sum, there is much to be learned about the relationship between the built environment and travel behavior. It is critical to formulate appropriate analytical frameworks and to apply more rigorous methodology to further improve our understanding of land-use/transportation connections. In the next chapter, we present our research design and methods, aiming to meet the research needs that we have identified.

Table 2.6 Built Environment-Travel Behavior Relationship

	INTENSITY	INTEGRATION	URBAN FORM	Aggregate Outcome
Trip Frequency	May generate or attract more trips (Crane 1996, Kitamura, et al. 1997)	Higher integration could increase trip frequency (Handy 1996)	unclear (Friedman, et al. 1992	Total Trips
Trip Length	Shorter average trip length (Holtzclaw 1994, Newman & Kenworthy 1989)	Integration is expected to reduce average trip length (Giuliano & Small 1993)	Depending on the physical layout (McNally & Ryan 1993, Crane 1995)	VMT
Mode Choice	Higher density, less drive-alone trips (Pushkarev & Zupan 1977, Cervero & Kockleman 1996)	Encourage non-drive modes (Cervero 1996, Kockleman 1997)	There may be indirect (latent) effect (Cervero & Girham 1995, Crane & Crepean 1998)	Modal Split
Departure Time and Trip Scheduling	unclear	unclear	unclear	Peaks
Route Choice	unclear	unclear	Affecting people's spatial cognition and route choice set	Congestion
Trip Chaining	unclear	More likely to trip chaining (Srinivasan 1998)	unclear	Trip Rates & Distance
Teletravel	unclear	May reduce the needs for telecommuting	unclear	All

Notes:
Land use development *intensity* is usually measured by population, job, or housing density and by floor-area ratio (FAR) as well. *Integration* is commonly quantified by entropy of land use balance, dissimilarity index of land use mix, and accessibility index. Urban form is described by the road network pattern or by calculating percent of four-way intersections and cul-de-sacs. Index of pedestrian walking environment has also been suggested.

Chapter 3

Research Design and Methodology

3.1 Introduction

- **A Brief Description of the Research Design**

Our research is mainly concerned with the effectiveness of land use-based mobility strategies in improving accessibility and reducing automobile dependency. To address the specific research needs identified in preceding chapter, we take a disaggregate, empirical approach. This approach demands explicit modeling of accessibility and automobile dependence. Consequently, one main task of the research design is to clarify and to operationalize these concepts in this specific research context. More important is to place these concepts and modeling methods in a coherent analytical framework.

Modal split and trip making are two key aspects of transportation policy analysis concerning urban travel. Most undesirable travel outcomes are linked to the excessive trip making and the dominant role of the private automobile for travel. If the share and magnitude of automobile travel can be reduced, issues such as congestion, environmental degradation, and energy consumption would be eased to a significant extent. Accordingly, this research investigates the potential of land use as a mobility tool by focusing on these two key aspects of travel behavior, mode choice and travel demand (i.e. trip frequency), and their relationships to the built environment characteristics and the transportation policy environments. Automobile dependency is considered as an extreme situation of mode choice and trip making. Given that automobile dependence is the focal concern to the public and the policy makers, it is examined in greater detail.

In summary, accessibility, automobile dependency, and policy effectiveness form three key elements of the research design. The three elements are interrelated and they are structured in this research in the following way: Accessibility, defined and measured at the individual level, provides an analytical framework that links together household/personal travel decisions, transportation and land use policy instruments, and the planning goal (of enhancing accessibility). Within this framework, automobile dependency is empirically examined and explained through disaggregate modeling of mode choice, trip frequency and the degree of captive driving. Policy effects are analyzed using the empirical results through simulations, i.e. through incremental logit modeling of changes in accessibility and individuals' mode choice behavior in responding to policy changes.

In the following sections we first provide a review of accessibility models, along with a general description of the concepts of mobility and accessibility. Within that context, the specific accessibility model applied to this research is introduced. The model is built upon a travel mode choice framework. Next, we give a behavioral interpretation and an operational definition of automobile dependence and explain logit captivity modeling, an extension of the mode choice modeling for the measurement of automobile dependence. The statistical tools used to analyze individual travel demand, i.e. trip frequency are described subsequently. The reasons why we select Boston and Hong Kong as our empirical study cases are given in the following part. Finally, we describe the ways that data sets are organized and managed using computational tools such as geographic information system (GIS) and database management system (DBMS).

- **Glossary of Symbols**

For reference convenience, a list of symbols and notations is provided below.

α, β, γ	Parameters or vectors of parameters associated with specific independent variables
g, i, j, k, m, n	Subscripts that specify population groups, modes, zones, or individuals in a given context
A or A_i	Accessibility of an individual or a location i
C	Choice set that comprises travel modes available to an individual
C_{ij}	Cost of travel in time or distance between i and j
d_i	The odds that an individual is captive to i in the mode choice context. In statistical terms, 'odds' is defined as the ratio of the probability of success over the probability of failure.
O	Attributes (e.g. number of jobs) at origin
D	Attributes (e.g. number of jobs) at destination
L	Land use type
$P(i)$	Probability of an individual choosing alternative i
$P(C)$	Probability that an individual considers choice set C available
$P(i \mid C)$	Probability of an individual choosing alternative i given choice set C
U	Utility
X, Z	Vectors of independent variables

3.2 Accessibility Models: A Review

- **The Concepts of Mobility and Accessibility**

The concepts of mobility and accessibility are closely related and have been interchangeably used in many circumstances. Below we discuss briefly both the relationships and distinctions between the two.

Put in a succinct way, mobility refers to ability to move from one place to another, whereas accessibility refers to the ease to reach spatially separated opportunities. Mobility depends on individuals' physical attributes and household resources, the availability of travel means, and transportation infrastructure provided by the society. Accessibility, on the other hand, incorporates the distributional features of opportunities travelers try to reach. In other words, accessibility contains one additional feature to mobility, that is, land use.

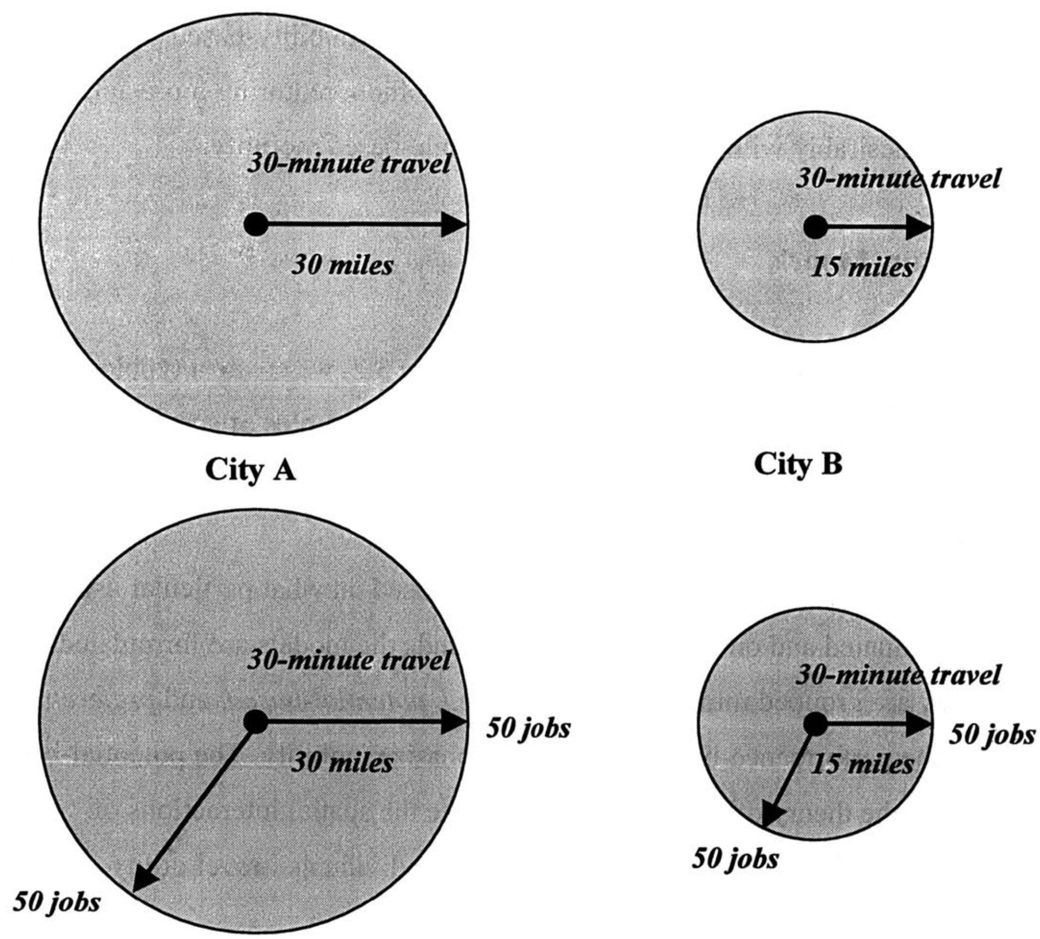
Mobility and accessibility are closely related. Higher mobility will potentially help enhance accessibility. However, the contribution of mobility to accessibility depends on how opportunities are distributed spatially, i.e., the land use patterns. In a given environment where opportunity distribution is fixed (at a particular point of time), higher mobility (e.g. higher travel speed) leads to higher accessibility, because more opportunities can be reached resulting from faster travel. In a situation that an individual's mobility is fixed (again, at a particular point of time), wider spread of the spatial activities will result in overall lower accessibility level, because less opportunities can be accessed in a given range of travel.

The two sets of diagrams in Figure 3.1 illustrate the relationships and differences between mobility and accessibility.

The upper set of the diagrams illustrates the mobility conditions in two hypothetical cities: City A and B. People in City A can travel 30 miles in 30 minutes, whereas people in City B can travel only 15 miles in 30 minutes. It means that, on average, people in City A have higher mobility than those in City B.

When talking about accessibility, we usually look at particular activities that people are participating in. Let's look at the employment accessibility in the two cities as illustrated by the lower set of the diagrams in Figure 3.1. Assume that City A has 100 jobs located in 30 miles distance from the city and City B has 100 jobs located in 15 miles. Within 30-minute travel, the two cities have the same number of jobs accessible. That is, people in the two cities have the same levels of job accessibility, although people in City B have lower mobility.

Figure 3.1: Mobility vs. Accessibility



Of course, this is a highly simplified example. In reality, opportunities and people are distributed across the entire geography of city. The accessibility level of the city can be evaluated in various ways (detailed in the following section). The point we are trying to make through the two sets of diagrams in Figure 3.1 is that accessibility can be improved with or without requiring higher mobility. In the latter case, land use plays the mobility role.

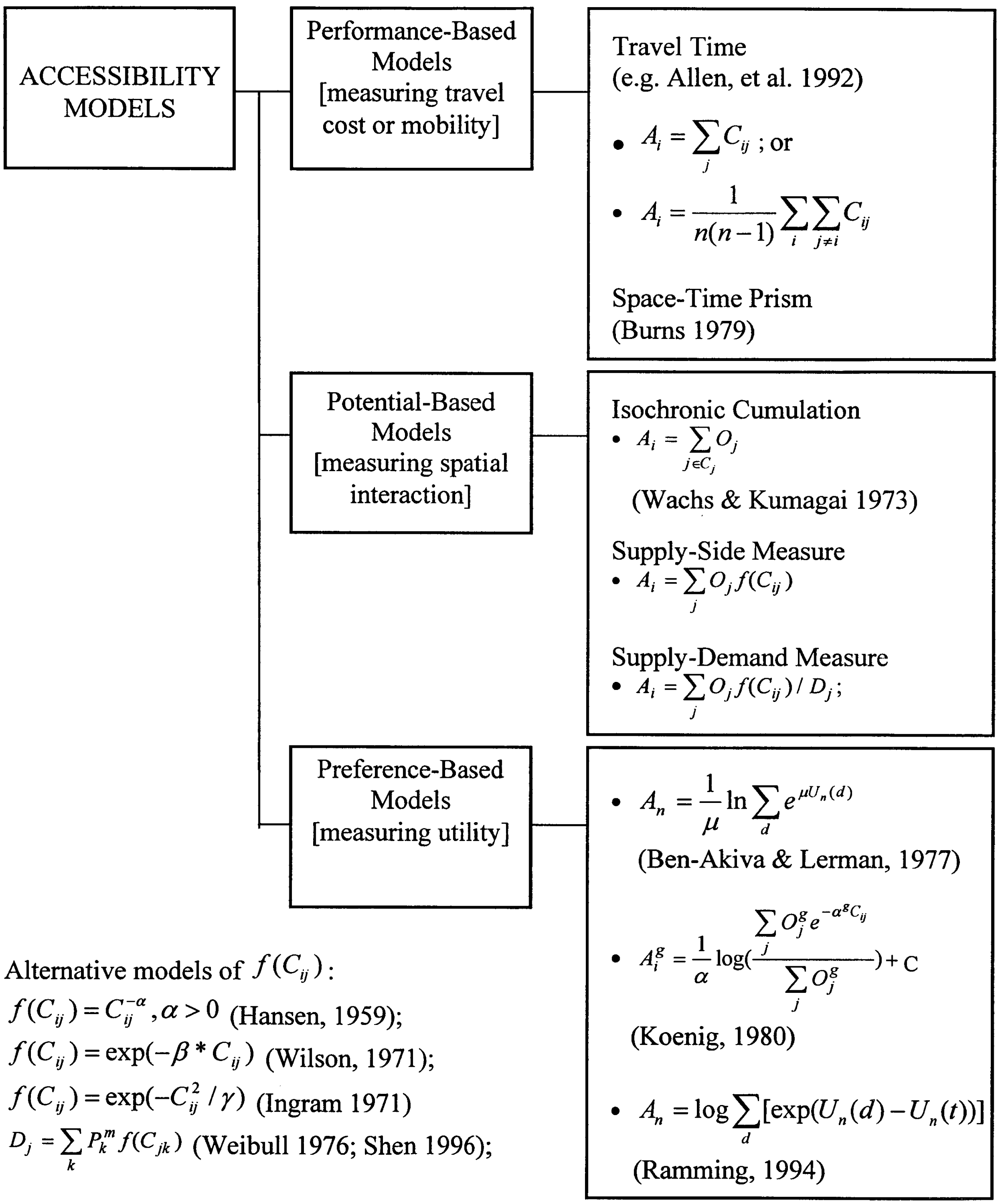
In summary, mobility may be interpreted as one component of accessibility--mobility plus land use equal to accessibility. Overemphasizing mobility, i.e. travel efficiency as a policy objective may generate undesirable outcomes, because a linear relationship between mobility improvement and motorization could be very easily perceived, which leads to excessive private vehicle use. This is evident in the development experience of US metropolitan areas in the past three to four decades. The idea of land use as a mobility tool is to adjust the historical imbalance of overemphasis on mobility-based strategy and to improve accessibility by changing land use patterns without requiring more auto-mobility, or more desirably with reduction of automobile-based mobility.

- **Accessibility Models**

Accessibility models take many different forms. In Figure 3.2, we create a typology of accessibility models selected from the literature reviewed. Examples of specific formulae and references are presented for each end box in the figure.

In our classification, accessibility models are grouped based on what particular aspect of accessibility is evaluated and on what theoretical grounds the models are formulated. Specifically, they are grouped into *performance-based, potential-based,* and *preference-based* models. The performance-based measures emphasize mobility. The potential-based measures, built on the theory of social physics, evaluate the spatial interactions of opportunities. The preference-based measures evaluate individuals' travel utility, which has its origin from microeconomics theories.

Figure 3.2: A Typology of Accessibility Models



Alternative models of $f(C_{ij})$:

$f(C_{ij}) = C_{ij}^{-\alpha}, \alpha > 0$ (Hansen, 1959);

$f(C_{ij}) = \exp(-\beta * C_{ij})$ (Wilson, 1971);

$f(C_{ij}) = \exp(-C_{ij}^2 / \gamma)$ (Ingram 1971)

$D_j = \sum_k P_k^m f(C_{jk})$ (Weibull 1976; Shen 1996);

U(d), U(t): individual utilities associated with destination *d*, travel *t* respectively;
A_i : the accessibility evaluated for zone i; *n, g* : individual *n* or group *g*;
C_{ij} : distance or time from zone i to zone j; P_k^m : population or workers taking mode *m*;
O_j : activities or attraction in zone j; α, β, γ: parameters reflecting distance deterrence.

(1) *Performance-Based Accessibility Models*

In performance-based accessibility models, travel costs are the only component that is taken into account. Travel costs take the form of travel time, speed, or generalized travel costs from one place/zone to all other places/zones. The advantage of this method is that accessibility values are measured in absolute terms (e.g. minutes). Different regions or urban areas can then be compared and evaluated by the quantified accessibility levels. Allen, et al. (1992) apply this type of models to compare accessibility in 60 US metropolitan areas. In their model, accessibility is measured as the normalized average travel time between two random locations in a given region. They find that Akron, Ohio and Sacramento, California respectively, are the most and least accessible regions in the US.

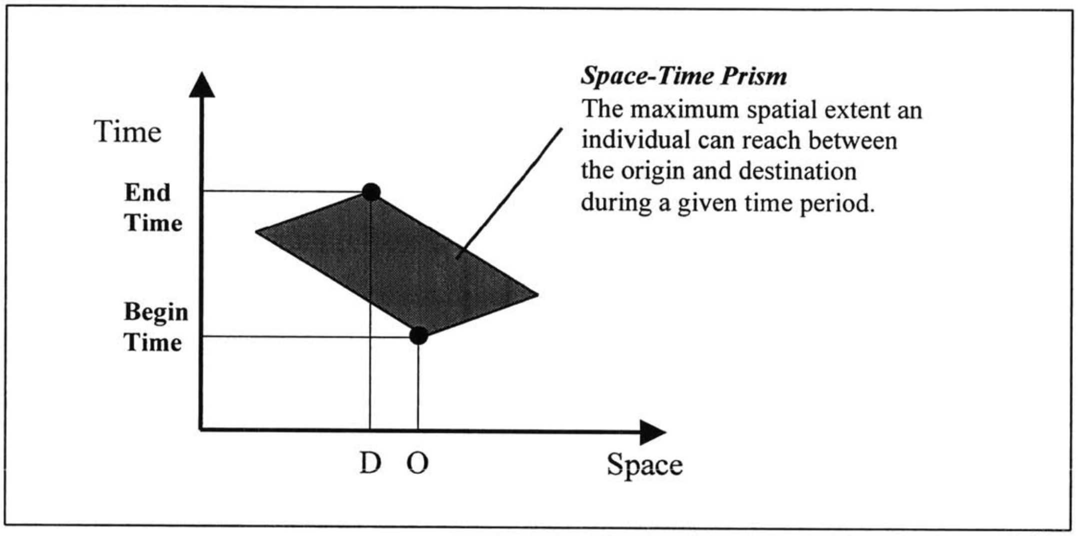
Burns (1979) develops Hagerstrand's time-geography concept into a diagram model of accessibility, namely the Space-Time Prism (Figure 3.3). It represents the spatial and temporal characteristics of an individual's behavioral constraints. To a specific individual, the number, size, and location of his/her space-time prisms depend on his/her daily activity characteristics and travel speed (on foot or by a transportation means). Accordingly, Burn proposes several strategies in terms of urban and transportation policies to reduce the constraints and, consequently, increase the accessibility of the individuals to various activities. The Space-Time Prism accessibility model has been further developed with a GIS environment by Miller (1999).

(2) *Potential-Based Accessibility Models*

In contrast to the performance-based accessibility models, the potential-based models take both travel costs and number of opportunities into account.

The isochronic cumulating method is widely applied in practice. It counts the total number of opportunities that could be reached within a threshold travel time or distance. The effect of distance or travel time on the attractiveness of opportunities is treated uniformly anywhere within the threshold, and no attraction is considered from any opportunity beyond that threshold. This measure is operationally convenient and intuitively easy to interpret. However, it ignores the fact that the attractiveness of opportunities does have a distance-decay effect on a given place: when the distance (or travel cost) increases, the attractiveness of the opportunities diminishes.

Figure 3.3: The Space-Time Prism of Individual Accessibility



Source: Burns, 1979. p.13

The gravity-based measure is first introduced by Hansen (1959) and later modified or extended in various forms. The early efforts are concentrated on the choice of an appropriate measure of impedance to reflect the perceived cost of travel. For example, Wilson (1971) suggests an exponential cost function instead of the power function used by Hansen. Ingram (1971) argues however, both of these distance functions tend to decay too rapidly in comparison with empirical evidence. He suggests that a modified Gaussian form is superior.

Observing that the Hansen (as well as Wilson and Ingram) formulae are limited to the "supply side" of accessibility measurement, Weibull (1976) and Shen (1998) propose a refined framework for modeling accessibility. It takes into account the "demand side" - the competition for available opportunities.

Specifically, when regional employment accessibility is to be measured, the refined method accounts for job competition among workers commuting by different modes, in addition to the basic two components in Hansen-type models - spatial separation and job attractiveness. The output of this measure is still a set of indices that have only relative meaning. However, it enables researchers to tell where are accessibility rich/poor location, because an accessibility value of one indicates the balance between job supply and demand in a given land use and transportation system (Shen 1998).

(3) *Preference-Based Accessibility Models*

Preference-based accessibility models refer to those that are built upon microeconomics principles or individual behavior to evaluate traveler preferences and travel (dis)utilities.

Koenig (1980) is initially concerned that the Hansen-type accessibility models are based purely on intuitions; they lack theoretical strength, although they have the advantage of being simple in structure. He then introduces behavioral modeling techniques into the formulation of accessibility models. Interestingly, he finds that the Hansen-type accessibility models, when applied carefully, provide quite correct or equivalent results to the behavioral theory-based models. He thus concludes that the Hansen-type, potential-based accessibility models are acceptable since they not only reflect transportation system conditions but also the wealth of choice provided by urban structure. Microeconomics approaches should be used for controlling the acceptability of those potential-based formulations.

A rather strictly behavioral-based accessibility model is proposed by Ben-Akiva and Lerman (1977). According to them, accessibility refers to some composite measure that describes the characteristics of a group of alternatives as they are perceived by a particular individual. It depends on both the alternatives being evaluated and the individual traveler for whom accessibility is being measured. In a mode choice context, accessibility of an individual is defined as the 'expected maximum utility' associated with all travel alternatives available to the individual.

In the direction of Ben-Akiva and Lerman, Ramming (1994) develops and operationalizes an accessibility model by summing up the destination utility and travel (dis)utility gained from the potential trips made by an individual (or a group of individuals). In this context, accessibility refers to the set of activities to which a person has the potential to travel, even if such a trip is not made. The destination utility is a linear function of the attributes of that destination location, such as the presence of a commercial product, the size of shops, number of jobs, etc. The travel (dis)utility is a linear function of another set of variables associated with the level of service that existing transportation system provides, such as in-vehicle, walk time, wait time, out-of-pocket cost, comfort, etc.

3.3 The Accessibility Model Applied to This Research

The accessibility framework has found a wide range of applications in transportation planning and policy analysis. Many have incorporated accessibility indicators to explain people's mobility demand* and travel behavior in terms of auto ownership, mode choice, trip frequency, trip duration, and trip chaining (e.g. Handy 1993, Kockelman 1997, Shen 1999, Srinivasan & Ferreira 1998). Others have used accessibility measures to examine the aggregate as well as the distributional impacts of alternative transportation policies or investments (e.g. Rietveld 1998, Zhang et al. 1998, 1999).

In this research, the accessibility model takes a functional form suggested by Ben-Akiva and Lerman (1977). It is expressed in travel utility terms within a mode choice modeling context.

Specifically, let $P(i)$ be the probability of a decision maker choosing alternative i from a feasible choice set C. Assume that individuals' choice decision can be explained by a set of observable variables (the vector X), including the social and demographic characteristics, attributes of the choice alternatives, and economic, transportation and land-use policy variables. Let β represents a vector of parameters to be estimated to capture the significance, directions, and magnitude of corresponding X in influencing choice decisions.

We can then estimate the choice probability with the following model, namely the multinomial logit (MNL) model:

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* In this research, we intentionally distinguish between the terms 'mobility demand' and 'mobility supply'. Mobility demand refers to people's desire to acquire greater capability to move, for example, to purchase a car, and their desire to make trips, i.e. travel demand. Mobility supply, on the other hand, refers to societal provision of infrastructure such as roads, and institutional arrangement such as creating transit agencies to meet mobility demand. The common mobility indicators like VMT and average travel time refer to the equilibrium point where mobility supply meets the demand. Therefore it is also termed 'revealed mobility'. Making distinction between mobility demand and supply helps clarify the role of land use as a mobility tool as we will show in later chapters, land use plays a mobility role as a supply factor. Therefore the effectiveness of land use as a mobility tool is conditional to existing transportation and land use practice, which in turn are much influenced by national and local governmental policies.

$$P(i) = \frac{e^{\beta X_i}}{\sum_{j \in C} e^{\beta X_j}} \quad \text{(Eq. 3.1)}$$

The logarithmic summation, or '*logsum,*' of the denominator of the MNL model gives a disaggregate measure of personal accessibility ***A***:

$$A = \ln \sum_{j \in C} e^{\beta X_j} \quad \text{(Eq. 3.2)}$$

In microeconomics terms, βX_j measures the observable portion of the utility associated with alternative *j*. Therefore, *accessibility A represents the total utility associated with all modes available to the individual. It is influenced by the number of alternatives available (i.e. the size of the choice set), individual social and demographic characteristics, attributes of the choice alternatives, economic, transportation and land-use policies, and importance of these factors (represented by β that are to be empirically estimated.)* Which specific variables eventually enter in the final model specification is the judgment of the analysts, depending on modeling techniques and availability and quality of data. Note that this expression is the same as the one shown in Figure 3.2 except that the parameter μ has been scaled to one. Doing so makes model estimation simpler without affecting the final results.

This preference-based (also referred as utility-based) accessibility model offers several analytical advantages over the conventional potential-based models in serving the specific needs of this research. Conventionally, the accessibility concept has been operationalized in a composite form to reflect the joint performance of land use and transportation systems. In a single index, which usually takes a gravity model-based formulation, attributes of the built environment and transportation systems are all combined at the aggregate level (e.g TAZ). The relative importance of the components of accessibility is thus difficult to identify and specific policy recommendations become less direct to formulate and evaluate. The purposes of this research require that an accessibility measure be able to link together individual decisions, policy instruments, and planning goal (of enhancing accessibility). It should enable us to identify the effects of a particular policy instrument on individuals' travel behavior while the effects of other variables are controlled for. The utility-based disaggregate accessibility measure allows us to perform the kind of analysis conveniently. Developed from the theories of consumer choice behavior, this type of accessibility models has theoretical and empirical advantages over the conventional Hansen-type measures (Handy and Niemeier 1997).

Another major benefit of applying the preference-based accessibility model is that the same choice modeling structure can be modified and extended to empirically quantify and examine automobile dependence. Consequently, our analysis on three aspects of travel behavior, mode choice, trip making, and automobile dependence can be placed in an integrated analytical framework. The following section explains in detail how automobile dependence is modeled with the extended mode choice modeling framework.

3.4 Defining and Measuring Automobile Dependency

- **Defining Automobile Dependency**

Automobile dependency generally refers to people's over reliance on private automobile for their daily activities and to the overwhelming design and development of the built environment primarily for the accommodation of car use. According to Newman and Kenworthy (1999, p.334), "automobile dependence is when a city or area of a city assumes automobile use as the dominant imperative in its decisions on transportation, infrastructure, and land use. Other modes thus become increasingly peripheral, marginal, or nonexistent until there are no real options for passenger travel other than the automobile." Similarly, Litman (1999) describes automobile dependency as high levels of per capita automobile travel, automobile oriented land use patterns, and reduced transportation alternatives. Major indicators used to characterize automobile dependence include vehicle miles traveled (VMT) per capita, share of automobile use among all travel modes, residential density and downtown and suburban parking supply.

This research is aimed to complement existing studies on automobile dependence that are mostly aggregate in nature. It attempts to advance the analysis by explicitly modeling and quantifying the degree of automobile dependence in a given geography or for a given population group. In this research, automobile dependence is interpreted from the perspective of individuals' mode choice behavioral. People's reliance on their automobile in their daily activities is attributable to various factors. For example, it may be simply because driving is inexpensive. It may be due to the fact that there is no other viable alternative near where people live and work. People may have family commitments (such as taking children to and from daycare centers) that cannot be feasibly fulfilled with other travel modes. They may lack sufficient knowledge or information about alternative travel modes (such as transit station locations at destinations, service routes, frequencies and operating hours). Their (mis)perception of the service quality, safety, and reliability of other modes may exclude consideration of these alternatives at the outset of their travel decision process. Some people may self-impose certain restrictions when deciding how to travel due to, for example, the concern about their social status, since transit is often portrayed as an inferior mode both technically and socially (for instance, the notion of 'transit is to serve the poor'). Still others rely on automobile because of their attitudes—they simply enjoy driving and will drive anyway regardless the existence of other alternatives.

This is to say that an individual becomes automobile dependent when other travel choices are excluded from his/her consideration, due to either external constraints or idiosyncratic reasons. S/he becomes *captive to driving* because, in a mode choice context, driving is the only element in his/her feasible choice set.

The above behavioral interpretation suggests an operational definition of automobile dependence: *the degree of automobile dependence is the extent to which an individual is captive to driving*. Following example illustrates further this choice-based definition of automobile dependence.

Suppose that, in a given metropolitan area, there are three major modes of transportation services: driving (driving alone or carpool/vanpool), transit (bus or rail), and others (walking or biking). For a specific trip, an individual chooses a specific mode out of the three possible alternatives to travel*. The three modes therefore comprise a full choice set, expressed as {driving, transit, others}. However, not everyone in the metropolitan area has the same choice set that includes *all* of the three modes. For example, an individual may not hold a driver's license and has no access to automobile. Only two remaining modes are therefore available to him/her. His/her choice set becomes {transit, others}. In another situation that a journey cannot be possibly accomplished on foot or by bike (e.g. it is too far to walk or bike), an individual would have a choice set that comprises only the motorized modes, {driving, transit}. When no transit is available or

* In reality, a journey may involve more than one mode. For instance, one may walk to a subway station and then take the subway. For analysis convenience, the journey can always be partitioned into individual trips so that each trip is made by one discrete mode. Alternatively, we may simplify the choice situation by considering only the major mode used for a journey.

an individual does not want to use transit anyway, and in addition, walking/biking is unfeasible, the only choice left to the individual is {driving}.

In general, a specific travel mode becomes an element of an individual's feasible choice set only when the individual knows and considers the mode available. A choice set becomes a feasible set to an individual only if all elements in the set are known to and considered as available by the individual. *When an individual has only driving mode available in his/her feasible choice set, we say the individual becomes captive to driving, i.e. s/he is automobile dependent.*

The above example suggests that automobile dependence can be analyzed through the process of choice set generation involved in an individual's travel decision. Obviously, to a specific traveler, which mode(s) comprise his/her choice set depends on a variety of constraints s/he faces. These include, as we mentioned earlier, transportation service constraints (e.g. alternative transportation services are not conveniently available near where the traveler lives or works), informational constraints (e.g. s/he does not know the availability of other choices), and attitudinal or self-imposed constraints (e.g. s/he does not want to use transit regardless). People's reliance on their automobile in their daily activities can be attributed to some or all of these constraints.

If we as analysts knew for sure the specific impacts each constraint has on individual's consideration of the availability of travel modes, or more specifically, if we knew for sure which mode(s) comprise an individual's choice set, we could then tell with certainty who was or was not automobile dependent (based on our definition of automobile dependence). In analyzing the mode choice behavior, however, the analysts usually do not have sufficient information about individuals' feasible sets of travel modes. This is because the choice set formation under the internal and external constraints is a subjective, latent process specific to each individual. For example, it is understood that people will consider transit unavailable if transit stations are too far away from where they live or work. However, the actual threshold distances defining whether transit is available are likely to vary among different people because individuals have different physical strength and walking preference. In most cases, for the sake of simplicity, we as analysts apply the rule-of-thumb to set one-quarter mile as the threshold distance to deterministically decide the availability of transit. Furthermore, individuals' attitudes to transit usually are not directly observable. When we see that driving mode has been chosen by an individual, we cannot say for sure if it is his/her choice outcome out of the consideration of both transit and driving, or it is the result that s/he perceives no other feasible choice. If the former is true, we say the individual is not automobile dependent, even though s/he does drive, because s/he has options. If the latter is true, then we say the individual is indeed automobile dependent because s/he has no alternative.

Lack of certain information on individuals' perception and consideration of what modes comprise their choice sets from which mode choice decisions are made leads to the treatment of choice set generation as a *probabilistic process*. Accordingly, *automobile dependence can be expressed as the probability that a choice set contains a single element, driving.*

Still, the probabilistic process of choice set generation cannot be modeled *directly* because we usually do not have empirical data indicating individuals' consideration of a specific choice set. What we observe are the actual, discrete mode choice outcome, i.e., either driving, or transit, or other modes chosen for a trip. Nevertheless, the data on the observed choice outcome can be utilized to estimate, *jointly* with mode choice modeling, the probabilities of the pre-defined choice sets being the actual choice sets considered by travelers. It therefore offers a special approach to analyzing automobile dependence within an extended mode choice modeling framework. The specific models used are called the *logit captivity* models. The basic logit captivity model, also known as the 'dogit' model, is formulated by Gaudry, et al. (Gaudry and Dagenais, 1979; Gaudry and Wills, 1979) initially for the purpose of allowing flexible structures with the conventional multinominal logit (MNL) models. Ben-Akiva and Swait (Ben-Akiva, 1977; Swait, 1984; Swait and Ben-Akiva, 1987a, 1987b) have offered formal derivation and extension of the model based on the notion of random constraints to choice set formation. In the following section, a simplified derivation of the logit captivity models is presented for the purpose of providing sufficient methodological and interpretation clarity to the empirical analysis of automobile dependence in the Boston and Hong Kong case studies.

- **Measuring Automobile Dependence**

An individual's mode choice behavior can be decomposed into a two-stage process: 1) choice set generation, and 2) mode choice from a given choice set. The first stage serves as a screening stage in which the individual appraises what alternatives are available. In the second stage, mode choice decision is made based on the screening results. The two-stage process can be modeled in the following formulation suggested by Manski (1977):

$$P(i) = \sum_{C \in G} P(i \mid C) * P(C) \quad \text{(Eq. 3.3)}$$

where $P(i)$ denotes the probability of an individual choosing mode i. $P(i|C)$ is the conditional probability of an individual choosing mode i given the choice set C. $P(C)$ is the probability that individual considers choice set C available out of all possible choice sets G.

To better explain the two stage choice behavior, let's consider again the three modes example we used in describing automobile dependence in Section 3.1. The universal or full choice set comprises all three modes, i.e. M = {driving, transit, others}. The probabilistic process of choice set generation means that any combination of the three modes could form a choice set and likely become the actual choice set considered by the individual (as oppose to deterministic choice set generation in which we can say with certainty which choice set is an individual's actual feasible choice set). Out of the three modes, the probabilistic process produces the following seven unique choice sets:

1. {driving}, 2. {transit}, 3. {others}, 4. {driving, transit}, 5. {driving, others}, 6. {transit, others}, and 7. {driving, transit, others}.

The first stage of the choice modeling is to estimate the probability that each of the seven choice sets becomes the actual choice set considered by an individual under the external and internal constraints, for instance, the probability of a choice set that contains *driving* mode only (i.e. the measure of automobile dependence), the probability of a choice set that contains *transit* mode only, … , the probability of a choice set that contains *driving* and *transit* only, … , the probability of a full choice set that contains all modes.
The second stage is to estimate the conditional probability that one specific mode is chosen *given a specific choice set*, for instance, the probability of *driving* given choice set 1:{driving}, the probability of *driving* given choice set 2:{transit}, … , the probability of *driving* given choice set 7:{driving, transit, others}. Summing all the conditional probabilities for *driving* gives the probability of *driving* being chosen.

For illustration purpose, let's assume that each of the seven choice sets is equally likely to be the actual choice set available to an individual. The probability that each of the seven choice sets becomes the actual choice set considered by an individual is then one seventh. In other words, the individual's probability of only having {driving} in consideration is 1/7; only having {transit} in consideration is 1/7; … having {driving, transit} in consideration is 1/7; and having the full choice set is also 1/7. Therefore, by our definition, *the individual's probability of being captive to driving, i.e. being automobile dependent, is 1/7 or approximately 14%.*

Let's further assume that each of the three modes is equally likely to be chosen in any circumstance. The conditional probability of driving given a choice set of 1:{driving} is therefore 100%. The conditional probability of driving given a choice set of 2:{transit} is zero… The conditional probability of driving given a choice set 7:{driving, transit, others} is 1/3.

Overall, according to E.q.3.3, the probability of driving is the sum of the seven conditional probabilities multiplied by their respective choice set probabilities.

$$\textit{Probability of driving} = 100\%*(1/7) + 0*(1/7) + 0*(1/7) + 50\%*(1/7) + 50\%*(1/7) + 0*(1/7) + 33.3\%*(1/7) = 33.3\%$$

Of course, for a specific individual, equal probabilities for all possible choice sets are unlikely the case. Putting in a generic form and taking a structure of the logit model, equation (3.3) gives a *marginal logit* formulation under the assumption of the independent and identical Gumbel distribution in the random terms across all modes and all choice sets as well (The assumption is referred as the Independent Availability by Ben-Akiva, 1977 and Swait, 1984).

$$P(i) = \sum_{C \in G} \frac{e^{V_i}}{\sum_{j \in C} e^{V_j}} \frac{e^{V_C}}{\sum_{g \in G} e^{V_g}} \quad \text{or} \quad P(i) = \frac{1}{\sum_{g \in G} e^{V_g}} \sum_{C \in G} \frac{e^{V_i}}{\sum_{j \in C} e^{V_j}} e^{V_C} \qquad (3.4)$$

In this expression, V_c is the systematic utility (as a function of observable independent variables) associated with choice set C and V_i the utility associated with mode i.

Choice sets in G can be re-grouped into three types: 1) the single-mode sets $\{i\}$, i.e. the choice sets containing a single mode only, 2) the full choice set $\{M\}$, i.e. the set containing all the modes available in the area of study, and 3) all other choice sets that contain more than one but not all of the modes available in the study area.

Accordingly, equation (3.4) becomes the following:

$$P(i) = \frac{1}{\sum_{g \in G} e^{V_g}} [e^{V_{\{i\}}} + e^{V_{\{M\}}} \frac{e^{V_i}}{\sum_{j \in M} e^{V_j}} + \sum_{C \in G \neq \{i\},\{M\}} \frac{e^{V_i}}{\sum_{j \in C} e^{V_j}} e^{V_C}] \qquad (3.5)$$

For notational clarity, braces are used to distinguish between a choice set and a travel mode. In equation (3.5), $\{i\}$ means a choice set containing the single mode i only, whereas $\{M\}$ means the set containing all modes, i.e. the full choice set. The value of

$e^{V_{\{i\}}}$ indicates the propensity of being captive to mode i, or the tendency of being automobile dependent when i represents the auto mode.

Obviously, it is extremely complicated to empirically estimate the model shown by equation (3.5) because the dimensionality of G increases rapidly at a rate of 2^M-1. Since the focus here is in the travel behavior captive to one specific mode (i.e. driving), the modeling structure can be simplified under the assumption that an individual is either captive to a specific mode i or free to choose from among all the alternatives in the full choice set M. Equation (3.5) thus reduces to the following:

$$P(i) = \frac{1}{\sum_{g \in \{j \in M\},\{M\}} e^{V_g}} [e^{V_{\{i\}}} + e^{V_{\{M\}}} \frac{e^{V_i}}{\sum_{j \in M} e^{V_j}}] \quad \text{or}$$

$$P(i) = \frac{e^{V_{\{i\}} - V_{\{M\}}}}{1 + \sum_{j \in M} e^{V_{\{j\}} - V_{\{M\}}}} + \frac{1}{1 + \sum_{j \in M} e^{V_{\{j\}} - V_{\{M\}}}} \frac{e^{V_i}}{\sum_{j \in M} e^{V_j}} \qquad (3.6)$$

Equation (3.6) resembles the Parameterized Logit Captivity (PLC) model (Ben-Akiva, 1977; Swait, 1984), with a slight difference in the choice set utility function. Both the dogit model and the PLC-identical model can be generated from Equation (3.6) when the expressions $e^{V_{\{i\}} - V_{\{M\}}}$ and $V_{\{i\}} - V_{\{M\}}$ are replaced with the non-negative constant d_i and $V'_{\{i\}}$, respectively (shown in Equation (3.7) and (3.8) below).

$$P(i) = \frac{d_i}{1 + \sum_{j \in M} d_j} + \frac{1}{1 + \sum_{j \in M} d_j} \frac{e^{V_i}}{\sum_{j \in M} e^{V_j}} \qquad (3.7)$$

where the constant d_i indicates the odds that an individual is captive to mode i.

$$P(i) = \frac{e^{V'\{i\}}}{1 + \sum_{j \in M} e^{V'\{j\}}} + \frac{1}{1 + \sum_{j \in M} e^{V'\{j\}}} \frac{e^{V_i}}{\sum_{j \in M} e^{V_j}} \tag{3.8}$$

It is worth noting the subtle difference between Equation (3.8) and the conventional PLC model that is inherited from the dogit formulation. In Equation (3.8) $V'_{\{i\}}$ represents the deviation of the utility with the single-mode choice set from the full choice set. Therefore the formulation offers an important policy-relevant interpretation that is not so apparent or intuitive in a conventional PLC model. That is, in the context of automobile dependence analysis, providing more travel options lowers the value of $V'_{\{i\}}$, and thus helps reduce automobile dependence.

Compared to conventional logit models such as MNL we used in the mode choice analysis, the captivity logit models are much more complicated to estimate because the models are no longer linear (in parameters) due to the presence of the captivity parameters. To estimate the captivity models we have to call the Maximum Likelihood Estimator (MLE) directly instead of applying the logit estimation routines provided by many computing packages. Doing so requires explicit expression and coding of the log-likelihood functions.

To reduce computational complexity (without losing the essence of the analysis), we simplify the modeling structure in the Boston and Hong Kong case study to a binary choice case. That is, mode choice decisions observed in the sample are considered as a choice between driving and non-driving. Driving includes driving alone or car-pool, whereas non-driving includes rail, bus, taxi, biking and others. Walking mode is excluded after we found that including it created strong statistical noise. This is because walking is only feasible at very limited, local scale. Treating it the same as rail or bus transit tends to distort the real effects of cost and land use factors on non-driving mode choice behavior.

A further simplification is made by restricting the sample to include those individuals who have driver's licenses or have access to private vehicles, meaning that no one in the sample is captive to the non-driving mode. This simplification forces the captivity coefficient for the non-driving mode to zero. It is necessary because only k-1 number of captivity coefficients, where k is the number of modes in the full choice set, can be identified (Swait, 1984).

Consequently, Eq. 3.7 is reduced to Eq. 3.9, which is termed in this study *the single coefficient automobile dependence model.*

$$P\ (driving) = \frac{d_{driving}}{1+d_{driving}} + \frac{1}{1+d_{driving}} * \frac{e^{\beta X_{driving}}}{e^{\beta X_{driving}} + e^{\beta X_{non-driving}}} \qquad \text{(Eq. 3.9)}$$

where $d_{driving}$ is the captivity coefficient of automobile dependence that is to be identified. β represents a vector of parameters to be estimated to capture the significance, directions, and magnitude of the corresponding independent variables of vector X in influencing choice decisions. The estimate of $d_{driving}$ is interpreted as the odds that the individual is automobile dependent. The first term on the right hand side is the probability of automobile dependence, whereas the first part of the second term is the probability of the individual being free to choose from the full choice set.

Similarly, Eq.3.8 becomes Eq. 3.10 below. Following the naming convention of PLC, the model is termed *the parameterized automobile dependence model.*

$$P\ (driving) = \frac{e^{\gamma Z_{driving}}}{1+e^{\gamma Z_{driving}}} + \frac{1}{1+e^{\gamma Z_{driving}}} * \frac{e^{\beta X_{driving}}}{e^{\beta X_{driving}} + e^{\beta X_{non-driving}}} \qquad \text{(Eq.3.10)}$$

where $rZ_{driving}$ is the utility function, or more specifically, the automobile captivity function containing the variable vector $Z_{driving}$ and the coefficient vector r that are to be empirically identified and estimated to account for the sources of automobile dependence.

3.5 Modeling Individual Trip Frequency

In transportation planning practice, modeling trip frequency, or trip generation, is usually done using regression methods. Two types of regression are commonly used. The first uses data aggregated at the zonal level, with the average number of trips per person or per household in the zone (in a given period of time, e.g. per day) as the dependent variable. The independent or explanatory variables include average zonal social-economic characteristics and land use patterns. Another type of regression uses disaggregate data at the household or individual level, with the number of trips made by a household or individual as the dependent variable and the household and personal characteristics as the independent variables.

In this research, we take advantage of the availability of disaggregate data for both the Boston and Hong Kong cases, and apply the second type of regression, namely logit regression, to model trip frequency. Typically, binary logit is used to model whether or not an individual makes a specific trip. In the sample data we have, the observations recorded are for individuals who have already made trips. What differs among individuals is the frequency of their trip making during the time period of survey. Multiple logit regression is therefore more suitable to our analysis. The specific type of multiple logit used is called *ordered logit*, or *ologit*, another member of the logit family. The technique is most commonly used in social and political sciences when the dependent variable is categorical or ordered, for instance, 'poor,' 'good,' and 'excellent.' It has also been applied to transportation in modeling the number of automobiles owned by a household, or the number of trips taken by an individual (e.g. Crane and Crepeau 1998). The estimated results are interpreted as the probability (or the odds) of making an additional trip, rather than the counting of number of trips, as a function of social, economic, and land use/transportation characteristics.

The conventional *ologit* imposes what is called the proportional odds assumption on the estimation. The assumption says that explanatory variables have the same effect on the odds that the dependent variable is above any category. For example, in modeling trip frequency, it is assumed that the influence of parking fee to an individual in making the first trip is the same as in making the third, the fourth, the fifth, … trip. This assumption is relaxed in generalized ordered logit, or *gologit* (Stata 1998). The advantage of gologit is that it allows us to identify what specific variables have *prolonged and differentiated influence* to individuals in making more trips. The technique is therefore particularly suitable to our interest in whether more integrated, denser land use patterns induce more frequent trip making.

Many statistical software support *ologit* estimation subroutines. We use Stata in this research. Both *ologit* and *gologit* are estimated in our case studies for comparison.

3.6 Land Use Indicators

In this research, three indicators of land use attributes are used: density, land use mix, and urban form. They are measured at both trip origins and destinations at the Traffic Analysis Zone (TAZ) level.

- Density

Both population and job densities are measured at the zonal level. For the Boston case, densities are calculated using the built-up area. For the Hong Kong case, information on the built up area is not available. Accordingly, raw densities are calculated using the total zonal land areas.

- Land Use Mix

Land use mix is evaluated based on a measure of entropy in the same form as in Frank (1996) and Cervero (1988). It is given by the following equation:

$$\text{Entropy} = -\sum_j \frac{[L_j * \ln(L_j)]}{\ln(J)} \qquad \text{(Eq. 3.11)}$$

Where P_j is the proportion of developed land in the *j*th use type.

Here the entropy index varies between 0 and 1 because of the normalization with 1 signifying perfect balance of the uses considered. Four (J=4) land use types are considered: residential, commercial, industrial, and recreation.

- Urban Form

The characteristics of urban form is calculated as the percentages of cul-de-sacs and four-way intersections in a zone. They are derived using GIS tools and the Census TIGER/Line files.

3.7 Why Boston and Hong Kong?

A methodological constraint to most existing studies on the built-environment/travel-behavior relationships in the US context is the rather uniform land use patterns, travel outcome, and policy environment in metropolitan areas across the country. Lack of significant variation in attributes of these factors potentially creates modeling identification problems and weakens the robustness of the analysis. A reasonable approach to overcoming the methodological limitation is to include other cases of world cities in which land use, travel, and policy environments differ significantly.

In the international context, perhaps the most widely cited study on this topic is the one by Newman and Kenworthy (1989, 1999) on 32 and later expanded to 46 global cities. In spite of its uniqueness, Newman and Kenworthy's work has invited criticism for its aggregate nature of analysis, and analytical weakness of not simultaneously controlling for socioeconomic and policy factors (e.g. income, prices, etc.) (Gomez-Ibanez 1991 and Pickrell 1999).

This dissertation research represents an effort to systematically examine the built-environment/travel-behavior relationships at the disaggregate level in the international context. It is based on two special cases: the Metropolitan Boston and Hong Kong.

Boston and Hong Kong represent two end groups on Newman and Kenworthy's well-known loglinear curve of urban-density/auto-use relationships (see Figure 2.3). Among the North American cities, Boston is an average case; it falls between the cities with very low density and very small share of non-auto uses such as Phoenix and Los Angeles, and the cities with higher density and relatively large share of transit uses such as New York City. Having considerable variations in characteristics of built environment and travel behavior within the region, Boston makes a fine case representing the US cities to study on land-use/transportation relationships.

In Hong Kong, natural geographical constraints create a high density, mixed land use pattern, which in turn helps create an integrated transit system with a reputation of high efficiency and high cost recovery rate (and even profits). It is widely cited as one of the best examples demonstrating the benefits of land-use/transportation integration. However, one fact about Hong Kong is often neglected. That is, the government has rigorously regulated automobile ownership and use by setting cap limits and very high taxes (Hau 1995). Then interesting questions arise: given a transit-favored land use patterns and availability of high quality, transit services, why does the government still need to exercise strong control on auto use? What impacts have the policies had on regional mobility and accessibility and how effective are they? Imagine that in the US land-use patterns were reconfigured to non auto-favored patterns, to what extend could we expect people to change their travel behavior, without other supporting measures?

Hong Kong serves as an interesting mirror case to our analysis in the Boston case. Analyzing the two special cases will improve our understanding of the built-environment/travel-behavior relationships, and shed new light on researching the conditions and effectiveness of land use in affecting travel.

To the broadest extent, this study reflects concerns over automobile dependence and spatial accessibility not only in the US, but also in the global context. As motorization continues to grow worldwide in parallel to increase in wealth, finding a sustainable way to accommodate the growing mobility demand is a great challenge to planners and policy makers worldwide. Some developed countries such as Australia have faced challenges similar to the US in dealing with automobile dependency and suburban sprawl. Many developing countries, however, tend to follow the same automobile-highway model to supply urban mobility and to provide regional access. Addressing the issue based on world cities will help promote international learning in transportation policy making. Analyzing Boston and Hong Kong, the two special cases, will set coordinates on two ends over a spectrum in land use development and transportation policies at the global scale. Hong Kong stands at the one end of the spectrum and Boston at the other. Other cases such as European or Asian cities will largely fall in between.

3.8 GIS and DBMS Tools

Statistical and spatial data sets are collected for both the Boston and Hong Kong case study. These data sets are from various sources. Some are point observations, while others are zonal aggregates. Still others are in matrix forms. These data sets need to be cleaned and linked together before they can be used for spatial and statistical analysis. For efficient data processing and management, GIS and DBMS tools are utilized. For each of the case studies, a database is set up using Sybase for PC. Figure 3.4 and Figure 3.5 illustrate the organizational chart of the Boston and the Hong Kong database, respectively.

Figure 3.4 Database Diagram for the Boston Case Study

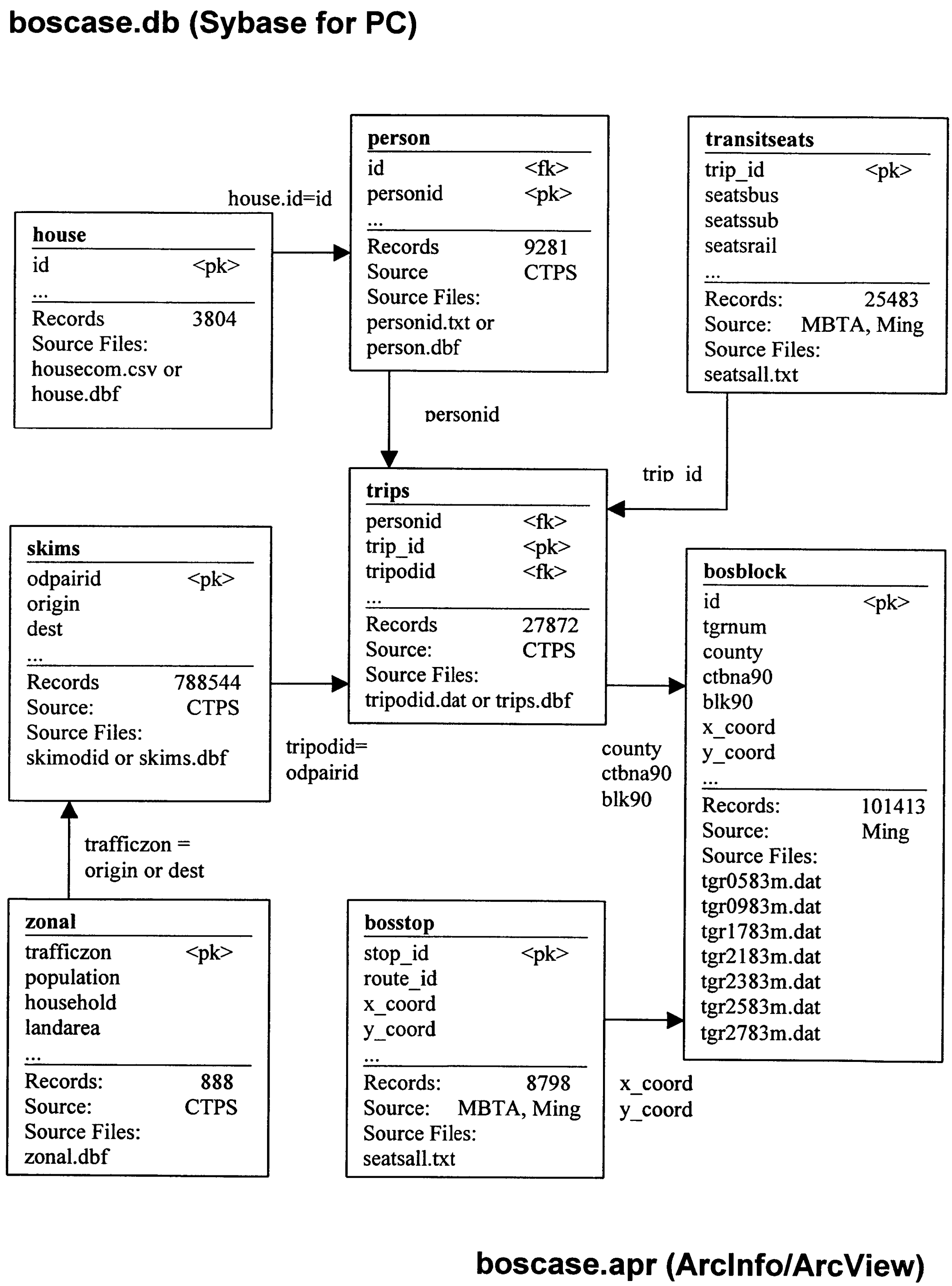
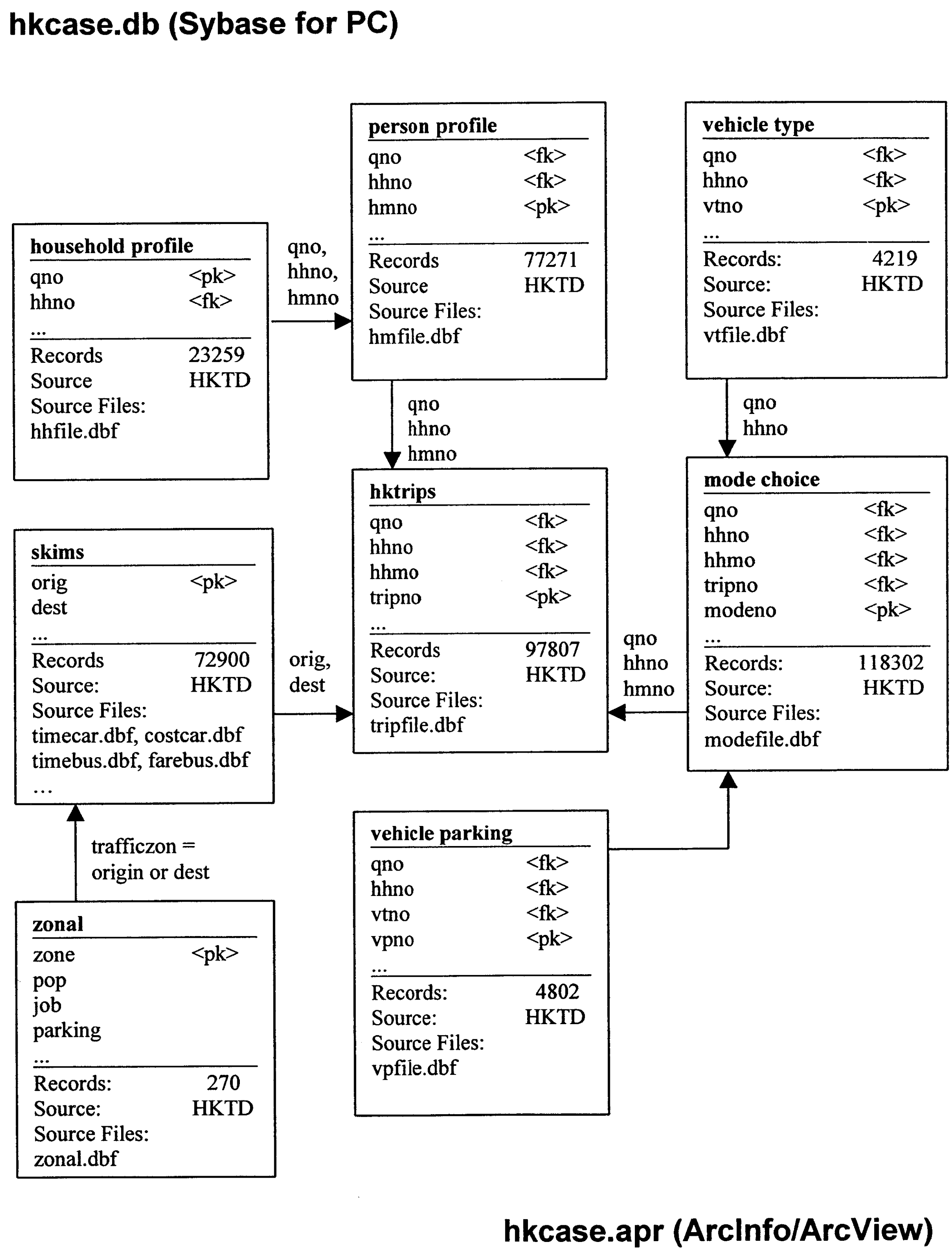


Figure 3.5 Database Diagram for the Hong Kong Case Study



Chapter 4

The Boston Case Study

Figure 4.1 Aerophoto: The Boston Downtown Area

Source: The MIT and MassGIS Orthophoto Project (http://ortho.mit.edu)

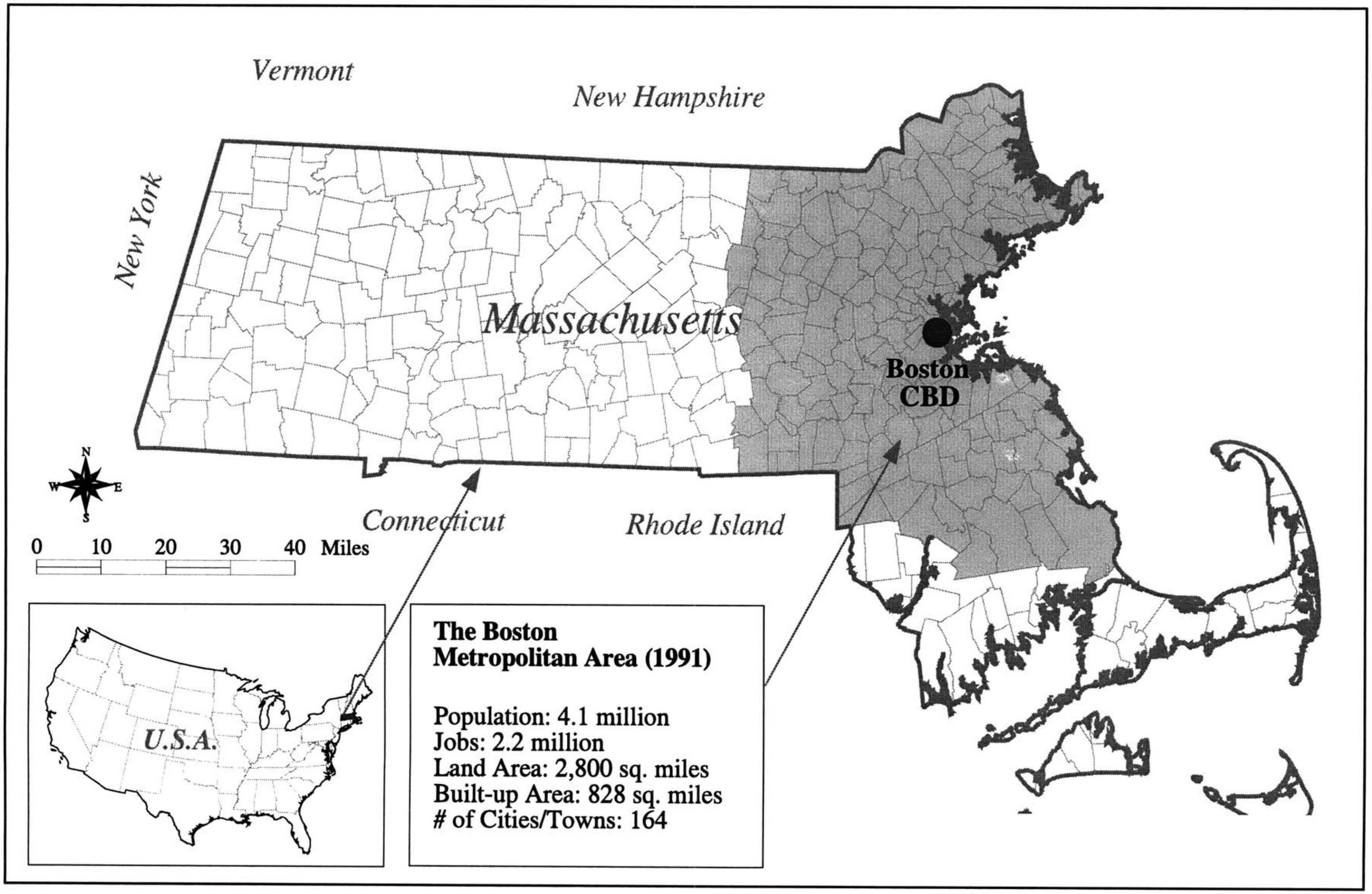
In this chapter we present our study on the Boston case, addressing the research questions stated in Chapter One. We first provide the basic social, demographic and geographical information about the study area in the Greater Boston. National and regional postwar trends in urban and transportation development are also briefly reviewed. The mobility supply in the study area in terms of road networks and transit services are described in rather detail. The major contents of this chapter include three sections on the empirical modeling of the built-environment/travel-behavior relationships focusing on travel mode choice, trip frequency, and automobile dependence. A fourth section is devoted to simulation analysis of the policy effects on travel behavior based on the empirical results. The chapter ends with a chapter conclusion.

4.1 Background Information

- **The Study Area**

Located in the northeastern US, Boston is commonly known as the "Hub of New England," reflecting its status as the focus of the regional economy. The metropolitan area is the largest in the Commonwealth of Massachusetts. Its economic influence goes beyond the state boundary. The 1990 Census shows that 10,000 out of a total of 500,000 average daily commuters working in the area came from the neighboring four states. Our study area contains the central portion within Massachusetts of the Census Boston MSA (Metropolitan Statistical Area). It consists of seven counties, 164 cities or towns and has a total area of approximately 2,800 square miles and a total population of 4.1 million (in 1991) (Figure 4.2). The area is a primary industrial, financial, and educational hub. Major economic sectors include banking and financial services, insurance, and real estate. Other businesses are in high technology, biotechnology, software, and electronics. Historically the capital of American higher education, the metropolitan area is home to 68 colleges, including Harvard University and the Massachusetts Institute of Technology. The City of Boston is one of the oldest in the U.S. The city's unique cultural and historic heritage makes it a center of tourism. Metropolitan Boston is among the few in the nation that have maintained a strong downtown economy.

Figure 4.2 The Boston Metropolitan Area



- **National and Regional Post-War Trends**

A single term that may best characterize the post-war development in the urban America is *decentralization.* During the post-war period, households, retail services, and jobs have been in succession leaving from the central city to the outer area, seeking for cheaper but more land and fresher air. Decentralization has thus created a metropolitan pattern typically featured with the continuous, low density, affluent suburb and comparatively a run-down, struggling inner core financially (and socially as well). At least four driving forces are thought behind the decentralization process: growing income, private motorization, availability of vast land resources, and government policy incentives.

Since the World War II, the US economy has been growing steadily, as it is shown by the growth of GDP per capita (Figure 4.3). From 1950 to 1994, the real GDP per capita increased from $12,000 to $27,000 (in 1994 dollars), more than double. The growing national wealth has made possible large public spending on road infrastructure. Rising personal income leads to continuous growth of private motorization. Since 1950 vehicle ownership has doubled, reaching nearly 800 vehicles per 1000 people in 1998 (Figure 4.4). Cheap gasoline and low costs of owning and operating automobiles reinforce the trend. From 1950 to mid-1990's, the real price of gasoline has decreased (Figure 4.3). The costs of owning and operating automobile remain virtually constant at less than half a dollar per mile (in 1998 value) (Table 4.1).

Improved personal mobility brought by private motorization and public provision of road infrastructure allow people to live farther and farther away from the central city as the construction of extensive highway networks provides access to vast open land, a resource that is abundant in this country. In addition, the government offers incentive policies such as tax reduction on mortgage payments to encourage home-ownership. All these factors are favorable to people's pursuing of the 'American Dream' of owning a suburban house and a new car, which has produced today's urban/suburban America.

Figure 4.3
GDP per capita, Gasoline Price in the US, 1950-1994

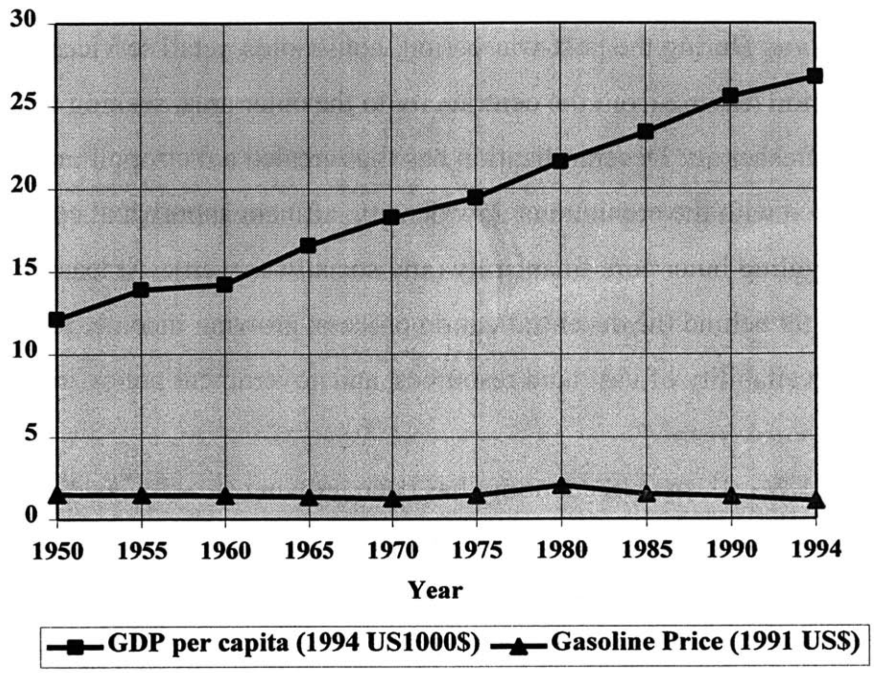
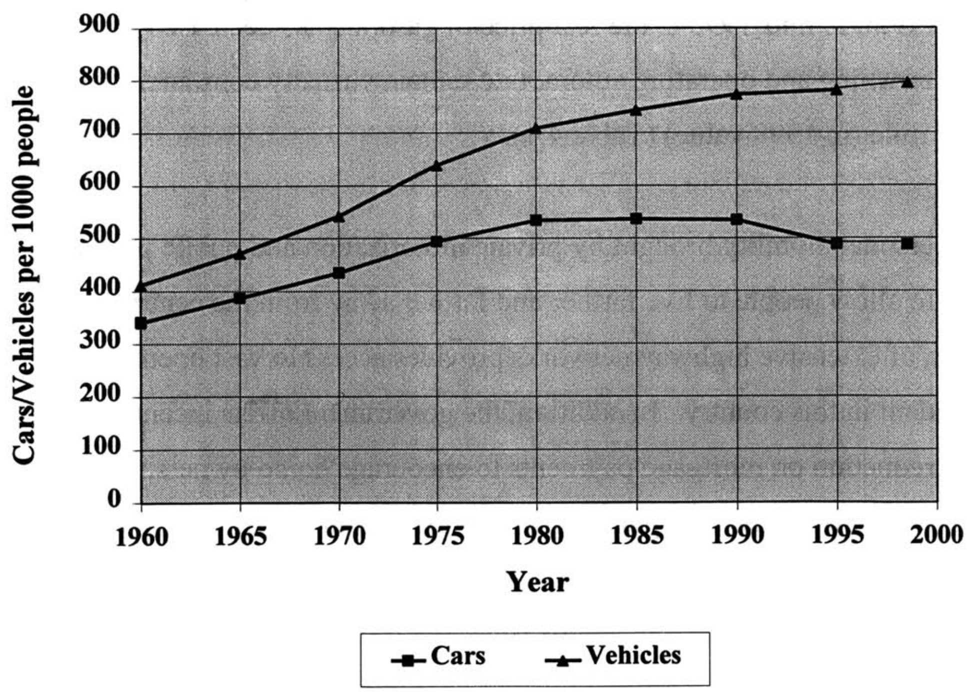


Figure 4.4
Motorization in the US, 1960-1998



Source: Bureau of Transportation Statistics, 1999

Table 4.1 Cost of Owning and Operating an Automobile in the US, 1975-98

	1975	1980	1985	1990	1995	1998
Total Cost per Mile						
(current cent)	14.4	21.2	23.2	33	41.2	46.1
(in 1998 cent)	43.6	41.9	35.1	41.2	44.1	46.1
Gas & Oil	4.8	5.9	5.6	5.4	5.8	6.2
As % of Total Cost	33.4	27.9	24	16.4	14.1	13.4
Maintenance	1	1.1	1.2	2.1	2.6	3.1
Tires	0.7	0.6	0.7	0.9	1.2	1.4
Total Cost per 15K Miles						
(current dollar)	2154	3176	3484	4954	6185	6908
(in 1998 dollar)	6522	6277	5271	6185	6620	6908
Variable Cost	968	1143	1113	1260	1440	1605
Fixed Cost	1186	2033	2371	3694	4745	5303

Source: Bureau of Transportation Statistics, 1999, *National Transportation Statistics*, US

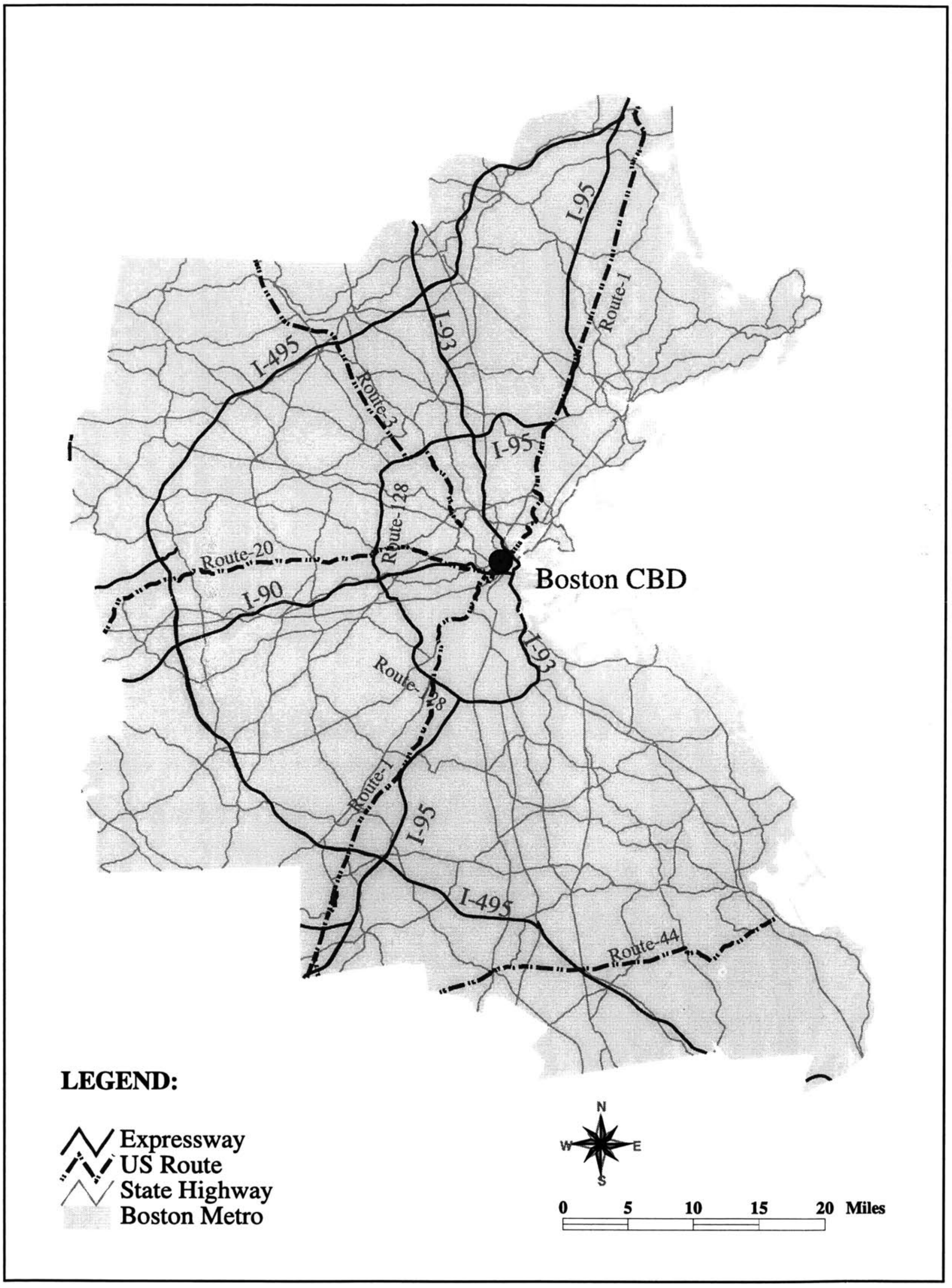
The metropolitan Boston shares the experience with other US cities of the post-war development. Beginning in the 1950s with the construction of the Massachusetts Turnpike and Route 128, an extensive highway system has been built, including both radial and circumferential routes (Figure 4.5). These roads provided good access to inexpensive suburban land, leading to a strong movement to the suburbs in the 1950s and the following decades. Thousands of mid- and higher-income families left the cities and moved to the suburbs, followed by the suburbanization of jobs (Figure 4.6). The development was typically low density, with land development at a much larger scale than population growth (Figure 4.7). A survey shows that between 1970 and 1990, the new land area development was the equivalent of over four cities the size of the City of Boston, while the population increase during this same time period was the equivalent of roughly half of City of Boston (CTPS 1999). In the meantime, the population living in the traditional inner core shrank from 60% to 42%. There has been a steady migration of people out of the urban core and into first the region along Route 128 or I-95 (the first ring road around Boston) and then to the region along I-495 (the second ring road). Areas of commercial and industrial development have also grown up along the Route 128 corridor and are now beginning to increase along the I-495 corridor.

In the Greater Boston area, there is no centralized organization or agency that has the authority to manage the entire region's physical development. Land use planning, development, and management are typically practiced at a local (town) scale. Each of the 164 cities or towns in the area has its own development plan and zoning regulation. Region-wide, the Boston Metropolitan Planning Organization (MPO) is responsible for carrying out comprehensive transportation planning. The Boston MPO is a cooperative board of 14 state, regional, and local entities. Currently, it covers approximately 1,405 square miles and encompasses 101 cities and towns with a total population of 3.07 million (roughly half and three fourths of our study area in area and population, respectively). It prepares and updates long-range transportation plans required by the federal government after the passage of the Federal-Aid Highway Act of 1962. The use of the plans is to set regional priorities for federally funded projects. In other words, the Boston MPO, like many other MPO's in the nation, has a limited role in affecting local development, especially land use.

- ***Mobility Supply in the Boston Area***

Urban mobility in the metropolitan Boston is supported by an extensive road network and a relatively efficient public transportation system. The roadway system is comprised of freeways, expressways, arterials, collector roads, local roads, and bridges. Within the 101 communities of the MPO region, there are 6,726 miles of arterials (including 1,138 miles of interstate highways), 2,816 miles of collector roads, and 13,932 miles of local roads (CTPS 1999). If we assume the region has the same level of vehicle ownership as the state and the national level, which was 795 vehicles per 1000 people in 1998, it gives a vehicle density of 104 vehicles per road mile (The actual vehicle ownership in the region is lower than the state or the national level, according to 1990 Census. The exact number for 1998 is not available.)

Figure 4.5 Highway Networks in the Boston Area



In spite of the post-war decentralization, Boston remains one of the most densely developed area in the country (Figure 4.6). The dense development supports a relatively large public transportation network, which in turn plays a vital role in supporting downtown economic activities and in providing mobility for residents and visitors.

The Boston metropolitan area is served by a hub-and-spoke network of rapid transit, light rail, local or express bus, commuter rail and commuter boat lines (Figure 4.8). The Massachusetts Bay Transportation Authority (MBTA) is the primary transit provider in the region. The MBTA directly operates or contracts out for service to 175 community districts using seven different modes: rapid rail transit, light rail, local or express bus, trackless trolley, commuter rail, paratransit vans and commuter boat. The commuter rail network extends beyond the MPO region to outer suburbs and towns. Local MBTA bus service is limited to an area extending from Boston to just beyond Route 128. The rapid and light rail lines form a radial network connecting to and through the inner city core.

The MBTA's 70 mile rapid transit and light rail systems comprise 125 stations on five lines: the Red Line, the Orange Line, the Blue Line, the Green Line, and the Mattapan High Speed Trolley. Daily ridership on the rapid transit/light rail system is approximately 647,000 trips per weekday.

The MBTA operates 170 bus routes, 11 express bus routes throughout the MBTA district serving the 44 communities. It has a bus fleet of 1020 vehicles. Four electric trackless-trolley lines also operate in Cambridge, Watertown and Belmont. Most of these routes have long histories, and many had their origins as streetcar lines built before 1900. Buses serve over 8,500 stops, approximately 360 of which are equipped with bus shelters. Park-and-ride lots for bus service have 691 parking spaces. In 1998, total bus ridership was approximately 375,000 trips per weekday.

The commuter rail network has a total length of 265 miles, comprising 13 radial lines, with 67 passenger-accessible stations. It serves 72 communities in the greater Boston region. In 1999, annual ridership was 35.8 million.

MBTA commuter boat service is operated by two contractors and operates between Boston and the outer islands. The RIDE service is a paratransit program operated by private carriers under contract to the MBTA that provides transportation to people who cannot use general public transportation because of disabilities. The Cape Ann Transportation Authority provides local service in the towns of Gloucester and Rockport. There are also public transportation services provided by local municipalities to supplement the MBTA services.

There is no significant difference between metropolitan Boston and the rest of the country in terms of fiscal policies and regulations on owning and using automobile and other private vehicles. There is a nation-wide fuel tax called the "Gas Guzzler Tax" that was imposed in 1978 and doubled in 1990 on new automobiles that have a fuel efficiency rating of less than 22.5 miles per gallon (MPG). However, nearly all new passenger vehicles currently available in the market have a fuel efficiency higher than 22.5 MPG. Light duty trucks are exempt from this tax. Massachusetts has a state sales tax of 5%, about the same as the national average. Table 4.2a and 4.2b list current vehicle registration and drivers' license fee schedules.

Table 4.2a Motor Vehicle Registration Fees in Massachusetts, 2001

Vehicle Type	Fees
Ambulance (Annual)	$25.00
Auto Home (Annual)	$25.00
Commercial up to 5,000 lbs (Biennial)	$12 per 1000 lbs, $96 min
Commercial over 5,001 lbs (Annual)	$15 per 1000 lbs
Moped (up to 2 years)	$20.00
Motorcycle (Annual)	$20.00
Motorcycle Vanity (Annual)	$70.00
Passenger (Biennial)	$30.00
Trailer (Annual)	$12 per 1000 lbs, $96 min
Vanity (Special Vehicles and Plates) (Annual)	$65.00

Source: Massachusetts Registry of Motor Vehicles, http://www.state.ma.us/rmv/

Figure 4.6 Spatial Distribution of Income in the Boston Area

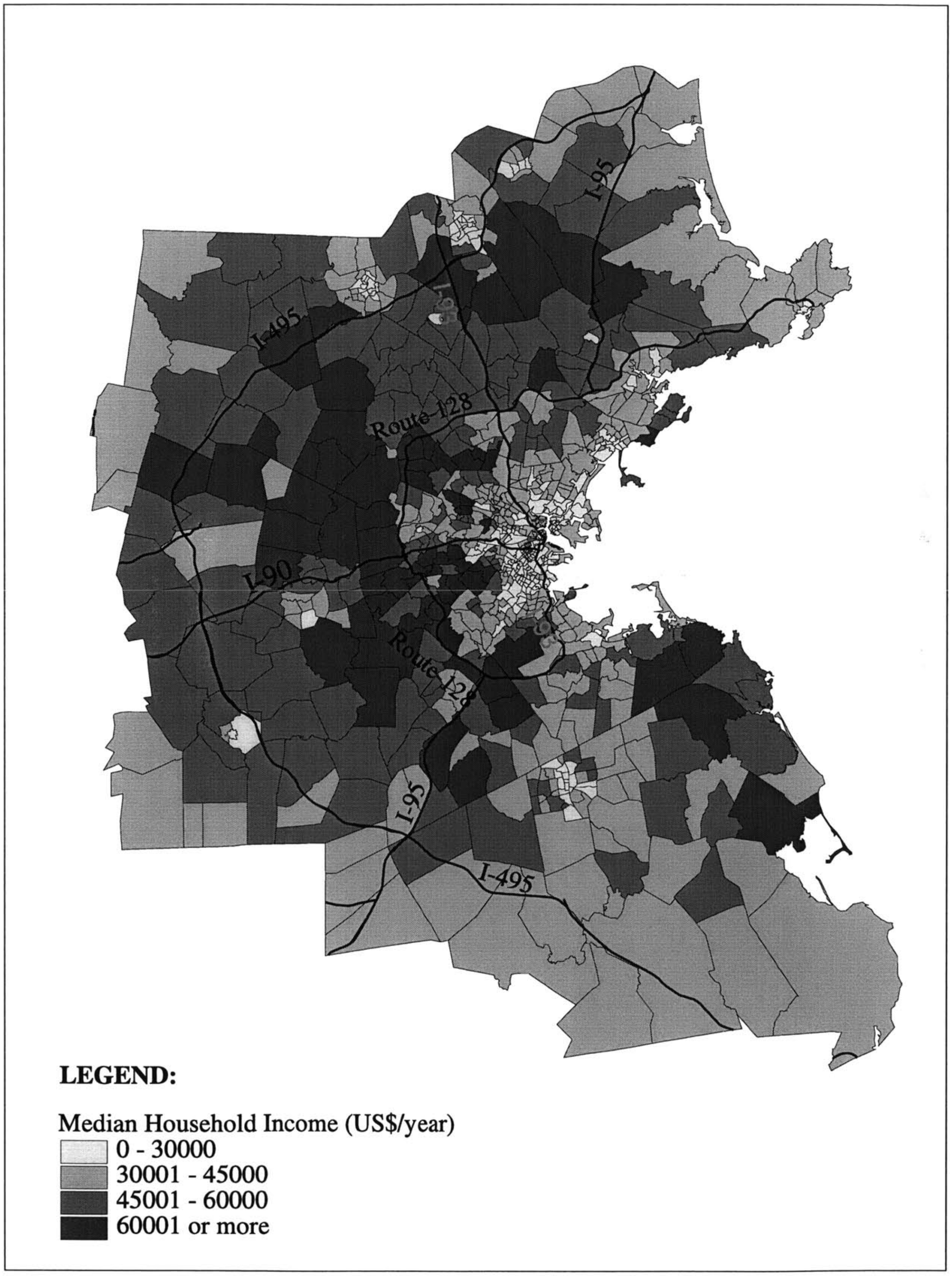


Figure 4.7 Population Density in the Boston Area

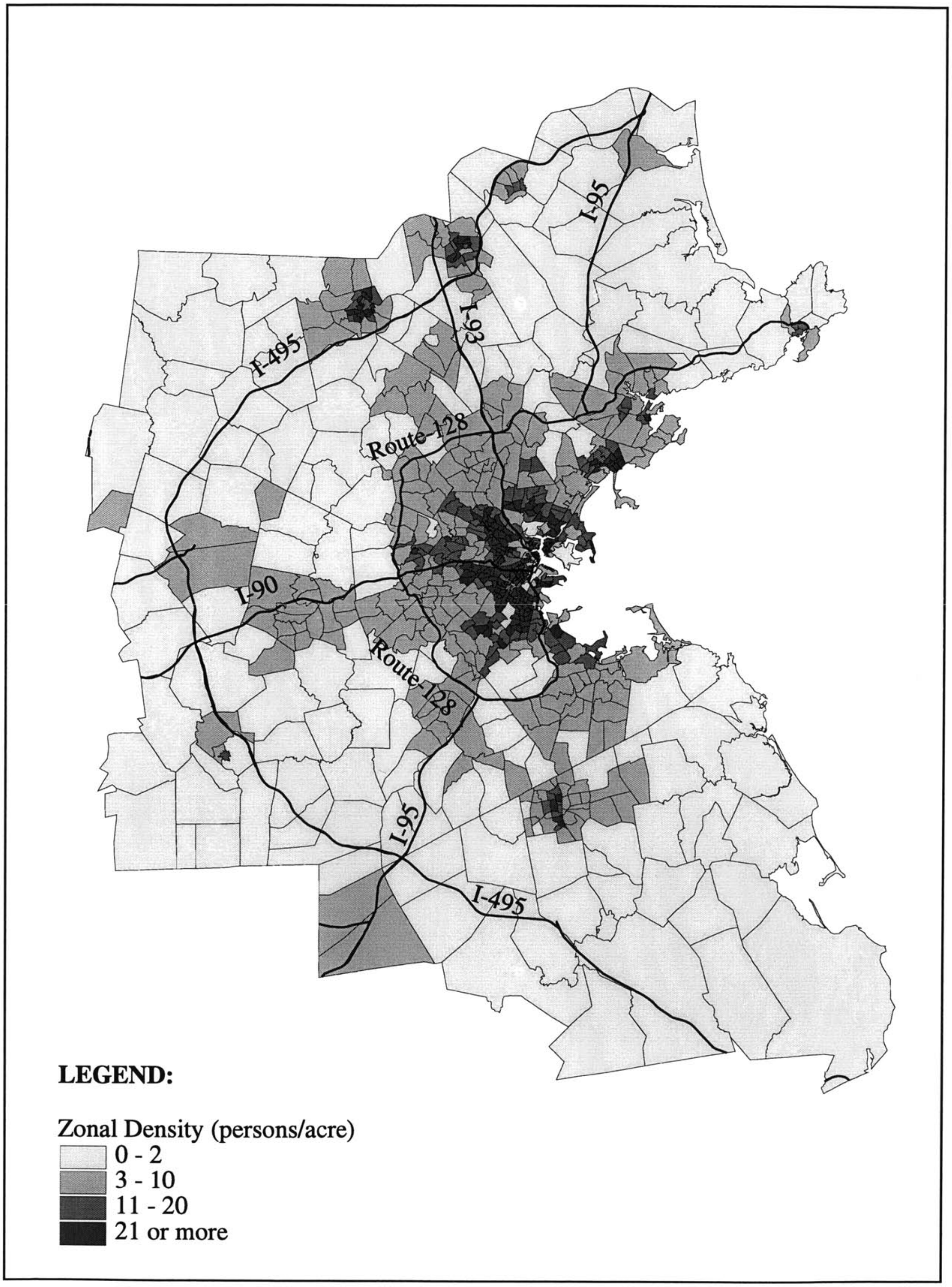


Figure 4.8 Public Transportation Networks in the Boston Area

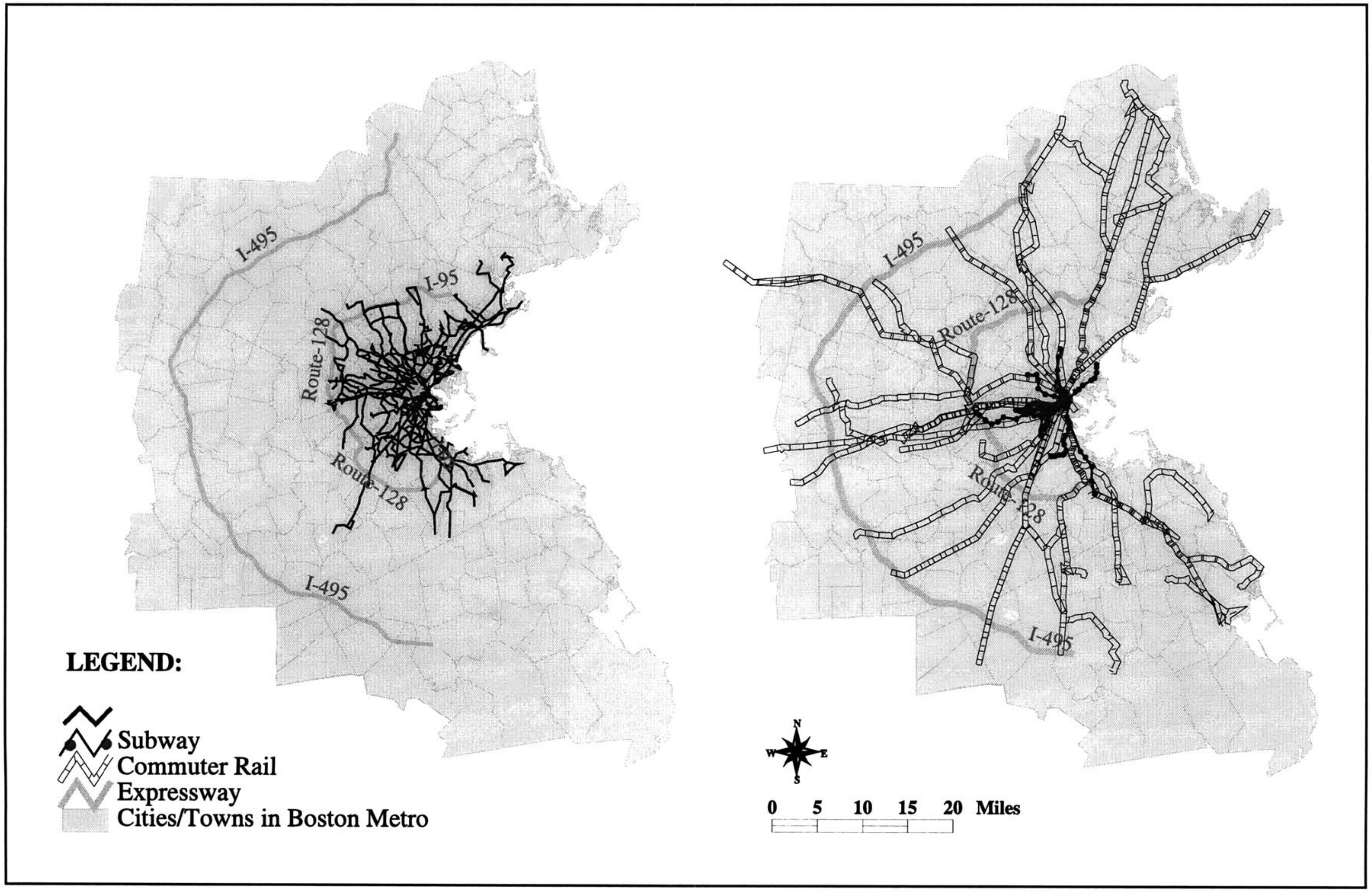


Table 4.2b License and Identification Card Fees in Massachusetts, 2001

RMV Transaction	Fees	Out of State Conversion Fees
Class A (5 years)	$52.50	$87.50
Class B (5 years)	$40.00	$75.00
Class C (5 years)	$33.75	$68.75
Class D (5 years)	$33.75	$68.75
Class M (Motorcycle only)	$33.75	$68.75

Source: Massachusetts Registry of Motor Vehicles, http://www.state.ma.us/rmv/

The Boston metropolitan area has an extensive, well integrated public transportation system, in addition to the highway network. It offers a variety of travel alternatives to local residents. Sharing the nation's development experience while having its own unique features of travel and settlement diversities, Metropolitan Boston offers a superior case to analyze built-environment/travel-behavior relationships in the US context.

4.2 Mode Choice and the Role of Land Use

The purposes of modeling mode choice are: (1) to answer the first of our five research questions, that is, whether land use characteristics is significantly associated with individual's travel choice decision after important behavioral variables such as price and taste preferences are controlled for; (2) to provide a modeling context for analysis of travel demand and automobile dependency reported in the following sections. The empirical results from the mode choice modeling are also the basis on which simulations of policy effects are done.

- **Data**

The following four types of data are used (Refer to Chapter 3 for the structure of the database set up in Sybase):

- 1991 Trip Diary Survey for the Boston metropolitan area. It contains three files: (1) The Household File on household social and demographic information and trip information for households that participated in the survey for a survey period of seven days; (2) The Person File on individual characteristics and trip information for each person in survey households; and (3) The Trip File on the purpose, mode, travel time and trip origin- and destination-locations for each trip made by persons in survey households at the census block level. There were 3,854 households surveyed, with a total of 9,281 persons who made 39,373 trips. Of the total trips, 2,993 were home-based work trips, which is the data set used for this study.
- Land use data and 1990 Skim Table, including population, employment, land uses with five classifications (industrial, commercial, residential, recreational, and undeveloped), and zonal travel time and costs by different modes for the 787 traffic analysis zones (TAZ).
- Transit operations data including average daily boarding, service capacities and frequencies by all types of transit modes at the stop or station level.
- Other data such as street networks, transit routes and station addresses.

Table 4.3 summarizes the descriptive statistics of the major control variables entered into the final choice model.

Figure 4.9a and 4.9b show the general spatial patterns of the origins-destinations for the home-based work trips by the four modes in our sample.

In this paper, four types of explanatory variables are considered (Table 4.4). The first one contains price variables associated with travel. They include travel-time cost variables such as in-vehicle and out-vehicle travel times (or distances), and monetary cost variables such as toll or transit fare costs and parking costs. To avoid a further level of complexity, vehicle fixed costs such as depreciation, insurance, registration, etc. are ignored here. Fuel costs of driving are also excluded due to lack of sufficient information on types and ages of vehicles used for commuting.

The second type of explanatory variables includes variables describing the social and economic characteristics of the travelers and their households. Specifically, these include age, gender, employment status, and driving capability (holding a driving license or not) of individuals, and household income, vehicle ownership, family structure and tenure status.

The third type of variables are the indicators of location characteristics and land use patterns of trip origins and destinations in terms of land development intensity, level of integration of different land use functions and spatial structure or form of the built environment. Trip location characteristics are indicated by the CBD dummy variable to distinguish trips ending in Boston CBD from others. Development intensity is measured by population and job densities at both trip origins and destinations at the TAZ level. Land use balance is measured by the entropy indexes in the common way at the TAZ level (see Frank and Pivo 1994 and Cervero and Kockelman 1997). Urban form features are characterized by a simple measure of the percentages of cul-de-sac and four-way intersections in a given TAZ.

The fourth, and final, type of variables are the three indicators specifically characterizing transit supply, including area density of daily transit-seats supply measured at both trip origin and destination zones (ODENSEAT and DDENSEAT) and furthermore by the variable TRSEATS, which represents the transit supply level at the immediate vicinity of trip origin (1/4 mile). The former two reflect the average level of supply at the zonal level, whereas the latter reflects the micro level convenience to transit services.

Table 4.3: Descriptive Statistics for the Independent Variables

Variables	Mean	Std Dev	Minimum	Maximum
Trip Maker Socio-Demographic Characteristics				
Age (years)	43	17	17	91
Proportion of Female	0.45	0.5	0	1
Household Size (persons)	2.9	1.35	1	9
No. of Kids under Five	0.19	0.5	0	4
No. of Workers	1.96	0.89	0	7
Proportion of Fulltime Employed	0.77	0.42	0	1
Household Income (dollars)	57714	28485	15000	120000
No. of Vehicles in Household	1.91	1.03	0	8
Proportion in Owner-Occupied Unit	0.65	0.48	0	1
Land Use Attributes				
Net Job density at trip origins (jobs/acre)	17	74	0.08	1720
Net Job density at trip destinations (jobs/acre)	135	313	0.08	1851
Net Population density at trip origins (persons/acre)	22	31	0	221
Net Population density at trip destinations (persons/acre)	22	37	0	626
Entropy index of land use balance at trip origins	0.38	0.19	0	0.92
Entropy index of land use balance at trip destinations	0.43	0.23	0	0.92
Share of cul-de-sac intersections at trip origins	0.15	0.07	0	0.33
Share of non cul-de-sac interscestions at trip destinations	0.64	0.09	0.36	0.92
Travel Costs and Supply				
Trip Distance (miles)	8.92	8.7	0.3	58.2
Driving Time (minutes)	27.61	23.23	1	750
Transit Time (minutes)	41.4	32.07	0	270
Fare Costs (cents, one way)	302	175	60	960
Toll and Parking Costs (cents, one way)	172	277	0	983
Daily transit supply available to individual travelers in 1/4 mile of trip origins (100s seats)	190	361	0	3649
Density of daily transit seats supply in trip origin zones (100s seats/acre)	197	569	0	14290
Density of daily transit seats supply in trip destination zones (100s seats/acre)	618	1807	0	21498

Figure 4.9a Spatial Patterns of Home-Based Work Trips by Driving Modes in the Boston Area

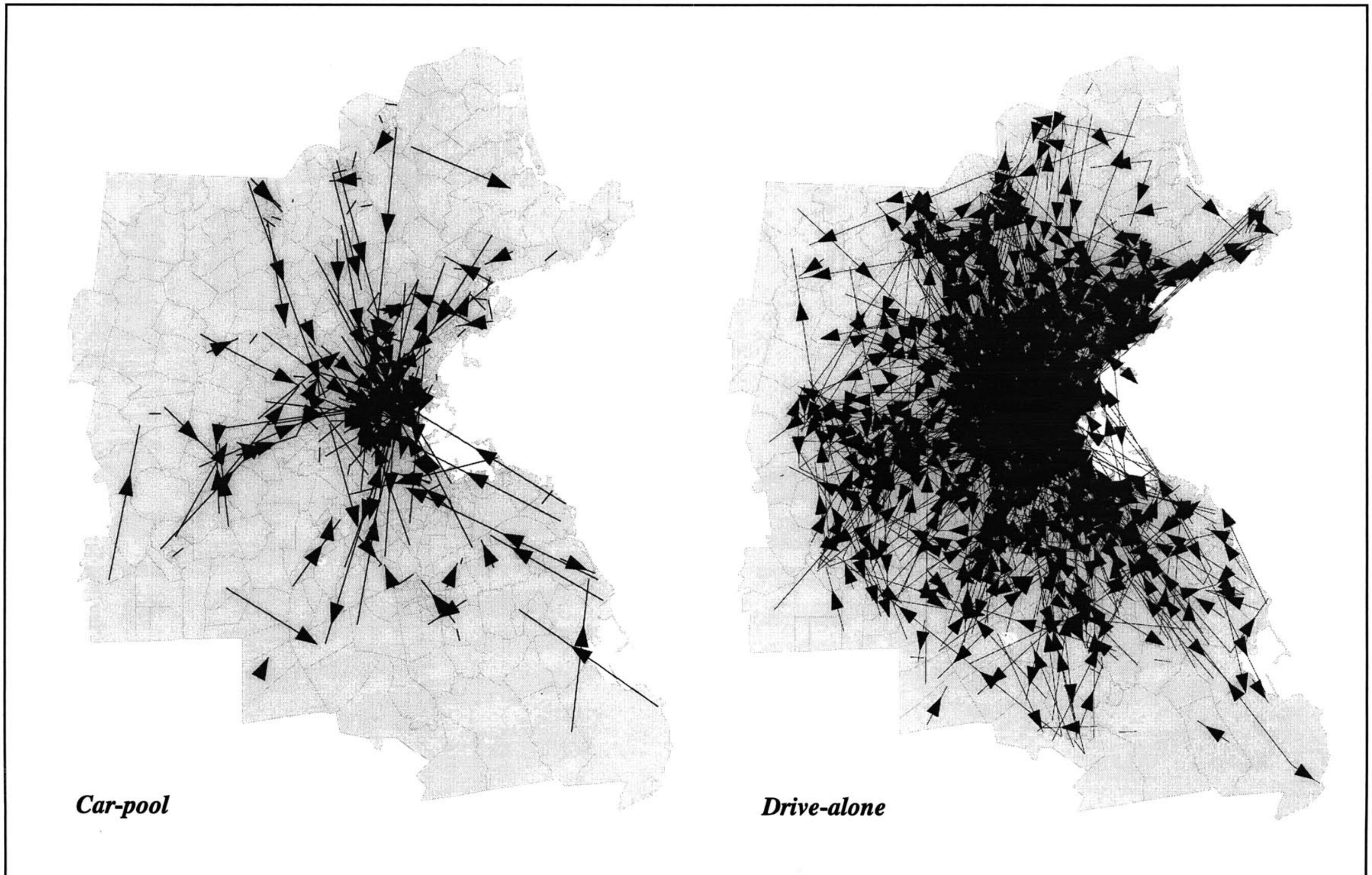


Figure 4.9b Spatial Patterns of Home-Based Work Trips by Non-Driving Modes in the Boston Area

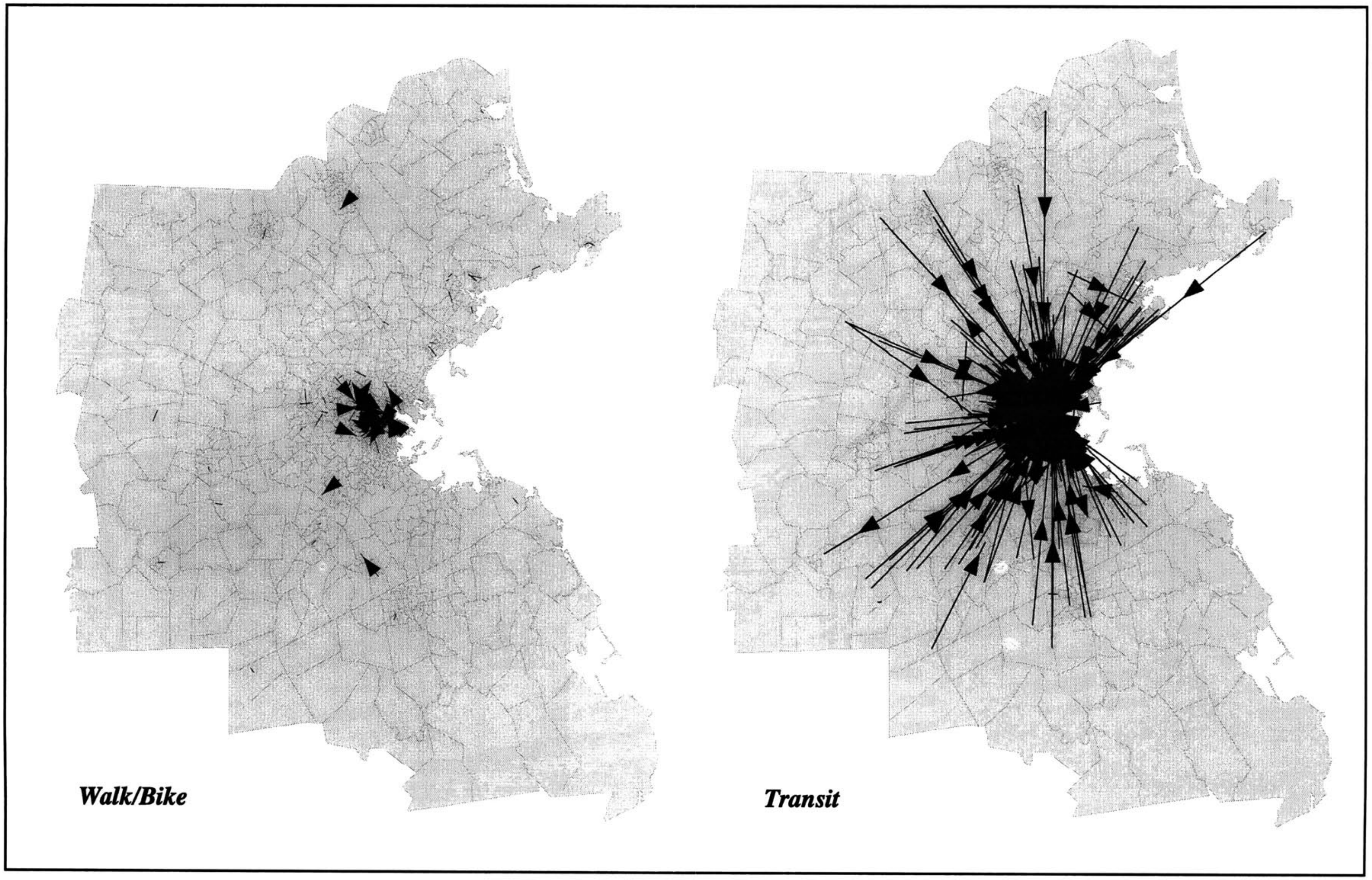


Table 4.4: Variable Definitions

Dependent Variable	
MODE CHOICE	1 WK: Walk, bike or other non-motorized modes; 2 TR: Transit (bus, subway, commuter rail, taxi); 3 CP: Car-pool; 4 DR: Drive-alone
Price Variables	
WKTIME	Travel time by non-motorized modes such as walk, bike, etc. (minutes).
TTIMETR	Total travel time by transit (minutes).
IVTIMECP	In-vehicle travel time by car-pool (minutes)
IVTIMEDR	In-vehicle travel time by driving-alone (minutes)
FARE/INC	Travel costs by transit divided by household income (cents/dollar)
TTCOSTCP/INC	Travel costs by car-pool divided by household income (cents/dollar)
TTCOSTDR/INC	Travel costs by driving-alone divided by household income (cents/dollar)
Household Recource Variables	
YOUNG	Age dummy variable; 1 if 30 years old or younger; 0 otherwise
EMPFULL	Employment dummy variable; 1 if full-time employed; 0 otherwise
OWNER	Home ownership dummy variable; 1 if own the house; 0 otherwise
FEMNOKID	Gender dummy variable; 1 if female without child under 5-year old; 0 otherwise
VEHOWN	Number of vehicles owned per worker in the household
Location and Land Use Variables	
CBD	CBD dummy variable; 1 if destination zone is in the CBD; 0 otherwise
ODENPOP	Population density at trip origins (persons/acre)
ODENEMP	Job density at trip origins (jobs/acre)
DDENPOP	Population density at trip destinations (persons/acre)
DDENEMP	Job density at trip destinations (jobs/acre)
OPCT1WAY	Share of cul-de-sac intersections in trip origin zones
DPCT3WUP	Share of non cul-de-sac interscestions in trip destination zones
OENTROPY	Entropy index of land use balance in trip origin zones
DENTROPY	Entropy index of land use balance in trip destination zones
Transit Supply Variables	
ODENSEAT	Density of daily transit seats supply in trip origin zones (seats/acre)
DDENSEAT	Density of daily transit seats supply in trip destination zones (seats/acre)
TRSEATS	Daily transit supply available to individual travelers at trip origins (seats)

- **Mode Choice Modeling Results**

Table 4.5a shows the model structure of the MNL model for individuals' mode choices for home-based work trips. Note that land use variables do not appear in all utility functions. This is because land use features do not change across modes. They enter the utility functions as alternative specific variables, reflecting the differentiated effects of land use attributes on the utility levels among different modes. Also note that, in a MNL model, the utility function associated with a specific mode includes only those variables that are believed affecting a traveler's consideration of that mode in the choice decision. Calculation of the utility level associated with one mode therefore should only consider the coefficients of the variables that finally enter the utility function. For example,

Walk Utility = b1 + b4*walktime + b11*young + b19*odenpop + b20*odenemp + b21*ddenpop + b22*ddenemp + b25*oentropy + b26*dentropy

Table 4.5b reports the estimation results. All estimated coefficients of the price variables have negative signs as expected and are significant at 95% or higher level of confidence. It conforms to our intuition that, when the price of travel by a mode increases (e.g. longer travel time or more monetary costs of travel), the demand for travel by that mode decreases. Except for the gender variable (FEMNOKID), the estimated coefficients associated with the variables characterizing travelers' social and economic status are all significant at 90% or higher confidence level, indicating the important influence of these factors on people's mode choice decisions on travel. Young people (YOUNG) are likely to walk or bike to work, whereas female workers with no children prefer transit (bus, subway, or commuter rail). Fulltime workers (EMPFULL) and those who own houses (OWNER) are more likely to drive alone to work, all else being equal. Obviously, when there are more vehicles per worker in a household (VEHOWN), people in the household are more likely to drive alone or car-pool to work than to walk or take transit. The latter three variables of employment status, home-ownership and vehicle ownership may capture in part the influence of income on mode choice as they all are highly correlated with the household income.

The location factor (CBD) captures the agglomeration effects of the downtown. After travel time, costs, job and population distributions, and transit supply are controlled for, the downtown-bound workers have strong preference for transit or car-pool.

Table 4.5a: Model Structure of Mode Choice for Home-Based Work Trips

Coefficient	Variable List	Variable List in Mode-Specific Utility Functions			
		Walk	Transit	CarPool	DriveAlone
b1	constant (wk)	one	-	-	-
b2	constant (tr)	-	one	-	-
b3	constant (cp)	-	-	one	-
b4	wktime (wk)	walktime	-	-	-
b5	ttime (tr)	-	ttimetr	-	-
b6	ivtime (cp)	-	-	ivtimecp	-
b7	ivtime (dr)	-	-	-	ivtimedr
b8	fare (tr)	-	faretr	-	-
b9	ttcost (cp)	-	-	ttcostcp	-
b10	ttcost (dr)	-	-	-	ttcostdr
b11	young (wk)	young	-	-	-
b12	empfull (dr)	-	-	-	empfull
b13	owner (dr)	-	-	-	owner
b14	femnokid (tr)	-	femnokid	-	-
b15	vehown (dr)	-	-	-	vehown
b16	vehown (cp)	-	-	vehown	-
b17	CBD (tr)	-	CBD	-	-
b18	CBD (cp)	-	-	CBD	-
b19	odenpop (wk, tr)	odenpop	odenpop	-	-
b20	odenemp (wk, tr)	odenemp	odenemp	-	-
b21	ddenpop (wk, tr)	ddenpop	ddenpop	-	-
b22	ddenemp (wk, tr)	ddenemp	ddenemp	-	-
b23	opct1way (dr)	-	-	-	opct1way
b24	dpct3wup (dr)	-	-	-	dpct3wup
b25	oentropy (wk, tr)	oentropy	oentropy	-	-
b26	dentropy (wk, tr)	dentropy	dentropy	-	-
b27	odenseat (tr)	-	odenseat	-	-
b28	ddenseat (tr)	-	ddenseat	-	-
b29	trseats (tr)	-	trseats	-	-

Table 4.5b: Mode Choice Model for Home-Based Work Trips

Variable List	Estimated Coefficient	Standard Error	t-Statistic
constant (wk)	**-1.5473**	**0.524**	**-2.95**
constant (tr)	**-2.6347**	**0.541**	**-4.87**
constant (cp)	**-1.61**	**0.455**	**-3.54**
wktime (wk)	**-2299.65**	**231.056**	**-9.95**
ttime (tr)	**-0.0125**	**0.004**	**-3.04**
ivtime (cp)	**-0.0548**	**0.006**	**-9.24**
ivtime (dr)	**-0.0485**	**0.005**	**-10.24**
fare (tr)	**-69.020**	**19.463**	**-3.55**
ttcost (cp)	**-168.373**	**25.744**	**-6.54**
ttcost (dr)	**-106.223**	**11.835**	**-8.98**
young (wk)	**0.8080**	**0.181**	**4.47**
empfull (dr)	***0.2013***	***0.122***	***1.65***
owner (dr)	**0.3973**	**0.110**	**3.62**
femnokid (tr)	0.2333	0.144	1.62
vehown (dr)	**1.0079**	**0.148**	**6.79**
vehown (cp)	**0.4750**	**0.178**	**2.67**
CBD (tr)	**0.8472**	**0.179**	**4.72**
CBD (cp)	**1.1676**	**0.255**	**4.58**
odenpop (wk, tr)	**0.01022**	**0.00299**	**3.42**
odenemp (wk, tr)	0.00120	0.00134	0.89
ddenpop (wk, tr)	**0.00390**	**0.00161**	**2.42**
ddenemp (wk, tr)	**0.00107**	**0.00025**	**4.20**
opct1way (dr)	-0.4996	0.891	-0.56
dpct3wup (dr)	***-1.0779***	***0.586***	***-1.84***
oentropy (wk, tr)	-0.0493	0.245	-0.20
dentropy (wk, tr)	***-0.3819***	***0.233***	***-1.64***
odenseat (tr)	-0.00012	0.00010	-1.25
ddenseat (tr)	0.00003	0.00003	1.22
trseats (tr)	**0.00041**	**0.00018**	**2.28**

Log likelihood = -1793.1
Number of observations = 2941
Percent correctly predicted = 78.8
Pseudo r-squared = 0.47
Pseudo adjusted r-squared = 0.46

NOTE:
Coefficients in boldface are significant with 95% confidence.
Coefficients in boldface and italic are significant with 90% confidence.
wk: walk mode; tr: transit; cp: car pool; dr: drive alone

Land use intensity and urban form indicators measured at trip destinations are all statistically significant. The positive coefficients of density variables (DDENPOP and DDENEMP) reveal that, when travel time, costs, transit supply and other factors are controlled, people working in places where employment and population densities are higher prefer transit or non-motorized means to driving in commuting. The same set of land use variables shows mixed results when measured at trip origins or travelers' home zones. People living in areas with higher population density (ODENPOP) tend to choose transit or non-motorized means to travel to work. Employment density at trip origins (ODENEMP), on the other hand, seems irrelevant to people's decisions on travel means to work.

It has been hypothesized that, if the built environment is configured in a rather connected form and if there is a large share of non-cul-de-sac intersections, driving mode is less likely to be chosen. In this analysis, the urban form factor at trip destination (DPCT3WUP) does show significant negative association with the probabilities of driving-alone or car-pooling. On the other hand, at trip origins, the effect of urban form on mode choice (OPCT1WAY) does not enter as significant. It is likely that the urban form indicators measured at the zonal level do not offer sufficient sensitivity to the micro influence of the built environment on people's mode choice behavior. Nevertheless, caution should be exercised when policy implications are drawn based on the performance of the urban form indicators similar to those used here (detailed discussion in Chapter 6).

The entropy measures of land use balance (OENTROPY, DENTROPY) perform poorly in this home-based work trip model. They both have unexpected, negative signs, which is counter-intuitive. One explanation may be that we are looking at home-based work trips only. Intuitively, if our travel purposes were to go to work places only, whether or not there was a balance of different types of land use at work places should not matter much to our consideration of travel means. It might matter if our trips were for non-work purposes and/or we considered chaining different activities together. Another explanation may be the possible measurement errors. The entropy indexes are calculated here using the TAZ as the spatial units, which vary in size from the central city to the suburbs. In the central city, a TAZ may contain a sew city blocks. In the suburbs, a TAZ may be as large as an entire town or city. The potential problem relating to varying sizes of TAZ can be avoided by rasterizing the TAZ coverage and calculating entropy indicators at a grid-cell basis. It is not done in this study as it will require substantial extra computing power and time.

Notably, average zonal transit supply (ODENSEAT and DDENSEAT) does not show significant influence on mode choice. What is important is the transit supply (TRSEATS measured in seats available) in the immediate vicinity of travelers' trip origins.

4.3 Individual Trip Frequency and the Role of Land Use

Analyzing and modeling individual trip frequency helps answer our second research question on whether land use 'causes' changes in travel behavior. It is both a theoretical and an empirical question that is of special importance to understand the role of land use as a mobility tool.

The analysis is done in two steps. First, we provide a qualitative reasoning about land use/travel behavior relationships based on two theories. One is the standard travel demand theory. The other is the theory of discrete choice. Second, we estimate empirical models to test the importance of land use attributes in affecting individual trip making using the ordered logit regression techniques.

- **Qualitative Reasoning on Land Use Affecting Travel Behavior**

What is the theoretical foundation of land use affecting individual travel demand? Standard theory states that an individual's travel demand is derived from his/her demand for engaging in activities or consuming services, such as work, shops, and schools. These activity and service opportunities are distributed over space, constituting the basic functional components of the built environment. Because these services and opportunities are separated by space, consuming them requires the consumption of transportation services at the intermediate stage in order to overcome the spatial separation. Consequently, the amount of transportation services needed (i.e. travel demand) depends on three factors: 1) the need to consume the end services relating to work, shopping, and schooling, which in turn relates to the individual's social-demographic characteristics like income, age, gender, occupation, and family structure; 2) the attractiveness of the end services in terms of price, quantity and quality of services and opportunities at travel destinations; and 3) the price, quantity and quality of transportation services.

Land use patterns, conventionally characterized by development intensity, integration and urban form, are spatial manifestation of urban services and activities. Variations in land use patterns certainly have effects on travel patterns. Will decrease or increase in land development intensity cause corresponding travel demand increase or decrease? The answer is not straightforward and the picture is rather complex because of the interactions among the three factors relating to travel demand.

When land is developed at a lower intensity, services and opportunities are more dispersed. If the basic needs to access the services and opportunities are fixed, for example, the need to go to work and school, a more dispersed land use pattern means longer travel on a per trip basis. It means more travel demand. For other needs that have certain flexibilities, for example, shopping, leisure and entertaining, individuals may reduce the frequency of visits to those places to balance the increased spatial separation, which eventually translates to higher costs. The net change in total travel demand is thus unclear, although in the long term there is a tendency of travel increase because the impacts of higher travel costs diminish when income grows.

The opposite case is when land is developed at a higher intensity. More intensive development means higher concentration of urban services and opportunities within a given amount of space. It also means increased proximity among the locations of homes and services and opportunities, or increased ease to reach the services and opportunities. On a per trip basis, travel cost decreases. The total travel, however, may not decrease because decreased spatial separation translates to savings in travel, which may be re-invested to make more frequent trips. This is especially likely for those trip purposes with flexibilities. Even for inflexible trip making such as go to work, when it is so convenient to travel between home and work, people may also make more trips, for example, by going home for lunch.

The above reasoning suggests that land use affects various aspects of travel. The net effects of changing land use patterns on travel demand, however, is unclear.

An alternative, plausible explanation to why land use may 'cause' changes in travel behavior, especially the mode choice behavior, can be provided based on the behavioral framework of the discrete choice theory upon which this research is built.

The choice theory suggests that a traveler's preference or probability of choosing a specific travel mode is determined by the satisfaction or utility level s/he gains from that mode *relative* to other modes. Any factor that affects the relative utility levels associated with available modes thereafter affects the traveler's decision making. Commonly considered factors include the traveler's social and demographic characteristics (e.g., gender, age, family structure), the household resource constraints s/he faces (e.g. income and time), and the performance of transportation services--in the mode choice case, the supply quantity and quality of available travel modes.

Land space is itself an important component of transportation supply. Any ground transportation requires land spaces to carry flows of goods or passengers. Some, such as motorized means, are generally more space-demanding than others. One task of land use planning and design is to allocate or supply land spaces for transportation infrastructure such as highways, streets, railroads, terminals that serve, connect, and organize other land use activities like industrial, commercial, residential and recreational. Varying in levels of detail depending on the nature and scope of projects, land use planning and design specify (or suggest) types and layout of links (e.g., arterial, collector or local roads), road and intersection spacing, width of right-of-way, station siting. (In practice, especially in the US, land use and transportation planning have largely been separate operations.) At the finer scale, such as area planning or subdivision design, laying out the circulation systems for vehicles and pedestrians is a key step of the process. How land spaces are allocated across different transportation systems, either by design or by regulations, has direct effects on modal supply. For example, allocating more land for parking spaces benefits motor vehicle users (only). Bus riders are better off if provided with exclusive bus ways or lanes. Biking and walking become more viable and attractive with the provision of designated bike paths or car-free zones or routes.

At the micro scale, the design quality of the physical environment is also part of the quality of modal supply, affecting the safety, comfort and convenience of transportation services. The design of cross-sections of roads, intersections, signs and signals, pavement, etc. all directly relate to road use. Similarly, the width and paving of pedestrian or bike paths, lighting, and the design of bus stop or train station all affect the supply quality of the walk, bike, and transit modes. From the transportation service perspective, improved urban design with a more pedestrian- or cyclist-friendly environment means improved quality of walk or bike modal supply.

At the macro scale, variation in land use patterns differentiates costs of supply across modes. For example, lower density means higher costs of travel for all modes due to increased spatial separation, but may result in higher marginal costs for transit supply due to the reduced pool of potential transit riders in the given area. The marginal costs to walking, biking, and other non-motorized modes are also greater than that of driving because they are more sensitive to changes in spatial separation than are the motorized modes. Attributes of land use affect modal supply in a way analogous to the effects of factor input on firms' production or costs. Lower density implies higher 'factor price' for modal supply, with higher incremental costs associated with transit compared to automobile.

In the US, no urban community is free of some kind of land use control exercised by the local governments. Existing land use patterns are by no means the outcome of free markets. Carrying the regulatory constraints imposed by the society over the allocation and design of spaces, land use planning can further alter the supply quantity, quality of spaces for the use of different transportation means, and thus their marginal costs of supply.

In Sum, land use influences people's travel behavior by having differentiated impacts on different modes in such respects as the quantity, quality, and marginal cost of modal supply.

- **Trip Frequency Modeling Using Ordered Logit Regression**

An empirical question to test land use's effects on travel is whether modifying land use patterns through densification, higher degree of mix, and alternative design of urban form will induce or suppress trip making. Common sense suggests that, if a store is nearby, people tend to visit it more frequently than if it is farther away. From policy making perspective, if improved accessibility resulting from modified land use induces more trips, the net benefit of land use on travel would diminish or disappear. In this empirical study, we would like to answer the following questions:

- Are people who live or/and work in denser areas likely to travel more frequently? If so, do they tend to make more driving trips, non-driving trips, or both?
- In which way the network configuration (i.e. the urban form) affects driving and non-driving trip rates?
- How do the balance and mixture of different land uses contribute to individuals' trip frequency?

The empirical tests are done through travel demand modeling applying the ordered logit regression, or *ologit*, (see Chapter 3 for detailed description on ologit method). The data sets are obtained from the 1991 Trip Diary Survey by aggregating all observations for each individual household member. They also break down by modes, i.e. driving vs. non-driving, and by trip purpose, i.e. total trips vs. non-work trips. Only home-based trips are included. The final data sets for modeling contain the dependent variables (number of trips made during the period of survey) by mode and purpose, and the independent variables including individual characteristics, land use and transportation attributes. In all models estimated, the dependent variable *trip frequency* takes one of four values: 1: making one trip; 2: making two trips; 3: making three trips; and 4: making four or more trips. (Note that since the dependent variable is treated as categorical in this case, whether it is coded as 1, 2, 3, 4 or as 12, 17, 20, 35 makes no difference, as long as they are in correct order.) For trip-specific variables such as trip distance and time, average values of all trips are taken.

Table 4.6 shows the ologit modeling results for all trips by all driving and non-driving modes. Interpretation of the results is analogous to the ordinary linear multiple regression except that the independent variables are interpreted as affecting the *odds* of making more trips, rather than generating more trips in absolute numbers. (Alternatively, we may record trip frequency as real number of trips made by individuals and estimate ordinary linear regression models. The advantage of using ordered logit is better shown when generalized ordered logit is applied in which we are able to differentiate the effects of the independent variables among different frequencies of trip making. See details in the following section.)

Trip time and distance indicating the costs of travel have significant, negative effects on travel demand. A person in a larger household tends to make more trips, probably because there are more home duties when there are more people around. A female with children tends to travel more, but the estimated coefficient does not show statistical significance. Note that urban form affects travel demand in different ways depending on the locations: trip origins or trip destinations. At trip origins, more cul-de-sac configurations of urban form reduces the odds of making more trips, while the opposite is true at destination zones. When trip distance is controlled for, the presence of more cul-de-sac intersections at home zones means inconvenience, a negative factor degenerating travel demand. At trip destination zones, having more cul-de-sac intersections may suggest convenience, for example, for parking, a positive factor encouraging more incoming trips.

Higher population density at home zones tend to generate more trips, as expected. Interestingly, population and employment densities at trip destination zones are negatively associated with individual trip making.

The three cut points, Cut Point 1, 2, and 3, correspond to three constant coefficients (also called "ancillary parameters) identified by Stata. They define the four outcome categories of 'one trip', 'two trips', 'three trips', and 'four or more trips' and are used to calculate each individual's probabilities of making 1, 2, 3, 4 or more trips.

Table 4.6 also reports the results of ologit modeling of travel demand for non-work trips. Costs and household size variables perform similarly to those in the all-trip model. Notably, female with children becomes significant. Obviously, female with kids travels more frequently because her needs to stop by daycare centers or to see doctors. Note that the urban form at home zones no longer has significant influence on travel demand. The effect of destination job density also becomes marginal because it is not directly relevant to non-work trip making.

Table 4.6 Ordered Logit Model of Trip Frequency: All Modes

	ALL TRIPS			**NON-WORK TRIPS**		
	Coef.	**Std. Err.**	**z**	**Coef.**	**Std. Err.**	**z**
Trip Time	-0.0319	0.0025	-12.81	-0.0092	0.0027	-3.37
Trip Distance	-0.0318	0.0076	-4.17	-0.0390	0.0114	-3.41
Park & Ride	-0.0758	0.1642	-0.46	-0.1838	0.2028	-0.91
Housing Owner	-0.0483	0.0610	-0.79	0.0247	0.0745	0.33
Housing Size	0.1063	0.0203	5.22	0.1021	0.0240	4.26
Female with Kids	0.0874	0.0983	0.89	0.4555	0.1058	4.31
% Cul-de-Sac (Orig.)	-1.7180	0.5180	-3.32	-0.6500	0.6613	-0.98
% Cul-de-Sac (Dest.)	2.9694	0.6157	4.82	2.3036	0.7717	2.99
Pop. Density (Orig.)	0.0037	0.0012	3.13	0.0058	0.0015	3.77
Pop. Density (Dest.)	-0.0013	0.0011	-1.26	-0.0003	0.0012	-0.27
Job Density (Orig.)	0.0000	0.0005	0.03	-0.0004	0.0007	-0.61
Job Density (Dest.)	-0.0016	0.0003	-5.84	-0.0006	0.0003	-1.78
Land Mix (Orig.)	0.1233	0.1049	1.18	-0.0344	0.1288	-0.27
Land Mix (Dest.)	0.8218	0.1084	7.58	0.8620	0.1313	6.57
Cut Point 1	0.3279	0.1670		1.3084	0.1930	
Cut Point 2	2.2425	0.1703		2.9255	0.1982	
Cut Point 3	3.9713	0.1844		4.5714	0.2159	
Number of obs.			5542			3791
LR chi-squared			789.71			189.03
Prob > chi-squared			0.000			0.000
Pseudo R-squared			0.0674			0.02
Log likelihood			-5461.56			-3742

To see how trip making by different modes relate to land use attributes, we re-estimate the same models for the driving mode (including drive-alone and car-pool) and the non-driving mode (including rail, bus, taxi, bike, and walk). The results are reported in Table 4.7 and 4.8 below. Main observations are highlighted as follows:

- Individual and household characteristics (e.g. age, household size, and employment status) and trip costs (time and distance) are the major factors that generate (or degenerate) individual trips.

- Higher densities at destinations consistently discourage driving for total trips and for non-work trips as well. Urban form indicators do not enter statistically significant for non-work travel demand, although they do appear important in the all-trip model. Principle explanation for this observation may be that, for non-work trip making, the destinations spread in different places due to the variety of non-work activities (e.g. eating out, shopping, visiting doctors). Therefore there are no systematic regularities in trip making relating to the network patterns. The estimated effects of land use mix on trip making are not reliable due to possible measurement errors in the calculation on the entropy indexes mentioned earlier in the mode choice analysis.

- For non-driving travel, supplying 'park-n-ride' spaces has positive effects on travel demand. More transit supply in terms of daily seats available in the immediate vicinity of trip origins are associated with larger demand of non-driving travel.

- Land use variables in the non-driving, all-trip model perform in a similar way to those in the driving-model. For the non-driving, non-work trips, however, they perform poorly. *The results imply that land use strategies may be effective in influencing commuting trips, which generally exhibit spatial and temporal regularities; but they may not be as effective in dealing with non-commuting trips unless the land use pattern of the entire metropolitan area is re-configured.*

Table 4.7 Ordered Logit Model of Trip Frequency: Non-Driving Modes

	ALL NON-DRIVING TRIPS			NON-WORK NON-DRIVING		
	Coef.	Std. Err.	z	Coef.	Std. Err.	z
Trip Time	-0.0279	0.0058	-4.80	-0.0222	0.0077	-2.89
Trip Distance	-0.1169	0.0471	-2.48	-0.0820	0.0676	-1.21
Park & Ride	0.8194	0.3935	2.08	0.5197	0.5286	0.98
Age 30 or Younger	0.4152	0.1335	3.11	0.3607	0.1753	2.06
Full Time Worker	-0.4374	0.1336	-3.27	-1.3731	0.2135	-6.43
% Cul-de-Sac (Orig.)	-2.0065	1.1001	-1.82	0.0101	0.0020	5.17
% Cul-de-Sac (Dest.)	2.4728	1.2949	1.91	-0.0001	0.0015	-0.07
Pop. Density (Orig.)	0.0061	0.0015	4.04	-0.8691	1.5045	-0.58
Pop. Density (Dest.)	0.0014	0.0012	1.25	-0.0621	1.7689	-0.04
Land Mix (Orig.)	-0.0976	0.2340	-0.42	-0.0381	0.3065	-0.12
Land Mix (Dest.)	1.0532	0.2172	4.85	0.7916	0.3032	2.61
Transit Seat Supply	0.0191	0.0066	2.91	0.0172	0.0088	1.96
Cut Point 1	1.6282	0.3144		1.6674	0.4040	
Cut Point 2	3.9524	0.3423		3.7708	0.4347	
Cut Point 3	5.5326	0.4217		5.4745	0.5299	
Number of obs.			1575			951
LR chi-squared			291.12			163
Prob > chi-squared			0.00			0.00
Pseudo R-squared			0.1383			0.12
Log likelihood			-907			-574

Table 4.8 Ordered Logit Model of Trip Frequency: Driving Modes

	ALL NON-DRIVING TRIPS			NON-WORK DRIVING TRIPS		
	Coef.	**Std. Err.**	**z**	**Coef.**	**Std. Err.**	**z**
Trip Time	-0.0296	0.0033	-9.01	-0.0054	0.0027	-2.01
Trip Distance	-0.0247	0.0087	-2.85	-0.0337	0.0125	-2.70
Housing Owner	0.1283	0.0804	1.60	0.2096	0.1015	2.06
Housing Size	0.1096	0.0244	4.48	0.0925	0.0293	3.16
Female with Kids	0.1715	0.1073	1.60	0.4729	0.1157	4.09
% Cul-de-Sac (Orig.)	-2.0315	0.6778	-3.00	-1.1415	0.8633	-1.32
% Cul-de-Sac (Dest.)	2.0407	0.7808	2.61	1.3543	0.9980	1.36
Pop. Density (Orig.)	-0.0055	0.0028	-1.95	-0.0043	0.0036	-1.18
Pop. Density (Dest.)	-0.0133	0.0031	-4.33	-0.0112	0.0040	-2.79
Job Density (Orig.)	-0.0003	0.0017	-0.20	-0.0002	0.0021	-0.08
Job Density (Dest.)	-0.0027	0.0009	-3.15	-0.0020	0.0012	-1.66
Land Mix (Orig.)	0.0691	0.1282	0.54	0.0077	0.1580	0.05
Land Mix (Dest.)	0.8385	0.1342	6.25	0.8333	0.1623	5.13
Cut Point 1	0.2939	0.2268		1.1229	0.2692	
Cut Point 2	2.1263	0.2303		2.7480	0.2743	
Cut Point 3	3.8316	0.2457		4.3481	0.2932	
Number of obs.			4045			2795
LR chi-squared			496.4			166.40
Prob > chi-squared			0.00			0.00
Pseudo R-squared			0.0599			0.03
Log likelihood			-3898			-2621

- **Trip Frequency Modeling Using Generalized Ordered Logit Regression**

Above travel demand analysis gives us a general picture of how important various social and spatial factors are to individuals' trip making by different modes and for different trip purposes. One restriction of the method is that it assumes constant marginal effects of the independent variables on all categories of the dependent variable, namely the *proportional odds assumption*. For example, in the all-driving trip model (Table 4.6), the estimated coefficient for household size is 0.1096, meaning that one addition to a household (e.g. a new born) would increase the odds of making at least two trips (vs. making only one trip) by about 12% (calculated as EXP(0.1096) =1.12 or 12% increase). The proportional odds assumption means the increment in household size would have the same effect of 12% odds increase in making at least three trips vs. making two or less trips, same effect of 12% odds increase in making at least four trips vs. making three or less trips, and so on.

In this section, the proportional odds restriction is relaxed in order to further investigate what factors are most responsible for generating higher individual travel demand. The analysis is extended by estimating generalized ordered logit models (See Chapter 3 for detailed description of this method).

Same sets of models as with ologit are estimated. Here we pay special attention to the driving trip models. Results for other models are also included for comparison with the ologit modeling results.

Table 4.9 shows results for trip making by driving modes for all and non-work trip purposes. Since there are four categories of trip frequencies (making 1, 2, 3, and 4 or more trips), three blocks of estimated coefficients with the same set of explanatory variables are generated. The coefficients under the heading *Block 1* correspond to the first dividing point between making one trip or making at least two trips. The coefficients under the heading *Block 2* correspond to the second dividing point between making two or less trips or making at least three trips. Similarly, the coefficients under the heading

Block 3 correspond to the third dividing point, between making three or less trips or making at least four trips. Examining the changes in magnitude and statistical significance of the coefficients associated with the same variables across the three blocks enable us to find out what factors attribute to more frequent travel.

The estimated coefficients in the first block appear very close to what we have obtained with ologit reported in the preceding section. In the second block, the urban form variables (i.e., % of cul-de-sac intersection at origins and destinations) no longer show statistical significance. Nor does the population density at home zones. What remain important to people in making two or more trips are the cost variables (trip time and distance), household size, population density and land use mix at destination zones. Under the heading *Block 3*, most land use variables become irrelevant except land use mix at destination as a trip generator and population density at origins as a trip degenerator. Cost factors and individual and household characteristics are mostly responsible to more frequent trip making.

For non-work, driving trips, travel demand is not as sensitive to trip time and distance as for total trips, which include commuting trips. Three variables that have consistently important influence on non-work driving trips are household size, female with children, and destination land use mix.

Table 4.9 Generalized Ordered Logit Model of Trip Frequency: All Modes

		ALL TRIPS			NON-WORK TRIPS		
		Coef.	Std. Err.	z	Coef.	Std. Err.	z
Block 1	Trip Time	-0.0277	0.0025	-11.06	-0.0070	0.0026	-2.74
	Trip Distance	-0.0326	0.0077	-4.21	-0.0419	0.0114	-3.67
	Park & Ride	-0.0529	0.1745	-0.30	-0.1519	0.2090	-0.73
	Housing Owner	-0.0982	0.0652	-1.51	0.0394	0.0773	0.51
	Housing Size	0.0892	0.0218	4.10	0.0986	0.0249	3.95
	Female with Kids	0.0531	0.1060	0.50	0.4234	0.1129	3.75
	% Cul-de-Sac (Orig.)	-1.8317	0.5473	-3.35	-0.4243	0.6846	-0.62
	% Cul-de-Sac (Dest.)	3.2334	0.6388	5.06	2.3486	0.7892	2.98
	Pop. Density (Orig.)	0.0033	0.0012	2.61	0.0058	0.0016	3.60
	Pop. Density (Dest.)	-0.0015	0.0011	-1.45	-0.0003	0.0012	-0.29
	Job Density (Orig.)	0.0001	0.0005	0.28	-0.0002	0.0007	-0.30
	Job Density (Dest.)	-0.0016	0.0003	-5.68	-0.0006	0.0003	-1.76
	Land Mix (Orig.)	0.0836	0.1118	0.75	-0.0964	0.1339	-0.72
	Land Mix (Dest.)	0.8676	0.1137	7.63	0.8681	0.1353	6.41
	Constant	-0.3507	0.1750	-2.00	-1.3480	0.1988	-6.78
Block 2	Trip Time	-0.0607	0.0053	-11.36	-0.0329	0.0064	-5.18
	Trip Distance	-0.0320	0.0164	-1.95	-0.0095	0.0199	-0.48
	Park & Ride	-0.0422	0.2617	-0.16	-0.2291	0.3262	-0.70
	Housing Owner	0.0624	0.0923	0.68	-0.0938	0.1098	-0.85
	Housing Size	0.1295	0.0290	4.47	0.1003	0.0351	2.86
	Female with Kids	0.0834	0.1321	0.63	0.4975	0.1420	3.50
	% Cul-de-Sac (Orig.)	-0.8427	0.8434	-1.00	-1.6051	1.0679	-1.50
	% Cul-de-Sac (Dest.)	1.2604	1.0712	1.18	1.9886	1.3243	1.50
	Pop. Density (Orig.)	0.0058	0.0020	2.93	0.0074	0.0025	3.00
	Pop. Density (Dest.)	-0.0010	0.0016	-0.59	-0.0002	0.0017	-0.12
	Job Density (Orig.)	-0.0011	0.0013	-0.84	-0.0038	0.0019	-1.99
	Job Density (Dest.)	-0.0028	0.0008	-3.56	-0.0009	0.0007	-1.23
	Land Mix (Orig.)	0.2067	0.1596	1.30	0.2267	0.1963	1.15
	Land Mix (Dest.)	0.6331	0.1761	3.59	0.8080	0.2108	3.83
	Constant	-1.8041	0.2560	-7.05	-2.5278	0.3024	-8.36
Block 3	Trip Time	-0.0969	0.0142	-6.81	-0.0696	0.0177	-3.94
	Trip Distance	-0.0911	0.0498	-1.83	-0.0340	0.0618	-0.55
	Park & Ride	-1.3177	1.0121	-1.30	-0.9624	1.0157	-0.95
	Housing Owner	0.2871	0.1964	1.46	0.2323	0.2332	1.00
	Housing Size	0.2100	0.0575	3.65	0.2110	0.0696	3.03
	Female with Kids	0.3780	0.2271	1.66	0.5100	0.2574	1.98
	% Cul-de-Sac (Orig.)	-1.5185	1.8410	-0.82	-1.0863	2.3337	-0.47
	% Cul-de-Sac (Dest.)	0.3039	2.3818	0.13	2.2093	3.1425	0.70
	Pop. Density (Orig.)	0.0050	0.0041	1.23	0.0074	0.0053	1.39
	Pop. Density (Dest.)	0.0025	0.0035	0.71	0.0047	0.0049	0.97
	Job Density (Orig.)	-0.0008	0.0035	-0.24	-0.0017	0.0049	-0.34
	Job Density (Dest.)	-0.0033	0.0022	-1.49	-0.0040	0.0035	-1.13
	Land Mix (Orig.)	0.2321	0.3238	0.72	0.2460	0.3990	0.62
	Land Mix (Dest.)	0.6883	0.3877	1.78	0.9075	0.4594	1.98
	Constant	-3.3363	0.5470	-6.10	-4.6067	0.6846	-6.73
	Number of obs.			5542			3791
	LR chi-squared			907.09			242.83
	Prob > chi-squared			0.00			0.00
	Pseudo R-squared			0.08			0.03
	Log likelihood			-5403			-3715

Table 4.10 Generalized Ordered Logit Model of Trip Frequency: Driving Modes

		ALL NON-DRIVING TRIPS			NON-WORK DRIVING		
		Coef.	Std. Err.	z	Coef.	Std. Err.	z
Block 1	Trip Time	-0.0260	0.0033	-7.89	-0.0043	0.0025	-1.75
	Trip Distance	-0.0247	0.0087	-2.82	-0.0347	0.0125	-2.78
	Housing Owner	0.0939	0.0840	1.12	0.2254	0.1037	2.17
	Housing Size	0.0787	0.0257	3.06	0.0823	0.0302	2.73
	Female with Kids	0.1553	0.1144	1.36	0.4440	0.1220	3.64
	% Cul-de-Sac (Orig.)	-2.0801	0.7068	-2.94	-0.8671	0.8819	-0.98
	% Cul-de-Sac (Dest.)	2.1888	0.8011	2.73	1.4355	1.0142	1.42
	Pop. Density (Orig.)	-0.0059	0.0029	-2.08	-0.0034	0.0036	-0.95
	Pop. Density (Dest.)	-0.0132	0.0031	-4.28	-0.0110	0.0040	-2.73
	Job Density (Orig.)	-0.0003	0.0017	-0.20	-0.0002	0.0021	-0.12
	Job Density (Dest.)	-0.0028	0.0009	-3.20	-0.0020	0.0012	-1.70
	Land Mix (Orig.)	0.0196	0.1347	0.15	-0.0443	0.1628	-0.27
	Land Mix (Dest.)	0.8290	0.1388	5.97	0.8053	0.1659	4.85
	Constant	-0.2202	0.2361	-0.93	-1.1420	0.2744	-4.16
Block 2	Trip Time	-0.0545	0.0069	-7.88	-0.0215	0.0080	-2.68
	Trip Distance	-0.0347	0.0189	-1.83	-0.0156	0.0243	-0.64
	Housing Owner	0.2857	0.1334	2.14	0.1056	0.1613	0.65
	Housing Size	0.1811	0.0348	5.21	0.1189	0.0440	2.70
	Female with Kids	0.1551	0.1467	1.06	0.5262	0.1598	3.29
	% Cul-de-Sac (Orig.)	-1.2777	1.1337	-1.13	-2.6682	1.4682	-1.82
	% Cul-de-Sac (Dest.)	0.7844	1.4257	0.55	0.9985	1.8153	0.55
	Pop. Density (Orig.)	-0.0003	0.0057	-0.05	-0.0106	0.0080	-1.34
	Pop. Density (Dest.)	-0.0178	0.0071	-2.51	-0.0133	0.0087	-1.53
	Job Density (Orig.)	-0.0013	0.0038	-0.36	-0.0008	0.0052	-0.15
	Job Density (Dest.)	-0.0023	0.0025	-0.91	-0.0015	0.0032	-0.45
	Land Mix (Orig.)	0.2138	0.2008	1.07	0.2175	0.2523	0.86
	Land Mix (Dest.)	0.7834	0.2272	3.45	0.9494	0.2794	3.40
	Constant	-2.1231	0.3701	-5.74	-2.4076	0.4439	-5.42
Block 3	Trip Time	-0.0730	0.0172	-4.24	-0.0240	0.0209	-1.15
	Trip Distance	-0.1292	0.0571	-2.26	-0.1084	0.0713	-1.52
	Housing Owner	0.4023	0.2823	1.43	0.2590	0.3594	0.72
	Housing Size	0.2710	0.0680	3.98	0.2484	0.0879	2.83
	Female with Kids	0.4983	0.2540	1.96	0.6008	0.2909	2.07
	% Cul-de-Sac (Orig.)	-3.1592	2.4804	-1.27	-3.5695	3.1655	-1.13
	% Cul-de-Sac (Dest.)	0.5792	3.4043	0.17	-1.3914	4.5109	-0.31
	Pop. Density (Orig.)	-0.0264	0.0142	-1.86	-0.0391	0.0241	-1.62
	Pop. Density (Dest.)	0.0147	0.0133	1.10	0.0024	0.0256	0.10
	Job Density (Orig.)	-0.0064	0.0182	-0.35	-0.0476	0.0306	-1.56
	Job Density (Dest.)	0.0012	0.0033	0.37	-0.0038	0.0081	-0.46
	Land Mix (Orig.)	0.1573	0.4395	0.36	0.5448	0.5553	0.98
	Land Mix (Dest.)	1.3030	0.4965	2.62	1.6890	0.6012	2.81
	Constant	-3.9415	0.7990	-4.93	-4.1542	0.9827	-4.23
	Number of obs.			4045			2795
	LR chi-squared			573.01			197.79
	Prob > chi-squared			0.00			0.00
	Pseudo R-squared			0.07			0.04
	Log likelihood			-3860			-2606

Table 4.11 Generalized Ordered Logit Model of Trip Frequency: Non-Driving

		ALL NON-DRIVING TRIPS			NON-WORK NON-DRIVIN		
		Coef.	Std. Err.	z	Coef.	Std. Err.	z
Block 1	Trip Time	-0.0263	0.0057	-4.57	-0.0208	0.0077	-2.72
	Trip Distance	-0.1223	0.0467	-2.62	-0.0857	0.0674	-1.27
	Park & Ride	0.8173	0.3976	2.06	0.4677	0.5312	0.88
	Age 30 or Younger	0.3859	0.1351	2.86	0.3093	0.1780	1.74
	Full Time Worker	-0.3735	0.1350	-2.77	-1.3613	0.2145	-6.35
	% Cul-de-Sac (Orig.)	-1.8764	1.1167	-1.68	0.0093	0.0021	4.48
	% Cul-de-Sac (Dest.)	2.4668	1.3067	1.89	-0.0002	0.0015	-0.14
	Pop. Density (Orig.)	0.0052	0.0015	3.34	-0.5449	1.5279	-0.36
	Pop. Density (Dest.)	0.0013	0.0012	1.08	-0.2892	1.7954	-0.16
	Land Mix (Orig.)	-0.1074	0.2364	-0.45	-0.0197	0.3099	-0.06
	Land Mix (Dest.)	1.0268	0.2186	4.70	0.7768	0.3062	2.54
	Transit Seat Supply	0.0206	0.0067	3.08	0.0197	0.0089	2.22
	Constant	-1.6495	0.3170	-5.20	-1.6854	0.4079	-4.13
Block 2	Trip Time	-0.0469	0.0174	-2.69	-0.0326	0.0198	-1.65
	Trip Distance	-0.2012	0.1982	-1.02	-0.0705	0.2185	-0.32
	Park & Ride	0.6472	1.0733	0.60	1.1316	1.1306	1.00
	Age 30 or Younger	0.6042	0.3006	2.01	0.6513	0.3689	1.77
	Full Time Worker	-1.2637	0.3574	-3.54	-1.1503	0.4624	-2.49
	% Cul-de-Sac (Orig.)	-3.7568	2.6931	-1.39	0.0100	0.0033	3.06
	% Cul-de-Sac (Dest.)	0.2153	3.3836	0.06	0.0004	0.0028	0.12
	Pop. Density (Orig.)	0.0077	0.0028	2.73	-4.8884	3.4459	-1.42
	Pop. Density (Dest.)	0.0001	0.0025	0.03	1.1164	4.0804	0.27
	Land Mix (Orig.)	-0.2063	0.5279	-0.39	-0.2796	0.6381	-0.44
	Land Mix (Dest.)	1.3767	0.5385	2.56	1.1862	0.6568	1.81
	Transit Seat Supply	0.0085	0.0148	0.58	-0.0011	0.0198	-0.06
	Constant	-3.1036	0.8043	-3.86	-3.3963	0.9583	-3.54
Block 3	Trip Time	0.0975	0.1200	0.81	0.0418	0.0975	0.43
	Trip Distance	-5.6401	3.0775	-1.83	-1.7365	1.4854	-1.17
	Park & Ride	-5.2150	4160.19	0.00	-11.1212	3845.46	0.00
	Age 30 or Younger	1.8648	1.1667	1.60	1.4481	1.2862	1.13
	Full Time Worker	2.0560	1.5619	1.32	-0.4490	1.4533	-0.31
	% Cul-de-Sac (Orig.)	14.4181	9.3978	1.53	0.0227	0.0101	2.25
	% Cul-de-Sac (Dest.)	24.4309	14.7827	1.65	0.0064	0.0134	0.47
	Pop. Density (Orig.)	0.0221	0.0106	2.10	8.7156	12.0023	0.73
	Pop. Density (Dest.)	0.0089	0.0109	0.82	2.6186	17.3347	0.15
	Land Mix (Orig.)	-1.9730	1.8248	-1.08	-1.4788	2.4484	-0.60
	Land Mix (Dest.)	2.0323	2.5099	0.81	2.3905	2.3371	1.02
	Transit Seat Supply	-0.0111	0.0518	-0.21	-0.0470	0.0886	-0.53
	Constant	-10.6896	3.7598	-2.84	-8.2031	5.1663	-1.59
	Number of obs.			1575			951
	LR chi-squared			332.87			179.76
	Prob > chi-squared			0.00			0.00
	Pseudo R-squared			0.1581			0.14
	Log likelihood			-886			-565

4.4 Automobile Dependency and the Role of Land Use

In previous sections we analyze the effects of land use and transportation pricing factors on travel by modeling individuals' trip making and mode choice behavior. In this section, we go one step further and attempt to measure the degree to which individuals are dependent on their cars, or in other words, the extent in which they become captive to car use. Further, we try to explicitly account for factors explaining their automobile dependent behavior, paying particular attention to those factors related to the built environment.

The modeling of automobile dependency applies the same methodology as that in previous sections in terms of data sets, unit of analysis (i.e. individuals), and modeling framework (i.e. discrete choice analysis). To serve our specific study purposes, an extended logit modeling technique called 'captivity logit modeling' is utilized. The method is described and explained in detail in Section 3.4 of Chapter 3.

The analysis consists of two steps. First, we estimate single coefficient automobile dependence models, in which the coefficient captures the average degree to which an average person in a given geographic area (or in a given income group, or in any single market segment) is captive to driving. The general form of this set of models is shown in Equation 3.9 on page 80 in Chapter 3. Second, we re-estimate the models by formulating the indicator as a function of a number of factors that contribute to people's automobile dependency, and examine the effects of those factors. The general form of this set of parametrized automobile dependence models is shown in Equation 3.10, also on page 80 in Chapter 3.

All models are estimated using Stata 7.0, a statistical package developed by Stata, Corp. Appendix A.1.3 and A.2.3 report the estimation programs and procedures.

- **Measuring Automobile Dependency: Single Coefficient Captivity Logit Modeling**

A number of models are estimated with the full sample and with specific market segments differentiated by income and geographic locations of residence and travel destinations. For comparison purposes, we maintain the same specifications across all models. Variables are kept in the models even though in cases they enter as statistically insignificant. The focus of interpretation and discussion is primarily on the magnitude and statistical importance of the driving captivity indicators in these models. Below we show and interpret the results directly, leaving technical details of the modeling processes to the Appendix.

Model B1, shown in Table 4.12, represents the base model estimated with the full sample. The estimated captivity coefficient has a value of .292 at 99% level of significance level. It reads that, in the Boston metropolitan area, the odds of an individual being captive to automobile in travel for all home, work and leisure activities are 0.292. Speaking in probability terms, we may interpret the estimated coefficient as follows: on average, a Bostonian has a 23% chance being dependent on his/her car. [The formula for probability calculation using the odds ratio is: probability = odds / (1+ odds). In this model, probability = 0.292/(1+0.292) = 23%. See Chapter Three for detail.] With simple generalization, we may conclude from this estimation that, in aggregate, 23% of some four million people in the metropolitan Boston area are automobile dependent.

Model B2 estimates the automobile dependence of those who's work and non-work activities all take place in the suburb. (In this study the suburb refers to the cities and towns outside Route-128, or the areas beyond the second ring defined by the Boston MPO. See Figure 4.10) That is, they live in the suburban area, commute to work in the suburban area, and go shopping or eat out in places that are also located in the suburb. The odds that they are captive to cars are 5.987 (The estimate is statistically significant at 95% confidence level). In other words, there are 86% chances that suburban Bostonians depend on automobiles for their daily activities. They either have no options, or don't know other possible travel choices, or don't like other means to travel regardless.

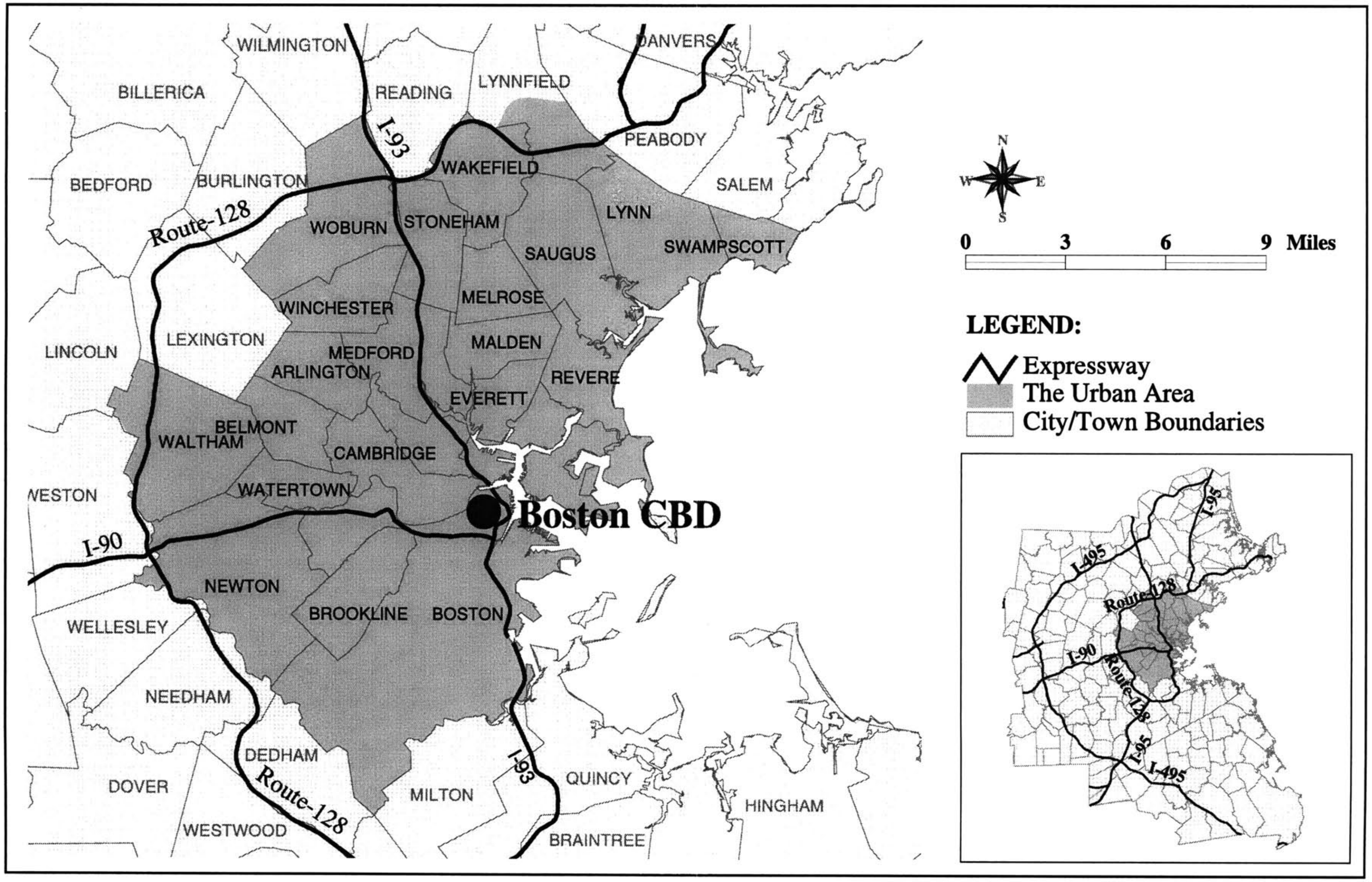
In contrast, Model B3 estimates the automobile dependence of those who's work and non-work activities all take place in the urban area. These people live, commute to work, and go shopping or eat out in places in or close to the urban center. As the model estimate shows, the odds that they are captive to cars are 0.193 (significant at 99% confidence level). In other words, there are 16% chances that the urban Bostonians depend on automobiles for their daily activities. Given the fact that the urban Boston has a quite extensive and efficient public transportation system, the urban Bostonian's 16% degree of automobile dependency cannot be attributed to the lack of travel alternatives. Other factors such as family constraints, perception, information, and/or habits may dominate.

Table 4.12

Single-Coefficient Automobile Dependency Model: All Trips by Locations

	B1: Region-wide		**B2: Suburb-to-Suburb**		**B3: Urban-to-Urban**	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1245	-17.11	-0.1068	-3.19	-0.1833	-13.32
Driving Cost	-0.1079	-4.89	19.0320	0.01	-0.0734	-4.61
Trip Distance	0.1235	6.82	0.2206	2.69	0.1398	2.66
CBD	-1.5266	-6.74			-0.9336	-3.7
Vehicles per Worker	1.0077	7	0.5638	1.88	1.3060	6.32
Full Time Worker	0.7124	4.49	1.0154	2.45	0.6086	2.74
Housing Owner	0.4521	3.06	1.1378	2.29	0.0159	0.08
Constant	3.0708	10.08	1.3950	1.53	3.2507	7.18
Non-Driving						
Trip Time	-0.0257	-5.97	-0.0131	-1.29	-0.0450	-5.71
Trip Cost	-0.0789	-4.68	-0.0242	-0.65	-0.1018	-3.94
Age 60 or Older	0.4678	2.23	0.6728	1.32	0.6740	2.3
Age 30 or Younger	1.0895	6.9	1.8178	3.61	1.3701	6.26
Transit Seat Supply	0.0431	5.51	-0.0012	-0.03	0.0387	3.61
Captivity Coefficient	**0.2923**	**6.46**	**5.9870**	**1.9**	**0.1934**	**5.02**
Number of obs		7158		3636		2464
Wald chi-squared (7)		470.39		22.84		244.19
Prob > chi-squared		0		0.001		0
Log likelihood		-1230.11		-294.69		-623.68

Figure 4.10 Boston Suburban-Urban Cities/Towns



Model B4~B6 reported in Table 4.13 estimate the automobile dependency of three income groups of the population, the high, the medium, and the low, respectively. The higher income is defined as with annual household income greater than $90,000 in 1991, whereas the lower income has an annual household income less than $30,000 and the medium income falls in between. The results show that, interestingly, the higher income is moderately captive to automobile with an odds ratio of 0.095, or a probability of 9% (statistically significant marginally at the 90% level). On the other hand, the odds ratios of being captive to automobile for the medium and low income groups are 0.285 and 0.264, or with probabilities of 22% and 21%, respectively.

Table 4.13 Single-Coefficient Automobile Dependency Model: All Trips by Income

	B4: High Income		**B5: Medium Income**		**B6: Low Income**	
	Coef.	***z-test***	***Coef.***	***z-test***	***Coef.***	***z-test***
Driving						
Driving Time	-0.1193	-8.4	-0.1014	-11.07	-0.1567	-9.54
Driving Cost	-0.2898	-3.7	-0.1621	-5.81	-0.1014	-4.12
Trip Distance	0.1174	3.28	0.1054	4.44	0.1427	3.36
CBD	-0.9674	-1.98	-1.5238	-4.82	0.3868	0.67
Vehicles per Worker	1.6067	4.1	0.7454	4.09	1.0916	3.58
Full Time Worker	0.8668	2.53	0.5718	2.62	0.9967	3.15
Housing Owner	0.3077	0.78	0.4352	2.17	0.4784	1.7
Constant	2.1025	2.66	3.3904	7.97	2.3190	4.01
Non-Driving						
Trip Time	-0.0277	-2.79	-0.0143	-2.62	-0.0508	-4.62
Trip Cost	-0.2794	-2.44	-0.0847	-2.19	-0.0891	-3.54
Age 60 or Older	0.8594	1.94	0.1668	0.54	0.4852	1.28
Age 30 or Younger	1.3670	3.94	0.9512	4.49	1.1370	3.55
Transit Seat Supply	0.0081	0.41	0.0407	3.64	0.0377	2.52
Captivity Coefficient	**0.0952**	**1.75**	**0.2852**	**4.59**	**0.2654**	**3.47**
Number of obs		1379		3973		1806
Wald chi-squared (7)		126.87		261.09		115.14
Prob > chi-squared		0.000		0.000		0.000
Log likelihood		-205.06		-659.43		-328.31

Above modeling is for all trip purposes. To test whether captive driving behavior varies by trip purposes, we re-estimate the same set of models described above, but stratifying the sample to home-based work (HBW) and home-based non-work trips (HBNW). The results are reported in Table 4.14~17. A number of observations are highlighted below.

Table 4.14

Single-Coefficient Automobile Dependency Model: Work Trips by Locations

	H1: Region-wide		**H2: Suburb-to-Suburb**		**H3: Urban-to-Urban**	
	Coef.	***z-test***	***Coef.***	***z-test***	***Coef.***	***z-test***
Driving						
Driving Time	-0.1106	-11.86	-1.1105	-1.52	-0.1812	-9.91
Driving Cost	-0.1897	-5.66			-0.0733	-3.31
Trip Distance	0.0927	4.21	4.6424	1.43	0.1567	2.64
CBD	-1.3741	-4.77			-1.0368	-3.26
Vehicles per Worker	1.3877	6.16	0.6951	0.36	1.5444	5.52
Full Time Worker	0.7072	2.57	-30.6904	-1.34	0.7170	1.98
Housing Owner	0.3717	1.7	3.5781	0.71	0.0764	0.3
Constant	2.6822	5.68	17.3772	1.15	2.5914	3.89
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Non-Driving						
Trip Time	-0.0210	-3.38	-0.5120	-1.37	-0.0436	-4.15
Trip Cost	-0.1065	-4.15	-0.7930	-0.88	-0.0935	-2.63
Age 60 or Older	0.0401	0.12	-23.9447	-1.22	0.0605	0.14
Age 30 or Younger	0.8751	3.63	38.0611	1.42	1.0604	3.63
Transit Seat Supply	0.0437	3.7	-3.6373	-1.28	0.0340	2.2
	-----------	---------	-----------	---------	-----------	---------
Captivity Coefficient	**0.2245**	**4.82**	**20.4981**	**3.55**	**0.0950**	**2.65**
Number of obs		2818		1196		990
Wald chi-squared (7)		236		2.37		122.44
Prob > chi-squared		0		0.795		0
Log likelihood		-599.13		-57.44		-310.11

- For suburb-suburb work trips, the estimated coefficients associated with the mode choice variables are all statistically equal to zero (Model H2 in Table 4.14). It is likely due to insufficient observations in the sample for non-driving trips. Nevertheless, the sign and magnitude of the captivity coefficient does suggest that suburban residents/workers are highly dependent on automobile for commuting.

One apparent explanation is that, due to historical reasons, the public transportation system (particularly rail transit) in the Boston region has been developed in a radial pattern serving mostly suburb-urban, urban-urban trips.

- The estimated automobile captivity coefficients for non-work activities are generally greater than those for work trips. For example, region-wide, the odds ratio of being captive to automobile for HBW trips is 0.224 (Model H1 in Table 4.14), whereas for HBNW trips, the ratio is 0.565 (Model N1 in Table 4.16). This conforms to the common knowledge that people tend to rely more on cars for non-work activities because these activities usually take place in various destination locations. The needs of non-work activities are generally better met by more flexible travel means such as private automobile.

- For commuting trips, the high and medium income groups do not appear to be captive to automobile, whereas the lower income group does (Table 4.15). This result is consistent with other studies finding the importance of the automobile in accessing jobs for the low income, minority people (Taylor and Ong, 1995; Ong, 1996; Shen, 1998). The result can be explained by the occupational characteristics of different income groups. It is generally the case that a significant portion of the lower income drivers works on the part-time jobs or the jobs with multiple locations (e.g. cleaning, delivery). These jobs demand frequent and flexible travel typically in the non-peak hours when public transportation services, if any, are less available. Private transportation means thus becomes a necessity. On the other hand, the higher income people typically have stable jobs with regular work hours at fixed locations, for example, in the downtown area. These trips, having certain spatial and temporal regularities, are well served by the subway and the commuter rail in the region. Furthermore, the growing congestion in the central Boston area, especially during the rush hours, makes transit services relatively more attractive. All these factors help the regular commuters become less dependent on their own transportation.

- For non-work travel, the higher income group does not show significant captivity to driving, but the medium and the lower income groups do, with captivity probabilities between 45% and 23%, respectively. Possible explanation to the high income people's non-automobile dependency for their non-work travel is that their income is high enough to allow them not to drive by themselves for social, leisure, and other non-work-related activities—they may ride on taxi, hire limos, and use other luxury travel means.

Table 4.15

Single-Coefficient Automobile Dependency Model: Work Trips by Income

	H4: High Income		**H5: Medium Income**		**H6: Low Income**	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1090	-6.53	-0.0825	-6.93	-0.1643	-5.88
Driving Cost	-0.3476	-3.47	-0.1660	-4.39	-0.3126	-3.85
Trip Distance	0.1277	3.05	0.0486	1.38	0.1208	1.62
CBD	-0.9923	-1.62	-1.4378	-3.83	2.3171	1.56
Vehicles per Worker	1.3504	2.75	1.0152	3.7	2.1992	3.03
Full Time Worker	0.9404	1.62	0.5832	1.74	1.1018	1.6
Housing Owner	0.2569	0.48	0.4238	1.7	0.7888	1.31
Constant	1.6990	1.58	2.8717	5.05	2.3840	1.93
Non-Driving						
Trip Time	-0.0274	-2.12	-0.0140	-1.71	-0.0691	-2.86
Trip Cost	-0.2623	-1.79	-0.0976	-2.01	-0.0836	-1.55
Age 60 or Older	-0.0375	-0.06	-0.0908	-0.2	1.1260	1.28
Age 30 or Younger	1.1883	2.67	0.6184	2.26	1.0631	1.42
Transit Seat Supply	-0.0142	-0.53	0.0440	3.17	0.0902	2.72
Captivity Coefficient	**0.0368**	**0.99**	**0.0925**	**1.00**	**0.3237**	**3.79**
Number of obs		558		1573		687
Wald chi-squared (7)		88.98		121.16		44.16
Prob > chi-squared		0		0		0
Log likelihood		-111.81		-342.26		-118.94

Table 4.16

Single-Coefficient Automobile Dependency Model: Non-Work Trips by Locations

	N1: Region-wide		N2: Suburb-to-Suburb		N3: Urban-to-Urban	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1490	-11.23	-0.1556	-4.71	-0.1729	-7.39
Driving Cost	-0.0704	-3.01			-0.0540	-2.07
Trip Distance	0.2200	5.62	0.2386	2.88	0.1482	1.39
CBD	-1.0347	-2.63			-0.5569	-1.29
Vehicles per Worker	0.6825	3.62	0.6137	1.9	0.9961	3.3
Full Time Worker	1.0144	4.2	1.4585	2.76	1.0008	3.05
Housing Owner	0.6238	2.82	1.5654	3.16	0.0358	0.12
Constant	3.3985	7.72	1.9056	2.15	3.5423	5.36
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Non-Driving						
Trip Time	-0.0277	-4.08	-0.0167	-1.31	-0.0439	-3.66
Trip Cost	-0.0629	-2.6	-0.0058	-0.16	-0.0946	-2.4
Age 60 or Older	0.7361	2.56	0.4654	0.84	1.0310	2.56
Age 30 or Younger	1.4490	6.07	1.2894	2.72	1.8123	5.26
Transit Seat Supply	0.0450	4.04	0.0164	0.35	0.0476	3.1
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Captivity Coefficient	**0.5655**	**5.05**	**3.6840**	**2.75**	**0.3682**	**3.51**
Number of obs		4340		2461		1474
Wald chi-squared (7)		173.68		33.17		81.68
Prob > chi-squared		0.000		0.000		0.000
Log likelihood		-592.99		-213.14		-294.60

Table 4.17

Single-Coefficient Automobile Dependency Model: Non-Work Trips by Income

	N4: High Income		**N5: Medium Income**		**N6: Low Income**	
	Coef.	***z-test***	***Coef.***	***z-test***	***Coef.***	***z-test***
Driving						
Driving Time	-0.1364	-4.62	-0.1330	-6.73	-0.1584	-6.51
Driving Cost	-0.2015	-1.42	-0.1198	-2.35	-0.0571	-1.75
Trip Distance	0.1108	1.26	0.2351	4.01	0.1870	2.6
CBD	-0.3037	-0.31	-1.1837	-1.92	0.6699	0.79
Vehicles per Worker	1.8044	2.66	0.3499	1.37	0.8560	2.41
Full Time Worker	1.2402	2.08	0.7313	2.12	1.3844	3.09
Housing Owner	0.4527	0.72	0.5577	1.68	0.4799	1.32
Constant	2.4700	1.93	3.5906	5.21	2.1901	2.98
Non-Driving						
Trip Time	-0.0281	-1.77	-0.0185	-1.94	-0.0458	-3.37
Trip Cost	-0.3492	-1.68	-0.0888	-1.38	-0.0991	-2.85
Age 60 or Older	1.8842	2.62	0.3547	0.77	0.6553	1.48
Age 30 or Younger	1.8545	2.96	1.4058	4.17	1.4617	3.56
Transit Seat Supply	0.0381	1.23	0.0417	2.32	0.0231	1.23
Captivity Coefficient	**0.2091**	**1.19**	**0.8241**	**3.65**	**0.2995**	**2.19**
Number of obs		821		2400		1119
Wald chi-squared (7)		43.9		82.2		54.58
Prob > chi-squared		0.000		0.000		0.000
Log likelihood		-85.10		-293.44		-195.18

- **Explaining Automobile Dependency: Parametrized Captivity Logit Modeling**

The single coefficient automobile dependence models have demonstrated empirical advantages in quantifying the degrees of automobile dependency. Their relative simple formulation makes it convenient to compare and contrast the varying degrees of automobile captivity among different income groups and geographical locations. One limitation of these single coefficient models is that they do not provide sufficient information on what specific factors (e.g. land use and/or transportation) attribute to the measured automobile dependency, since all these factors are compressed in the single, composite coefficient.

In this section, we relax the single coefficient constraint and formulate it as a function of various parameters related to land use and transportation characteristics. These are the parameterized automobile dependence models as shown in Eq. 3.10 on page 80 in Chapter 3. The models allow us to explicitly estimate and examine the contributions of land use and transportation characteristics to individuals' automobile dependency. The costs of using such models, obviously, are the increased complexity of model specification, estimation and computing time as well.

To allow clear comparability, we maintain the same model specifications in the utility functions as for the single coefficient captivity models. For instance, as shown in Table 4.18, the first two blocks include variables and estimated coefficients associated with driving and non-driving modes, respectively. The variables entered here are identical to those in the single coefficient captivity models. The third block includes variables identified to be associated with automobile dependency. They form an automobile captivity function for a specific population group or geographic location with which the model is estimated. The auto captivity function is itself linear in parameters. Therefore, the estimated coefficients can be interpreted in the same way as conventional linear regression with the 'dependent variable' here being the odds of becoming captive to automobile. Our discussions on the modeling results will focus on the captivity functions.

Table 4.18: Parametrized Automobile Dependency Model: All Trips by Locations

	B1: Region-wide		B2: Suburb-to-Suburb		B3: Urban-to-Urban	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1448	-13.75	-0.0810	-4.09	-0.1783	-12.83
Driving Cost	-0.0422	-2.61			-0.0388	-2.49
Trip Distance	0.2369	6.66	-0.0706	-0.58	0.3572	5.35
CBD	-1.2163	-5.31			-0.8555	-3.4
Vehicles per Worker	0.7034	4.63	0.2091	0.78	0.9834	4.83
Full Time Worker	0.6556	3.54	1.2649	3.6	0.4865	2.15
Housing Owner	0.2566	1.54	0.7853	2.13	-0.0486	-0.25
Constant	2.2630	6.38	2.4308	3.06	2.4302	4.97
Non-Driving						
Trip Time	-0.0249	-5.08	-0.0154	-1.55	-0.0380	-4.8
Trip Cost	-0.0635	-3.41	-0.0382	-1.16	-0.0746	-2.74
Age 60 or Older	0.3297	1.43	0.5118	1.2	0.6798	2.31
Age 30 or Younger	1.2105	6.65	1.6944	4.74	1.3348	5.93
Transit Seat Supply	0.0078	0.78	-0.0492	-1.25	0.0196	1.72
Auto Captivity Function						
Number of Vehicles in Household	0.4702	4.35	0.5802	2.3	0.4200	2.35
Female with Kids	0.6090	1.74	1.3388	1.81	0.3251	0.5
Trip Distance	-0.0851	-2.36	0.2393	2.1	-0.5494	-2.9
Population Density at Destination	-0.0349	-0.69	0.0243	0.07	0.0508	0.75
Population Density at Origin	0.0291	0.33	0.1434	0.31	0.0856	0.83
Job Density at Origin	-0.0803	-1.22	-0.1285	-0.35	-0.0921	-1.31
Job Density at Destination	-0.0563	-3.05	0.2014	0.65	-0.0321	-1.23
% 4-way Intersection at Origin	-2.4784	-1.6	1.2231	0.3	-2.6639	-1.15
% 4-way Intersection at Destination	1.6536	1.16	6.2354	1.63	-0.1407	-0.07
% 1-way Intersection at Origin	-2.9954	-1.26	-0.4086	-0.07	-3.2140	-0.88
% 1-way Intersection at Destination	4.8913	2.04	6.2262	1.02	2.1881	0.56
Transit Seat Density at Origin	-0.0016	-1.87	-0.0160	-1.51	-0.0016	-1.97
Transit Seat Density at Destination	-0.0007	-1.6	-0.0004	-0.07	-0.0009	-2.53
Entropy at origins	0.8670	2.44	0.5582	0.58	1.3069	2.35
Entropy at Destinations	0.0211	0.06	-1.2343	-1.17	0.5225	0.89
Constant	0.4023	0.24	-6.2822	-1.73	1.3989	0.52
Number of obs		7158		3636		2464
Wald chi-squared (7)		231.11		30.01		196.9
Prob > chi-squared		0		0		0
Log likelihood		-1149.503		-285.2155		-598.62

Table 4.19: Parametrized Automobile Dependency Model: All Trips by Income

	B4: High Income		B5: Medium Income		B6: Low Income	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1374	-8.53	-0.0984	-11.3	-0.1419	-10.45
Driving Cost	-0.1996	-2.24	-0.0212	-0.85	-0.0458	-2.98
Trip Distance	0.2357	4.4	0.0205	0.68	0.0717	1.34
CBD	-0.7967	-1.59	-0.8784	-3.32	0.3151	0.74
Vehicles per Worker	1.4337	3.39	0.4866	2.84	0.7951	2.91
Full Time Worker	0.9432	2.57	0.3618	1.69	0.8016	2.9
Housing Owner	0.5352	1.2	0.2209	1.17	0.2246	0.86
Constant	1.3782	1.45	2.5430	5.59	1.9345	3.56
Non-Driving						
Trip Time	-0.0286	-2.84	-0.0246	-4.13	-0.0521	-4.98
Trip Cost	-0.1839	-1.47	-0.0749	-2.07	-0.0669	-2.97
Age 60 or Older	0.6064	1.28	0.1608	0.56	0.3514	1.04
Age 30 or Younger	1.4247	3.85	0.9334	4.63	1.0067	3.57
Transit Seat Supply	0.0042	0.18	0.0338	2.89	0.0177	1.27
Auto Captivity Function						
Number of Vehicles in Household	-0.0493	-0.09	0.6583	3.08	0.1550	0.5
Female with Kids	2.8520	1.2	0.1237	0.23	2.1945	1.86
Trip Distance	-0.7752	-2.02	0.1056	2.45	0.1330	2.04
Population Density at Destination	-0.1154	-0.27	-0.2489	-1.65	0.0314	0.11
Population Density at Origin	2.0214	2.36	-0.2549	-1.57	0.3571	0.96
Job Density at Origin	-1.5948	-2.49	0.1472	1.71	-0.3699	-0.97
Job Density at Destination	-0.3382	-1.99	-0.3445	-4.11	-0.1774	-1.2
% 4-way Intersection at Origin	5.9236	0.64	-0.1154	-0.04	-6.2842	-1.1
% 4-way Intersection at Destination	2.7298	0.37	0.6305	0.25	13.9124	2.37
% 1-way Intersection at Origin	11.5675	1.01	-4.0377	-0.95	-15.3083	-1.99
% 1-way Intersection at Destination	11.2675	1.07	-1.6220	-0.36	33.6569	2.7
Transit Seat Density at Origin	-0.0010	-0.38	0.0008	1.37	-0.0075	-2.75
Transit Seat Density at Destination	-0.0011	-0.72	-0.0018	-1.2	-0.0018	-1.18
Entropy at origins	4.7413	2.03	-0.6285	-0.89	1.9125	1.43
Entropy at Destinations	0.3195	0.2	1.1837	1.67	-0.4247	-0.38
Constant	-11.8987	-1.34	1.8601	0.62	-8.7509	-1.39
Number of obs		1379		3973		1806
Wald chi-squared (7)		119.11		211.87		148.49
Prob > chi-squared		0.000		0.000		0.000
Log likelihood		-179.61		-609.46		-305.07

As in previous section, Model B1 (Table 4.18) is estimated with the region-wide full sample, whereas Model B2 and B3 are for the suburban and urban segments, respectively. Notably, across three models, number of vehicles in household shows consistently strong influence on automobile dependency. This result reveals an internal link between household mobility decision and the mode choice behavior: when more automobiles are available, they are more likely to be used. Gradually, when driving becomes a routine, the drivers start paying less attention to alternative forms of travel. To the far end, they stop considering other travel modes and become habitually captive to driving. In a dynamic process, automobile dependence forms and grows, rather than stays at a steady state (Goodwin, 1997). This means that, in a highly motorized country like the US, overcoming automobile dependence faces a very high starting bar in terms of both the current intensity of dependence and the potential resistance to slowing down, stopping or reversing the trend of automobility from a large driving population.

Females who have small children at five or younger tends to rely more on automobile, particularly in the suburb. Early studies have offered explanations to the growing dependence of the working female parents on the automobile (e.g. Rosenbloom, 1992), and the explanations remain valid. Participating in the labor force as the second, or in many cases the only income-earning member in the household, the working mother has to juggle a variety of travel needs such as chauffeuring children to day-care centers or doctors and going shopping or to the banks, in addition to work. The complexity and variability of the travel needs often make non-driving impractical. However, if she lives and does daily activities in the urban area, she becomes less dependent on her cars, as indicated by the insignificant coefficient in Table 4.18, the Urban-to-Urban model. This is because many factors helping reduce the need for automobiles present in the urban area. For example, baby-sitting and other home services can be relatively easily provided at the working mother's home location rather than for her to travel around. Baby-sitting and home services are largely low-pay jobs. The service providers mostly have limited income and are part-time workers. They rely on public transportation that is mostly available in the urban area. To the working parents, the solutions to automobile dependence are largely beyond transportation but from the supply of social services.

The automobile is preferred for longer travel to other modes; when the toll and parking charges are negligible, driving is further encouraged. Travel costs are higher with longer distance regardless of modes. However, the effects of the increased trip distance on different modes vary because the sensitivities of the modes to distance are different. To capture the direct and differentiated effects of distance on travel by different modes, the travel distance variable is specified in both the mode utility function and the auto captivity function. The differentiated effect is shown in the mode utility function. In the region-wide model (Table 4.18), the positive and significant coefficient (with a value of 0.237) associated with trip distance in the driving utility function means that, when distance increase, driving is preferred to non-driving, all else being equal. (Travel distance is computed here as the airline distance between the origin and destination of any given trip. It is the same regardless which travel mode is used. Therefore the variable behaves in the same way as other alternative-specific socioeconomic variables such as gender or age, reflecting the differences in preferences for driving and non-driving as a function of trip distance. See Ben-Akiva and Lerman, 1985.)

In the captivity function, the distance variable has a negative and significant coefficient (-0.085), capturing the effect of distance as a cost variable. When distance increases, the cost or price of driving increase, which leads to decrease in auto dependence. Similar results are obtained in the urban-to-urban model as in the region-wide model.

How to explain the opposite, positive signs of trip distance coefficient in the suburb-to-suburb model? Note that driving cost does not appear in the driving utility function of the suburb-to-suburb model. In this case study, driving cost considered includes toll and parking costs only. For the suburb-to-suburb trips, recorded toll and parking costs in the sample are all zero. The model drops the variable from the equation due to perfect collinearity, just like it does to the CBD indicator that is irrelevant to the suburb-to-suburb travel. When driving cost is literally zero and driving time is controlled for, longer distance means higher travel speed at no extra cost, which is something that all people like. That explains the positive, significant distance coefficient (0.2393) in the captivity function of the suburb-to-suburb model.

In reality, of course, the operating costs of driving consist of more than tolls and parking, including fuel, vehicle damage and depreciation. The effects of these costs are not captured in the present models. The results reported here, however, do support the arguments that cheap driving induces more and longer driving, and encourages higher degrees of automobile dependence. The policy implication is that increasing driving cost by policies like pricing is potentially an effective strategy to reduce automobile dependence.

Higher density is associated with lower level of automobile dependence. Overall, the performance of land use variables is rather mixed. Many of the estimated coefficients are individually not significantly different from zero. This may be due to the multicollinearity between some of the variables. Those that are significant, however, do have expected signs and show important influence on the odds of automobile captivity. For example, in the region-wide model, high job density at trip destinations is negatively associated with automobile captivity. More auto-oriented urban form measured by the share of cul-de-sac intersections is positively related to automobile dependency (a significant coefficient of 4.89). Higher degree of land use mix measured by entropy index tends to reduce the likelihood of being captive to driving.

It is important to note that variables measuring zonal transit supply have consistent, negative signs across the three models, meaning that more transit supply (in terms of seats per acre) helps reduce automobile dependency. They appear statistically insignificant in the suburb-to-suburb model partly because that there are not enough empirical observations on non-driving choices.

Model B4~B6 are estimated for three income groups, high, medium, and low, respectively, corresponding to the three income models in the single coefficient captivity logit modeling presented earlier. Note that number of vehicles in household only appears important to the medium income group in affecting odds of auto dependency.

For the higher income group, increased population density at home zones is associated with increased dependence on private travel means, reflecting perhaps the general disfavor to densification by the higher income people, at least in this country. For the medium income group, increased population density tends to lead to lower degree of automobile dependency. Higher job density, particularly in destination zones, is notably associated with lower probability of driving captivity. Again, transit supply is important in reducing automobile dependency, particularly for the lower income population.

For reference purposes, the same set of parametrized captivity logit models are estimated for home-based work and non-work trips. The results are reported in Table 4.20 ~ 4.23. Major findings from the results are highlighted below.

- For home-based work trips, job densities at both ends of trip making are important variables to account for, and thus to affect automobile dependency. On the other hand, for non-work trips, job densities become less relevant while population density becomes significant.

- Household mobility (number of vehicles in household) has significant influence on the odds of driving captivity for non-work trip purposes. For work trip purposes, however, increased transit supply (transit seat density) leads to decreased automobile dependency. Of special importance to non-work trip activities is household structure (female with small children).

- The models of the high income group for work and non-work trips perform poorly. None of the variables entered as statistically significant in the captivity functions. This is consistent with the results of the single coefficient captivity logit modeling reported earlier (e.g. Model H4 in Table 4.15), in which we do not find measurable evidence of the high income being captive to driving.

Table 4.20: Parametrized Automobile Dependency Model: Work Trips by Locations

	H1: Region-wide		H2: Suburb-to-Suburb		H3: Urban-to-Urban	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1106	-12.58	-1.0531	-2.2	-0.1830	-9.36
Driving Cost	-0.0269	-1.85	935.6209	.	-0.0608	-2.68
Trip Distance	0.0489	1.65	5.5415	3.32	0.1689	1.63
CBD	-0.7629	-3.17			-0.7137	-2.11
Vehicles per Worker	0.9830	5.11	-5.0773	-2.01	1.3191	4.49
Full Time Worker	0.5236	1.95	-15.5874	-2.69	0.8848	2.37
Housing Owner	0.2110	1.03	2.6366	0.67	-0.0786	-0.29
Constant	1.2657	2.46	13.3480	2.19	2.0112	2.76
Non-Driving						
Trip Time	-0.0382	-5.79	-0.2335	-3.15	-0.0446	-3.82
Trip Cost	-0.0483	-2	-0.9766	-1.29	-0.0943	-2.71
Age 60 or Older	-0.1635	-0.53	-31.5830	.	-0.1195	-0.27
Age 30 or Younger	0.7867	3.6	25.8622	.	1.1463	3.72
Transit Seat Supply	0.0215	1.76	-2.0992	-2.78	0.0211	1.18
Auto Captivity Function						
Number of Vehicles in Household	0.3476	1.54	-0.1390	-0.5	1.1337	3.56
Female with Kids	0.1790	0.2	-0.4214	-0.37	-16.1775	-0.01
Trip Distance	0.0616	1.71	-0.2518	-1.67	0.0722	0.43
Population Density at Destination	-0.0787	-0.59	0.4772	0.8	0.1798	1.59
Population Density at Origin	0.1771	0.88	-0.3442	-0.68	-0.1169	-0.79
Job Density at Origin	-0.2729	-1.7	-0.8940	-1.47	-0.0371	-0.49
Job Density at Destination	-0.3911	-2.96	-0.2406	-0.58	-0.1022	-2.46
% 4-way Intersection at Origin	-3.4919	-1.18	3.4085	0.52	-0.6913	-0.16
% 4-way Intersection at Destinatio	-0.8774	-0.28	5.6217	0.76	-4.5029	-1.38
% 1-way Intersection at Origin	-5.1576	-1.1	-8.1015	-0.84	2.2133	0.33
% 1-way Intersection at Destinatio	1.4228	0.3	10.8535	1.06	-0.1718	-0.03
Transit Seat Density at Origin	-0.0030	-2.11	-0.0066	-0.49	0.0012	2.21
Transit Seat Density at Destinatio	-0.0017	-1.58	-0.0081	-1.22	-0.0028	-2.11
Entropy at origins	1.2578	1.78	3.3761	1.92	-0.3045	-0.33
Entropy at Destinations	0.6795	0.95	0.5749	0.38	0.8557	0.66
Constant	4.5093	1.26	-2.5915	-0.41	0.7724	0.18
Number of obs		2818		1196		990
Wald chi-squared (7)		223.37				121.71
Prob > chi-squared		0				0
Log likelihood		-539.01				-283.55

Table 4.21: Parametrized Automobile Dependency Model: Work Trips by Income

	H4: High Income		H5: Medium Income		H6: Low Income	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1384	-6.39	-0.0895	-7.63	-0.1429	-6.47
Driving Cost	-0.1919	-1.74	-0.0076	-0.19	-0.0744	-3.15
Trip Distance	0.2556	4.59	-0.0564	-1.51	0.1137	1.53
CBD	-1.1702	-1.77	-1.0816	-3.13	0.8517	1.3
Vehicles per Worker	1.6469	2.88	0.8895	3.61	0.8496	1.68
Full Time Worker	1.1884	1.81	0.4902	1.34	0.8011	1.53
Housing Owner	1.4264	1.98	0.1616	0.61	0.2351	0.53
Constant	-0.6674	-0.53	2.1361	2.88	0.8762	0.97
Non-Driving						
Trip Time	-0.0347	-2.53	-0.0298	-3.45	-0.0593	-3.45
Trip Cost	-0.1096	-0.69	-0.0519	-0.99	-0.0421	-1.13
Age 60 or Older	-0.3231	-0.44	-0.0576	-0.13	-0.5305	-0.85
Age 30 or Younger	0.9949	2.02	0.9191	3	0.5210	1.05
Transit Seat Supply	-0.0144	-0.46	0.0633	3.5	0.0091	0.43
Auto Captivity Function						
Number of Vehicles in Household	-89.8690	-0.08	1.1612	2.15	62.1250	1.26
Female with Kids	305.5603	0.07	-1.4469	-1.26	-23.8414	-0.01
Trip Distance	-23.0605	-0.07	0.1504	1.78	-0.0804	-0.13
Population Density at Destination	13.9738	0.04	-0.5678	-2.17	14.0540	0.8
Population Density at Origin	43.2782	0.06	-0.4022	-1.51	64.4421	1.29
Job Density at Origin	-59.7572	-0.07	0.2015	1.29	-81.6214	-1.23
Job Density at Destination	-22.9151	-0.07	-0.5775	-3.37	12.2531	1.29
% 4-way Intersection at Origin	-2074.401	-0.08	-0.5537	-0.14	-197.1303	-0.91
% 4-way Intersection at Destination	-190.8589	-0.03	0.8125	0.18	1508.163	1.32
% 1-way Intersection at Origin	-3494.497	-0.08	-6.2396	-0.62	-513.7382	-0.94
% 1-way Intersection at Destination	66.8986	0.01	-3.4027	-0.49	3385.716	1.31
Transit Seat Density at Origin	0.0240	0.05	0.0016	2.34	-0.6697	-1.32
Transit Seat Density at Destination	-0.3347	-0.07	0.0001	0.53	-0.3350	-1.19
Entropy at origins	217.7685	0.06	-0.1120	-0.1	209.2463	1.21
Entropy at Destinations	361.4246	0.07	0.0942	0.1	263.4519	1.33
Constant	2019.4020	0.08	4.1869	0.97	-1632.4920	-1.33
Number of obs		558		1573		687
Wald chi-squared (7)		67.42		106.71		61
Prob > chi-squared		0.000		0.000		0.000
Log likelihood		-82.37		-300.73		-84.67

Table 4.22

Parametrized Automobile Dependency Model: Non-Work Trips by Locations

	N1: Region-wide		N2: Suburb-to-Suburb		N3: Urban-to-Urban	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.1647	-11.02	-0.1282	-5.14	-0.1394	-10.26
Driving Cost	-0.0156	-0.68			-0.0196	-1.1
Trip Distance	0.3450	6.66	-0.0508	-0.4	0.2369	2.5
CBD	-1.0902	-2.84			-0.6667	-1.84
Vehicles per Worker	0.4905	2.41	0.0808	0.26	0.7391	2.92
Full Time Worker	1.0813	4.22	1.6335	3.28	0.8991	3.21
Housing Owner	0.4975	2.12	1.2893	3.15	0.0870	0.33
Constant	2.7381	5.59	2.9212	3.54	2.8469	4.66
Non-Driving						
Trip Time	-0.0305	-4	-0.0145	-1.14	-0.0376	-3.49
Trip Cost	-0.0660	-2.49	-0.0396	-1.06	-0.0715	-2.11
Age 60 or Older	0.6143	2	0.3665	0.75	0.9873	2.8
Age 30 or Younger	1.6240	6.27	1.4836	3.43	1.5055	5.34
Transit Seat Supply	0.0263	1.98	-0.0290	-0.67	0.0285	2.03
Auto Captivity Function						
Number of Vehicles in Household	0.5304	3.3	1.1172	2.67	-0.0826	-0.13
Female with Kids	1.1903	2.66	1.9051	2.18	0.5315	0.3
Trip Distance	-0.1844	-2.51	0.2748	2.27	-7.4782	-2.5
Population Density at Destination	-0.1713	-2.44	-0.0215	-0.05	0.2167	0.41
Population Density at Origin	-0.0253	-0.19	0.8751	1.12	-1.1230	-1.8
Job Density at Origin	0.0833	1.11	-0.1559	-0.32	0.4505	1.3
Job Density at Destination	-0.0097	-0.38	0.1092	0.28	0.3473	1.82
% 4-way Intersection at Origin	-1.9621	-1.02	-0.2091	-0.04	-11.6807	-0.99
% 4-way Intersection at Destination	2.9140	1.44	5.2231	1.06	43.6081	2.34
% 1-way Intersection at Origin	-2.9583	-0.88	2.5168	0.33	-23.5379	-1.35
% 1-way Intersection at Destination	2.2136	0.57	1.5858	0.19	32.0929	1.39
Transit Seat Density at Origin	-0.0007	-0.95	-0.0216	-1.93	-0.0024	-1.01
Transit Seat Density at Destination	-0.0003	-1.33	0.0057	0.83	-0.0058	-1.75
Entropy at origins	0.5845	1.11	0.8816	0.69	8.7958	2.1
Entropy at Destinations	-0.2616	-0.58	-1.2908	-1.01	-1.0976	-0.37
Constant	-0.3134	-0.13	-7.6150	-1.67	-19.1189	-0.91
Number of obs		4340		2461		1474
Wald chi-squared (7)		146.39		40.46		155.08
Prob > chi-squared		0.000		0.000		0.000
Log likelihood		-557.81		-199.48		-272.80

Table 4.23

Parametrized Automobile Dependency Model: Non-Work Trips by Income

	N4: High Income		**N5: Medium Income**		**N6: Low Income**	
	Coef.	***z-test***	***Coef.***	***z-test***	***Coef.***	***z-test***
Driving						
Driving Time	-0.1301	-5.77	-0.1535	-6.6	-0.1769	-6.35
Driving Cost	-0.1304	-0.93	-0.0333	-0.64	-0.0462	-1.22
Trip Distance	-0.0640	-0.82	0.3190	3.74	0.3517	3.22
CBD	0.7215	0.71	-1.3665	-2.25	0.6363	0.68
Vehicles per Worker	2.0998	3.24	0.1901	0.68	0.8003	2.04
Full Time Worker	1.6625	2.58	0.9282	2.36	1.4789	2.99
Housing Owner	0.5756	0.91	0.5738	1.58	0.4936	1.26
Constant	1.5131	1.13	2.8876	3.62	1.5593	1.88
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Non-Driving						
Trip Time	-0.0270	-1.65	-0.0196	-1.83	-0.0503	-3.23
Trip Cost	-0.4966	-2.21	-0.0882	-1.24	-0.1048	-2.71
Age 60 or Older	2.0365	2.73	0.0583	0.11	0.7390	1.52
Age 30 or Younger	1.6928	2.64	1.4965	4.07	1.7969	3.78
Transit Seat Supply	0.0451	1.3	0.0242	1.17	0.0167	0.7
	-----------	---------	-----------	---------	-----------	---------
Auto Captivity Function						
Number of Vehicles in Household	-105.4276	-0.83	0.4444	2.2	0.3163	0.83
Female with Kids	154.3870	0.19	1.0698	2.01	2.4986	2.03
Trip Distance	18.1547	0.82	-0.0413	-0.46	-0.4037	-1.57
Population Density at Destination	25.7822	0.7	-0.1408	-1.56	-0.3867	-2.16
Population Density at Origin	-7.1348	-0.17	-0.0483	-0.28	0.1532	0.6
Job Density at Origin	-127.0540	-0.8	0.0547	0.54	0.3435	1.54
Job Density at Destination	-15.3048	-0.85	-0.0103	-0.31	-0.0423	-0.73
% 4-way Intersection at Origin	67.6251	0.18	-0.8866	-0.35	-6.5753	-1.45
% 4-way Intersection at Destination	-60.1857	-0.21	2.9332	1.09	-3.5032	-0.71
% 1-way Intersection at Origin	714.0935	0.68	-3.0978	-0.63	-18.5920	-2.41
% 1-way Intersection at Destination	-167.8438	-0.53	6.4487	1.22	-7.0889	-0.7
Transit Seat Density at Origin	0.5361	0.77	-0.0001	-0.09	-0.0051	-2.45
Transit Seat Density at Destination	-0.1204	-0.75	-0.0003	-1.33	0.0005	1.26
Entropy at origins	183.4213	0.85	0.8704	1.27	-0.8282	-0.69
Entropy at Destinations	-97.5473	-0.73	0.4544	0.73	-1.0877	-1.22
Constant	194.8903	0.81	-2.0769	-0.58	12.2157	1.94
Number of obs		821		2400		1119
Wald chi-squared (7)		43.9		65.86		58.15
Prob > chi-squared		0.000		0.000		0.000
Log likelihood		-64.68		-274.23		-175.71

4.5 Simulations of Pricing and Land Use Policy Effects

The analysis presented in this section answers our fourth research question on the comparable magnitudes of land use and transportation pricing policies. It is based on the mode choice modeling results reported in section 4.2. The effects of a specific policy (e.g. densification or higher toll charge) on mode choice and accessibility are simulated through linear extrapolations of the impacts the corresponding policy variable (indicated by the estimated coefficient) , while all else being held constant. The method is formally known as the Incremental MNL modeling (Ben-Akiva and Lerman 1985, p.114).

Before presenting the simulation analysis, we first empirically verify the mode choice modeling results.

- **Empirical Verification of Modeling Results**

To empirically verify our estimation, several economic parameters are computed (Table 4.24). They are then judged based on our qualitative knowledge or the results reported by other studies in the literature.

The ratios of travel time coefficients over travel cost coefficients associated with the same travel modes provide estimates for travelers' values of time (VOT). In general, higher income commuters value travel time more than do the lower income people. Those who choose faster travel modes such as driving value travel time more than do those choosing slower modes such as transit. For example, the VOT estimated from this model for an average commuter who drives alone and has an annual household income of $52,000 values his/her travel time at $14.16 per hour. For a commuter whose annual household income is $100,000, the estimated value of time is then $27.23. The magnitudes of these estimates are in consistent range with those reported by other studies (e.g. Kokelman 1998, Mohring 1999 p.209).

Also calculated and reported in Table 4.24 are elasticities of mode choice probabilities with respect to population density and driving costs (toll and parking fees) for the entire sample and for each income group. When density increases, the probabilities of choosing driving modes (car-pool and drive alone) would decrease, whereas the probabilities of choosing non-driving modes would increase. A close reference we found is that by Cervero and Kokelman (1997), who measured the elasticity of probability of choosing non-single-occupant-vehicle with respect to land use intensity factor for non-work trips. Their estimate was 0.098, which is close to ours (0.113) of transit choice probability with respect to population density.

The calculated elasticities of mode choice probabilities with respect to driving costs show that lower income travelers are generally more sensitive to driving costs than are the higher income travelers, which makes intuitive sense. Again, the magnitudes of the estimates are consistent with the results reported by Pickrell and Shoup (1975) when time factor is taken into account.

In sum, our choice modeling provides reasonable and reliable estimates that can be utilized in further steps to analyze the effects of transportation and land use policies on travel.

Table 4.24: Value of Time and Elasticities of Mode Choices

Value of Time

	Annual Household Income		
	Lower	Midium	Higher
Transit	$3.25	$5.63	$10.83
Car-pool	$5.84	$10.13	$19.48
Drive-alone	$8.17	$14.16	$27.23

Elasticities of Mode Choice Probabilities with Respect to Population Density

	Annual Household Income			
	Lower	Midium	Higher	Overall
Transit	0.087	0.126	0.135	0.113
Car-pool	-0.082	-0.056	-0.054	-0.063
Drive-alone	-0.038	-0.036	-0.035	-0.036
WalkBike	0.129	0.172	0.192	0.160

Elasticities of Mode Choice Probabilities with Respect to Driving Costs

	Annual Household Income			
	Lower	Midium	Higher	Overall
Transit	0.163	0.250	0.176	0.206
Car-pool	-0.120	-0.135	-0.116	-0.128
Drive-alone	-0.070	-0.050	-0.026	-0.050
WalkBike	0.192	0.149	0.101	0.156

NOTES:

(1) Annual Household Income Range

Lower	<= $35,000
Midium	> $35,000 & <= $70,000
Higher	> $70,000

(2) For value of time calculation, the figures for three income groups are $30,000, $52,000, and $100,000, respectively

(3) Elasticities reported above are probability-weighted average individual elasticities for each income category and each mode. See Ben-Akiva & Lerman, 1985, p.113

- **Comparable Magnitude of the Effects of Pricing and Land Use on Travel**

Table 4.25 reports the pseudo-beta coefficients calculated by multiplying the estimated coefficients by the standard deviations of the corresponding variables. They are analogous to the beta coefficients in ordinary regressions and provide an overall picture showing the relative contributions of the independent variables in explaining mode choice (Levine 1998). It is evident that price variables, i.e. travel time and monetary costs, generally exert the strongest influence on mode choice. For example, for the car-pool mode, the pseudo-betas for travel time and costs are 1.27 and 1.36, respectively. They are both larger than those of vehicle ownership variable VEHOWN (0.29) and location variable CBD (0.47), suggesting their greater importance to people's mode choice decisions. For the drive-alone mode, the same pattern is observed. It is also observed that the pseudo-beta of travel cost variable for the car-pool mode is larger than that of travel time while the opposite is true for the drive-alone mode. It implies that car-poolers are more sensitive to monetary costs, whereas those driving-alone are more responsive to travel time costs.

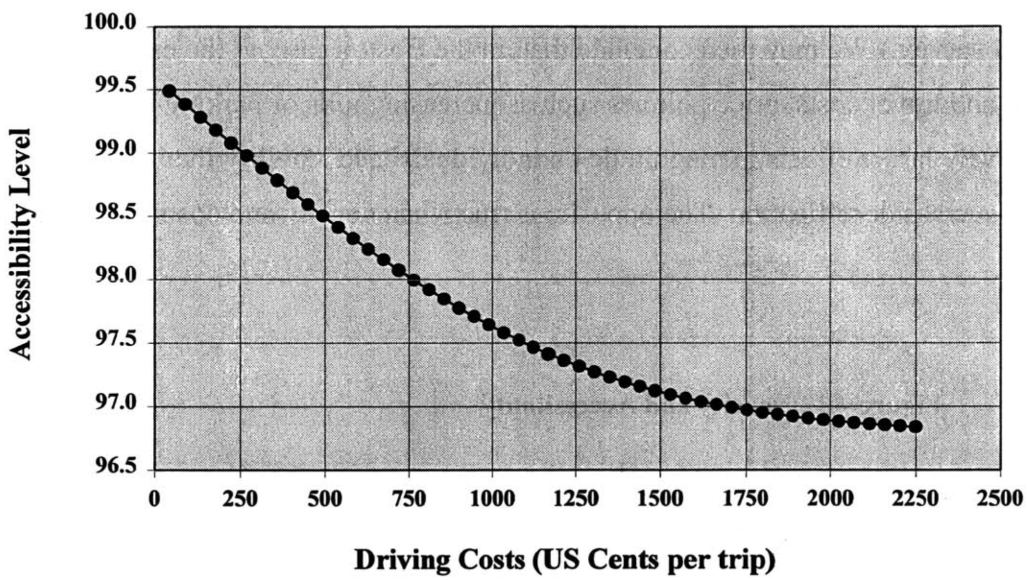
Table 4.25: Pseudo-Beta Coefficients of MNL Mode Choice Model

Independent Variable	Standard Deviation	Pseudo-Beta
Walk		
wktime (wk)	0.0007	1.64
odenpop (wk, tr)	35.8417	0.37
young (wk)	0.4457	0.36
ddenemp (wk, tr)	315.2768	0.34
ddenpop (wk, tr)	39.3993	0.15
dentropy (wk, tr)	0.3208	0.12
odenemp (wk, tr)	91.2199	0.11
oentropy (wk, tr)	0.2740	0.01
Transit		
ttime (tr)	32.8664	0.41
odenpop (wk, tr)	35.8417	0.37
fare (tr)	0.0051	0.35
CBD (tr)	0.4114	0.35
ddenemp (wk, tr)	315.2768	0.34
trseats (tr)	388.5198	0.16
ddenpop (wk, tr)	39.3993	0.15
dentropy (wk, tr)	0.3208	0.12
femnokid (tr)	0.4905	0.11
odenemp (wk, tr)	91.2199	0.11
odenseat (tr)	631.3103	0.08
ddenseat (tr)	2023.1460	0.07
oentropy (wk, tr)	0.2740	0.01
Car Pool		
ttcost (cp)	0.0081	1.36
ivtime (cp)	23.2316	1.27
CBD (cp)	0.3994	0.47
vehown (cp)	0.6197	0.29
Drive-Alone		
ivtime (dr)	23.5704	1.14
ttcost (dr)	0.0068	0.73
vehown (dr)	0.5970	0.60
owner (dr)	0.4640	0.18
dpct3wup (dr)	0.0876	0.09
empfull (dr)	0.4159	0.08
opct1way (dr)	0.0635	0.03

- **Simulation #4.1: Driving Costs on Accessibility**

Figure 4.11 graphs the relationships between driving costs and accessibility (i.e. the logsum). Given the estimated negative coefficients of travel cost variables, increasing driving costs (e.g. higher tolls and parking fees) would reduce utility associated with driving mode and thus, all else being equal, decrease the individuals' accessibility. The convex, downward sloping curve suggests that the effect of driving costs on accessibility is larger when the costs are at the lower end.

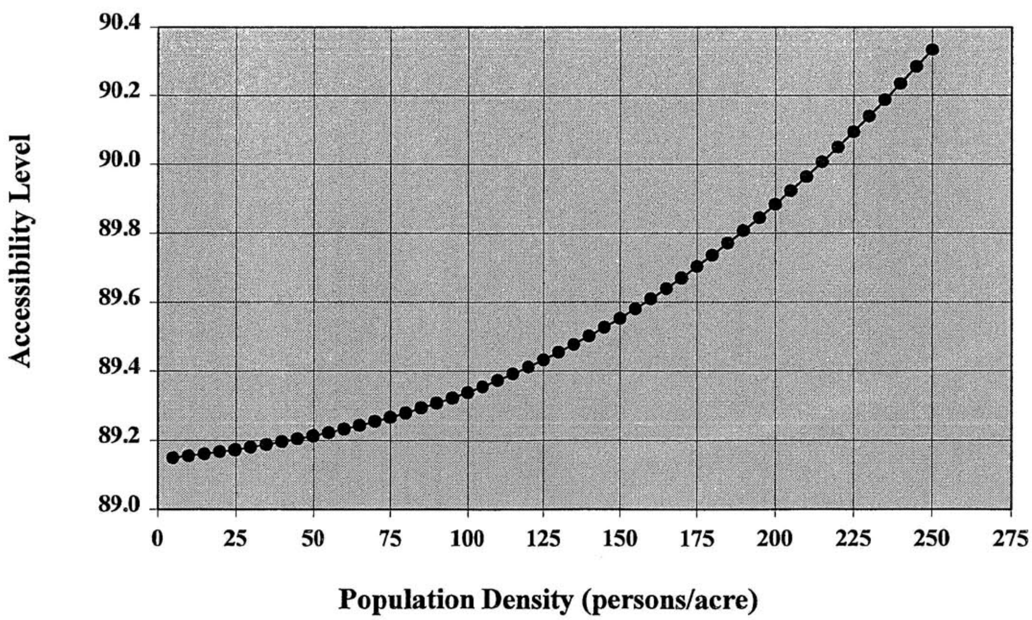
Figure 4.11 Driving Costs and Accessibility



- **Simulation #4.2: Population Density on Accessibility**

On the other hand, the positive coefficients of density variables suggest a positive relationship between density and accessibility. As density increases, the utility associated with walking or transit modes increases, which leads the individual to a higher level of accessibility, all else being equal. This is shown in Figure 4.12 by the extrapolation of the relationship between accessibility and population density. The shape of the curve in Figure 4.12 suggests that *the marginal accessibility improvement resulting from increasing density is smaller when density is relatively low than when density is higher.* (In the Boston area the average net population density was about 8 persons per acre; the average commuting costs, including tolls and parking costs were 172 cents each way at the time of survey.) We may then conclude that, in the Boston case, at the existing levels of density and travel costs, price policies such as increasing tolls or parking fees would have relatively larger effects in magnitude on individuals' accessibility than land use initiatives such as densification. The opposite is true when density and costs pass certain thresholds.

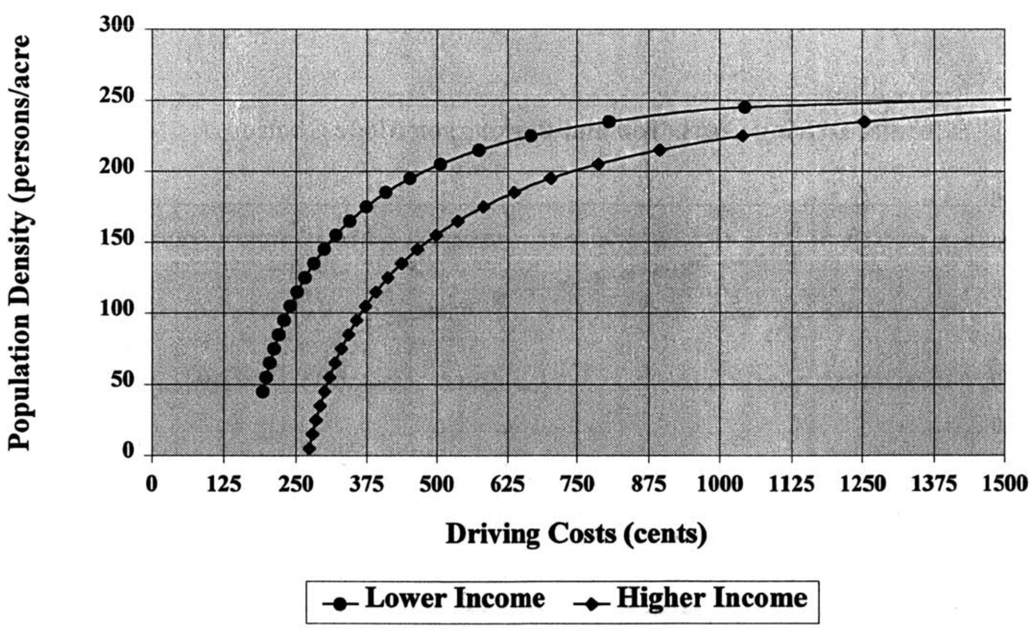
Figure 4.12 Density and Accessibility



- **Simulation #4.3: Driving Costs vs. Population Density with Accessibility Held Constant**

This point is further illustrated by graphing density against driving costs while *holding accessibility constant*. Figure 4.13 shows two such iso-accessibility curves with different income levels. The concave, upward sloping curves suggest that, when density and driving costs are both at the lower end, a small change in costs needs to be accompanied by a relatively large change in density in order for the individual to be at least as well off as before. The fact that the lower income curve is 'higher' than the higher income curve can be interpreted as that lower income people are generally more willing to live at higher density than the higher income people are. This is largely the case in the US cities.

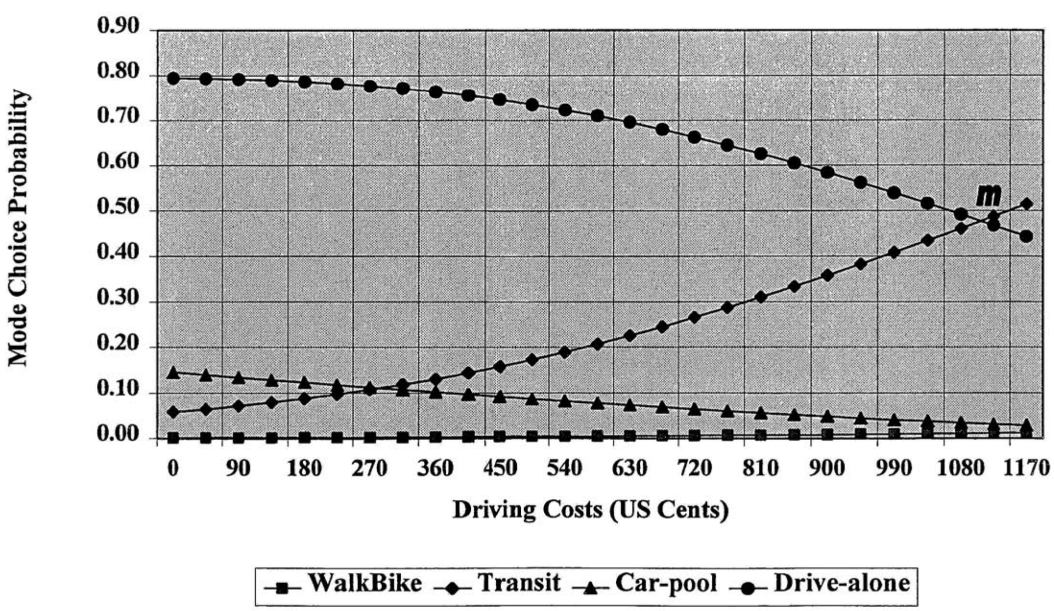
Figure 4.13 Iso-Accessibility Curves



- **Simulation #4.4: Driving Costs on Mode Choice Probabilities**

Figure 4.14 simulates the effects of driving cost increases (e.g. higher tolls and/or higher parking fees) on the choice probabilities of four commuting modes while all other factors are held constant. As driving costs increase, the probabilities of choosing driving alone or car-pooling decrease, whereas the probabilities of choosing transit or other non-driving modes increase. The two choice probabilities associated with driving alone and transit modes intersect at point ***m*** when the two are equal. The location of point ***m*** indicates the magnitude of a policy measure required to make a commuter indifferent between driving alone or taking transit. It provides a benchmark with which the effectiveness of different policy strategies can be compared. (Whether the policy making should be aimed at equalizing the likelihood of the two modes being used is rather a different subject of debate.) From Figure 4.14 we observe that to make a commuter indifferent between taking transit and driving alone (i.e. equal choice probabilities between the two modes), driving costs have to increase to a level of around $12 each way between home and work every day, all else being equal.

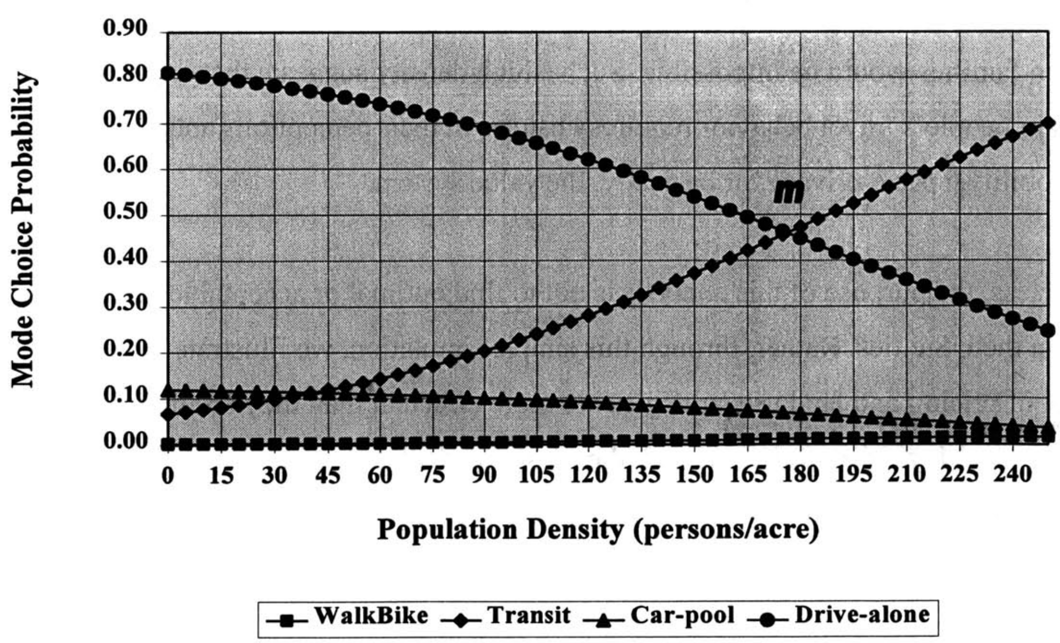
Figure 4.14
Effects of Driving Costs (Toll and Parking) on Mode Choice



- **Simulation #4.5: Population Density on Mode Choice Probabilities**

Figure 4.15 extrapolates the relationships between population density and mode choices. Increased density is associated with increased probability of commuting by transit but decreased probability of driving, either alone or car-pooling. As the benchmark point ***m*** indicates, travelers become neutral in driving-alone or taking transit, at a probability of .48, when density increases to nearly 180 people per acre. It is over 20 times denser than the current built-up area in greater Boston (8 people per acre)! Such an extremely high density is seen only in a few places in the world, for example, in Hong Kong. But it is far from any real experience in Boston or other metropolitan areas in the US. This simulation indicates that it is possible, technically, to alter people's travel behavior via densification strategy. The required increase in densities, however, has to be very large before any significant shift from driving to transit in mode choices can be seen. The required density increase is so dramatic that it is hardly to see any chance in the US cities for the densification strategy *alone* to achieve the objective of reducing auto use.

Figure 4.15 Effects of Population Density on Mode Choice



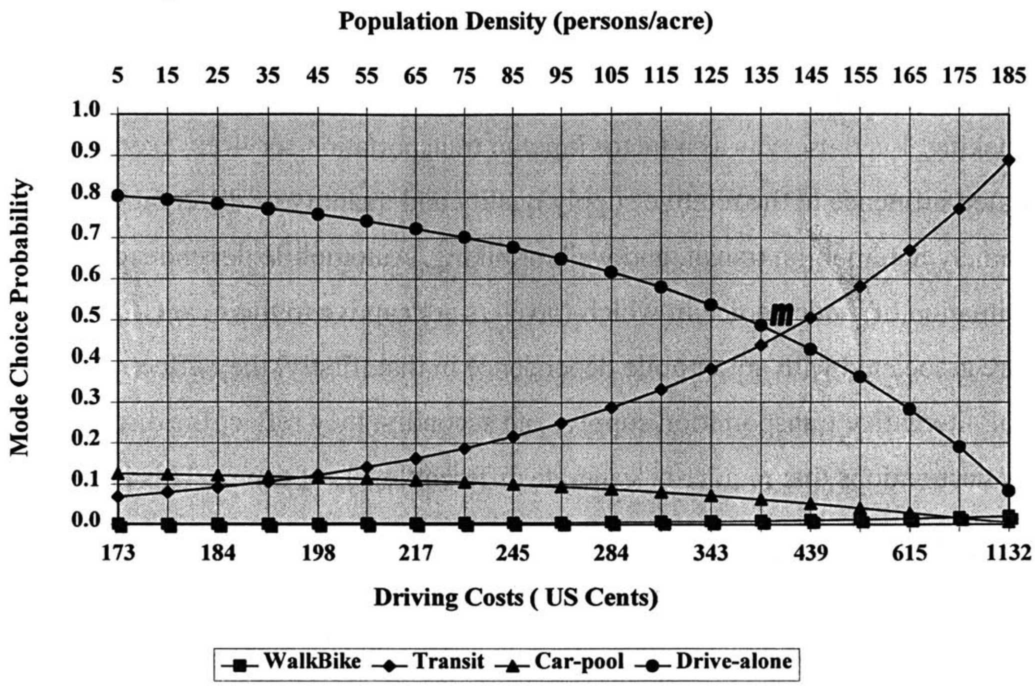
- **Simulation #4.6: Combination of Density and Costs on Mode Choice Probabilities with Accessibility Held Constant**

When the two factors, driving costs and population density, are combined, however, they are much more influential on travel mode choices than they act alone. Figure 4.16 shows the results of simulation of the joined effects of density and driving costs on mode choice *when travelers' welfare (i.e. accessibility) is held constant.* Note that the benchmark point ***m*** in this scenario has shifted inward to a large extent. If the break-even policies in Simulation #4 and #5 are applied together, that is, driving costs increased to $12 each way and density increased to 180 people per acre, there would be less than one-tenth of total commuters driving to work, on average. Nearly 90 percent of work trips would be made by transit. To reach the point where probabilities of driving and taking transit are equal, driving costs should rise to about $4.00 one way and density at 140 people per acre. If all other land use attributes and transit supply factors are taken into account, the required changes in density and costs would be further smaller.

Again, 140 people per acre is an extrapolation that is still far out of Boston development experience. At this density, suburban sprawl had to be converted to the vertical dimension. Spacious front, back, and side yards that are currently common to most American families would be impossible. Such a high density suggests that expecting changes in people's travel behavior requires changes in their perceptions and attitude about mobility, space, privacy, or basically, the value system.

Nevertheless, the purpose of this analysis is not to find optimal or acceptable level of density in the US cities. Rather, through this simple simulation, we illustrate that the bundling of pricing and land use strategies are more effectual than they are implemented separately. As Meyer (1999) has argued, the most practical and effective policies to influence travel behavior are those combining both the 'carrots and sticks'.

Figure 4.16
Combined Effects of Driving Costs and Density on Mode Choice



4.6 Chapter Conclusion

Land use attributes, along with travel costs and individuals' socioeconomic characteristics, are important factors affecting people's travel decisions on mode choice and trip making. Land use acts as a factor input to transportation services, exerting differentiated influence to the relative supply quality and quantity of different travel modes, namely automobile, transit, and walk or biking. Automobile dependence is an extreme situation of mode choice in which travelers are captive to their cars. Land use patterns are associated with automobile dependence in that, firstly, they affect the viability of alternative transportation supply; and secondly, they reflect the distributions of activity destinations that require or generate different levels of travel. This is evident with the relative low level of automobile dependence in the central Boston area where ample transit supply is available, and the high level of automobile dependence for the suburb-to-suburb trip makers.

It is important to emphasize that, due to the heterogeneity of the population in income, household structures, individual preferences, and home and activity locations, different attributes of land use affect different aspects of people's travel behavior (e.g. mode choice, trip making and automobile dependence) in ways that are not necessarily in consistent directions. This complexity makes it difficult to observe and predict the net effects of land use on travel, as shown by the results presented in this study and by the mixed empirical findings reported in the literature. It suggests that, unless supplemental policies such as pricing in controlling the demand side of automobile travel are in place, the effectiveness of land use as a supply tool to reduce automobile dependence and to enhance accessibility would be limited. This point is demonstrated by the Hong Kong case study presented in the following chapter.

Chapter 5

The Hong Kong Case Study

Figure 5.1 Aerophoto: Kowloon and the Hong Kong Island

Source: Space Imaging, Inc.
(http://www.spaceimaging.com/gallery/ioweek/archive/iow041501/hongkong_800.jpg)

5.1 Introduction

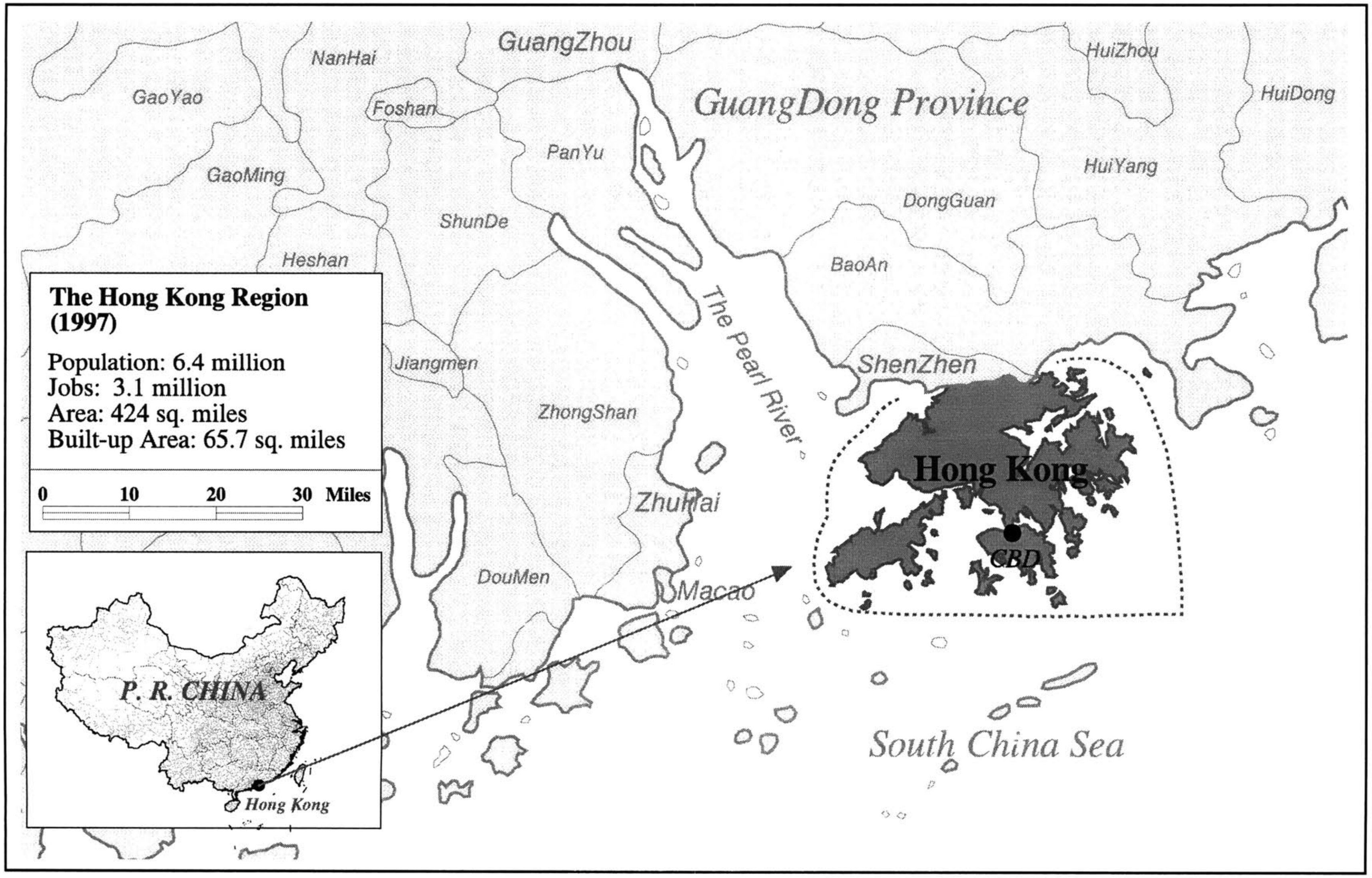
Out Boston case study presented in preceding chapter suggests that land use offers a potentially useful tool to modify mobility demand and to affect travel. The current auto-dominant travel pattern could change toward more balanced modal split if land use were to be re-configured to the form favorable to non-driving, for example, higher densities, greater mix of different uses, and pedestrian-friendly walking environment.

Hong Kong is the densest metropolis in the world. Featured with linear-clustering and mixture development patterns, its land use possesses technically all physical attributes that are desirable to non-auto-based travel. In fact, Hong Kong is known as a transit-based city in which its residents enjoy sufficient mobility and accessibility. It is an exceptional case demonstrating the important role of land use in mobility supply and accessibility provision. It is also a live example embodying the simulations of the effects of land use on travel behavior in the Boston case study.

Our purposes of presenting the Hong Kong case, however, go beyond the demonstration of the relationships between the built environment and travel behavior. The land use pattern in Hong Kong is so unique that any policy recommendation based on the Hong Kong reality to advocate land use strategies to influence travel is mostly likely to be rejected, because, by the US or Western conventions, such a high density is inconceivable.

The primary purpose of the Hong Kong case study is to show that, even in Hong Kong where the land use patterns are transit-friendly, the non-driving-dominant travel does not come by default with the unique land use. From this case study we show that land use and transit supply are only part of the story. The very experience of Hong Kong's transportation development reveals that land use and transit supply are necessary but not sufficient conditions to reduce auto travel and to sustain transit-based mobility.

Figure 5.2 The Hong Kong Special Administrative Region



It should be noted that, given the large differences in geographical, cultural, historical, institutional, and various other aspects between Boston and Hong Kong, issues of comparability between Boston and Hong Kong arise naturally. Here we do not intend to conduct a strict comparative analysis. Instead, we treat them as two stand-alone cases while applying the same analytical framework and research methods. Lessons can be learned and policy implications can be drawn from investigating the two sharp contrasting cases, especially when commonality and regularities (e.g. in individuals' behavioral responses to transportation pricing and land use strategies) between the two cases are found.

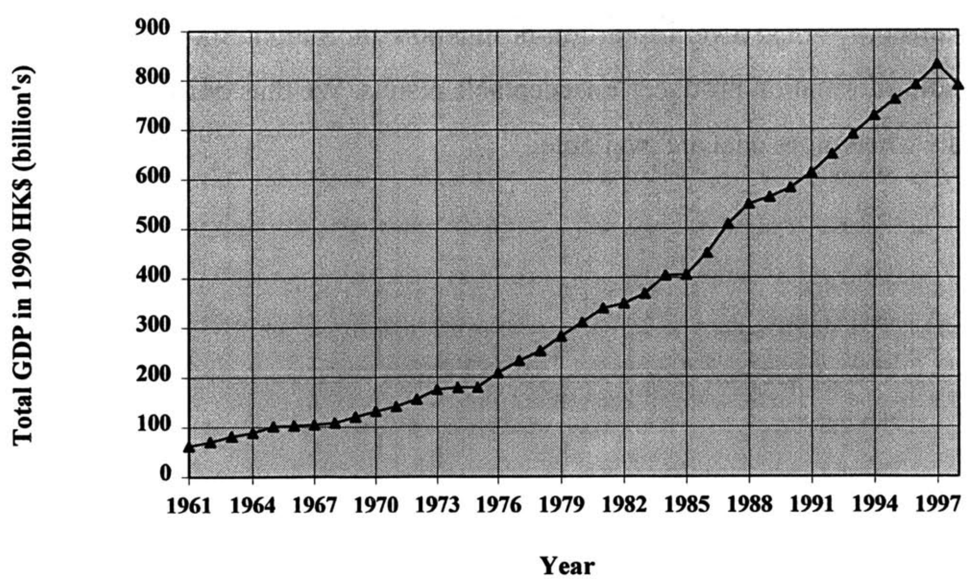
The case study follows a similar format to that of the Boston case. Beginning with the background information on Hong Kong, it presents a case of success on transit-based mobility supply. It then accounts for factors important to Hong Kong's success in maintaining sufficient mobility and accessibility to its citizens. Parallel to the Boston case, mode choice modeling, automobile dependency measurement, and policy effect simulations are presented subsequently. In this case study, trip frequency modeling is omitted due to the lack of detailed trip making information. For example, in the Boston case, the geographic locations of trip origins and destinations for all trips made during the entire week of the trip diary survey are available at the census block level, which allows us to derive rather accurate information on trip length. The Hong Kong sample, on the other hand, contains only zonal level trip origin-destination information. Lacking accurate trip length information produces unacceptable results. We thus decide to leave it for future analysis when more data are available.

5.2 Background Information

Hong Kong is located at the southeast tip of the Chinese coast where the Pearl River runs into the South China Sea (Figure 5.2). With a total area of 1098 km^2, the territory is home to 6.98 million people, of which 95 per cent are Chinese (the Year 2000 figures). A Special Administrative Region (SAR) of the People's Republic of China following the transition from British Colonial rule to Chinese sovereignty in 1997, Hong Kong remains a free port in the global economy and enjoys a high degree of autonomy (except defense and foreign affairs). It maintains a customs and immigration territory separated from Mainland China and exercises its own executive, legislative and independent judicial power.

Hong Kong is an international financial, trading and business center. After the phenomenal economic development at an annual rate of real GDP (gross domestic product) growth averaging six percent during the 1980s and 1990s, Hong Kong has become one of the most advanced economies in the world (Figure 5.3). Its per capita GDP has exceeded that of Great Britain since the early 1990s and reached the level of US$24,000 per capita in 2000.

Figure 5.3: Real GDP Growth in Hong Kong, 1961-1998



Merely a 'barren rock', Hong Kong has limited natural resources, except a deep-water harbor. Perhaps the most scarce resource is land. Of the total 1098 km^2 area, less than two percent (or roughly 20 km^2) is irrigated land (1993 estimate). Raw materials must be imported and fresh food and water for daily consumption are largely transported from its neighboring Guangdong Province of China. The hilly topography with steep slopes offers little of Hong Kong's land suitable for urban development. By 1996, only 170 km^2, or less than 16 percent have been developed or designated as developable (Table 5.1). Over the years, much of the added land for urban development is obtained through land reclamation. Since 1887 when the city first started land reclamation, the total reclaimed land accounts for 62 km^2 (or 36% of existing built up area) for residential, commercial and transportation infrastructure and other urban development.

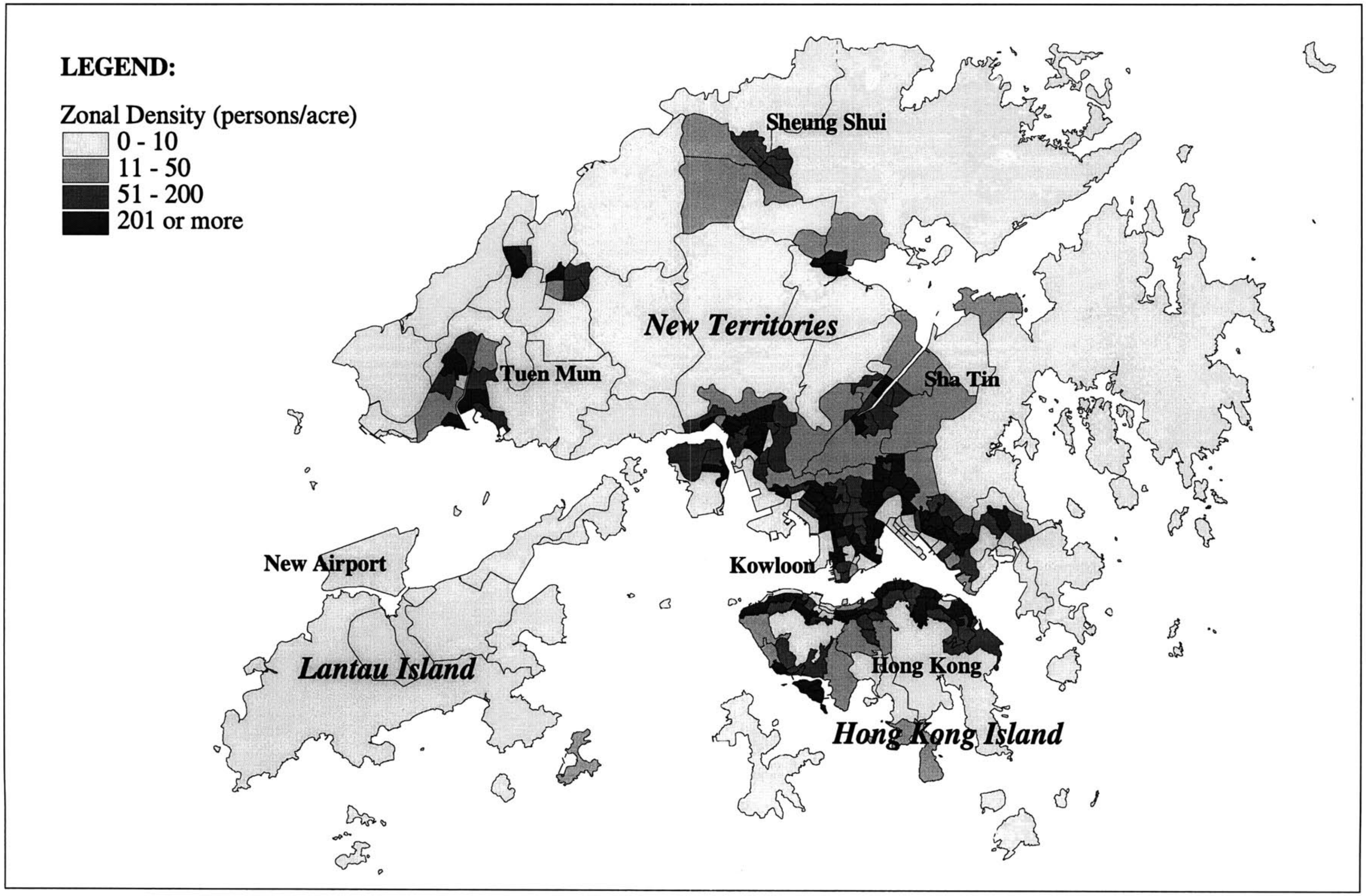
Table 5.1 Land Use in Hong Kong, 1996

Land Use Type	Area (km2)	(%)
A. Developed Land		
Commercial	2	0.2%
Residential	42	3.8%
Public Rental Houding	12	1.1%
Industrial	11	1.0%
Open Space	16	1.5%
Government, Institution and Community Facilities	18	1.6%
Vacant Development Land	41	3.8%
Roads/Railways	27	2.5%
Temporary Housing Areas	1	0.1%
Subtotal	***170***	***15.6%***
B. Undeveloped Land		
Woodlands	220	20.1%
Grass and scrubs	519	47.5%
Badlands, swamps and mangroves	44	4.0%
Arable	63	5.8%
Fish ponds	16	1.5%
Temporary structures/livestock farms	12	1.1%
Reservoirs	26	2.4%
Other uses	22	2.0%
Subtotal	***922***	***84.4%***
Total	**1092**	

Source: Dimitriou and Cook, 1998

Housing some seven million people on such a limited amount of land makes Hong Kong one of the most densely populated places in the world. The territory-wide population density is 6,350 people per km^2, whereas the population density of the built-up area is over 41,000 persons per km^2 (or nearly 166 persons per acre). Over half the population (52% as of 1998) concentrates at the metro area, i.e. the Hong Kong Island and Kowloon peninsula. In some areas along the northern coastal strip of Hong Kong Island, the western and eastern coastal strip of Kowloon, the population densities are as high as 50,000 per km^2 (over 200 persons per acre). (Figure 5.4)

Figure 5.4 Population Density in Hong Kong (1997)



5.3 A Case of Success in Transit-Based Mobility Supply

Because of the mountainous topography and concentration of a huge population, transportation planning and traffic management in Hong Kong are extraordinary challenging. In spite of the difficulties, however, Hong Kong's transportation practice has proved successful. Characterized as a transit city, Hong Kong provides its citizens high levels of mobility and accessibility that are comparable to those in automobile-oriented cities in many developed countries. Hong Kong's transportation strategies have been frequently cited as models for the development of other cities. Its experience has important implications to the global search for sustainable urban development and transportation policies.

The urban mobility and spatial access in Hong Kong are primarily provided by transit systems. In 2000, there were 6,354 public or franchised buses or cable cars operating on 983 fixed routes and 2,176 minibuses on flexible routes. There were also heavy or light rail services with a total of 128 kilometers in track length and 108 stations. 14 licensed ferry operators provide 32 regular passenger ferry services connecting Hong Kong Island to Kowloon and the outlying islands. In addition, there were 18,138 taxies territory-wide providing door-to-door services. Figure 5.5 shows the transit routes and stop/station locations on the Hong Kong Island.

Private vehicles play a secondary role in providing mobility and accessibility in Hong Kong. A 1992 survey shows that about one-sixth of Hong Kong residents have driver's licenses. 13% of households have cars or motorcycles and 1.6% have access to two or more vehicles. 2.9% have a goods vehicle or van available for commuting. In 1996 the private car and goods vehicle ownership were 52 and 77 per thousand people, respectively.

In Hong Kong there is a total of 1,885 kilometers of roadways (including designated highways and major road networks but excluding streets for local access) (Figure 5.6).

With a fleet of 503,974 licensed vehicles, the average traffic density is 267 vehicles per kilometer of road, among the highest in the world. The average travel speed, however, is relatively fast compared with other international cities (Table 5.2). For example, Hong Kong has per capita road supply only half of the Bangkok's. Road traffic flows (car and bus) in Hong Kong, however, are twice as fast as in Bangkok. The overall performance of the transportation system in Hong Kong with an average traffic of 28.1 kilometers per hour (km/h), is better than in Tokyo (25.3 km/h), and is close to Toronto (28.7 km/h).

Table 5.2 Road Supply and Traffic Speed in Selected World Cities, 1990

City	Road Supply (meters per capita)	Traffic Speed (km/h) Car	Train	Bus	Average
Hong Kong	0.3	25.7	40.2	18.4	28.1
Bangkok	0.6	13.1	34.0	9.0	18.7
Seoul	0.8	24.0	39.8	18.8	27.5
Singapore	1.1	32.5	40.0	19.2	30.6
London	2.0	30.2	48.3	19.0	32.5
Toronto	2.6	35.0	30.9	20.3	28.7
Tokyo	3.9	24.4	39.6	12.0	25.3
Sydney	6.2	37.0	42.0	19.0	32.7
Boston	6.7	52.3	32.6	20.1	35.0

Sources: Newman and Kenworthy 1999

Studies have suggested that income growth leads to growth in motorization, particularly to growth in private vehicle ownership and use (e.g. Ingram and Liu 1999). This is because as income grows, people's values of times increase and their desire to access more social services and opportunities increases. It results in greater demand for travel in magnitude, diversity and flexibility. The increased demand in various dimensions are operationally best met by private transportation means that are generally faster and more flexible. The general trend is evident at both the national and the urban level worldwide, as it has been shown by Ingram and Liu (1999).

What makes Hong Kong an outlier among the world cities is its high income but low levels of motorization and auto use. Its transit-based travel patterns do not fit into the conventional theory of *higher-income-more-car use*. As shown in Table 5.3, Hong Kong's motorization and private car ownership are only small fractions of those observed

Figure 5.5 Transit Routes and Stops on the Hong Kong Island in Hong Kong

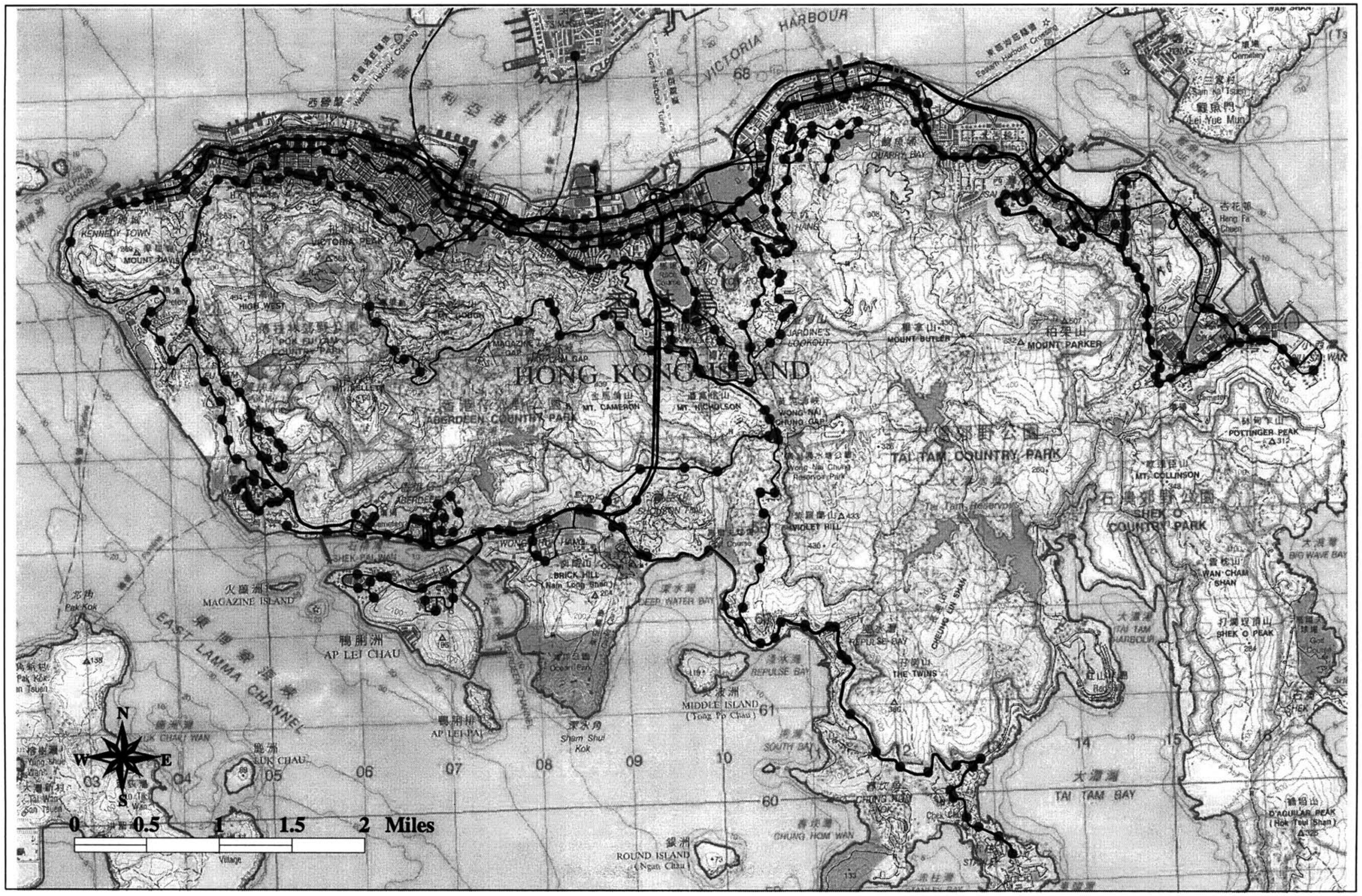
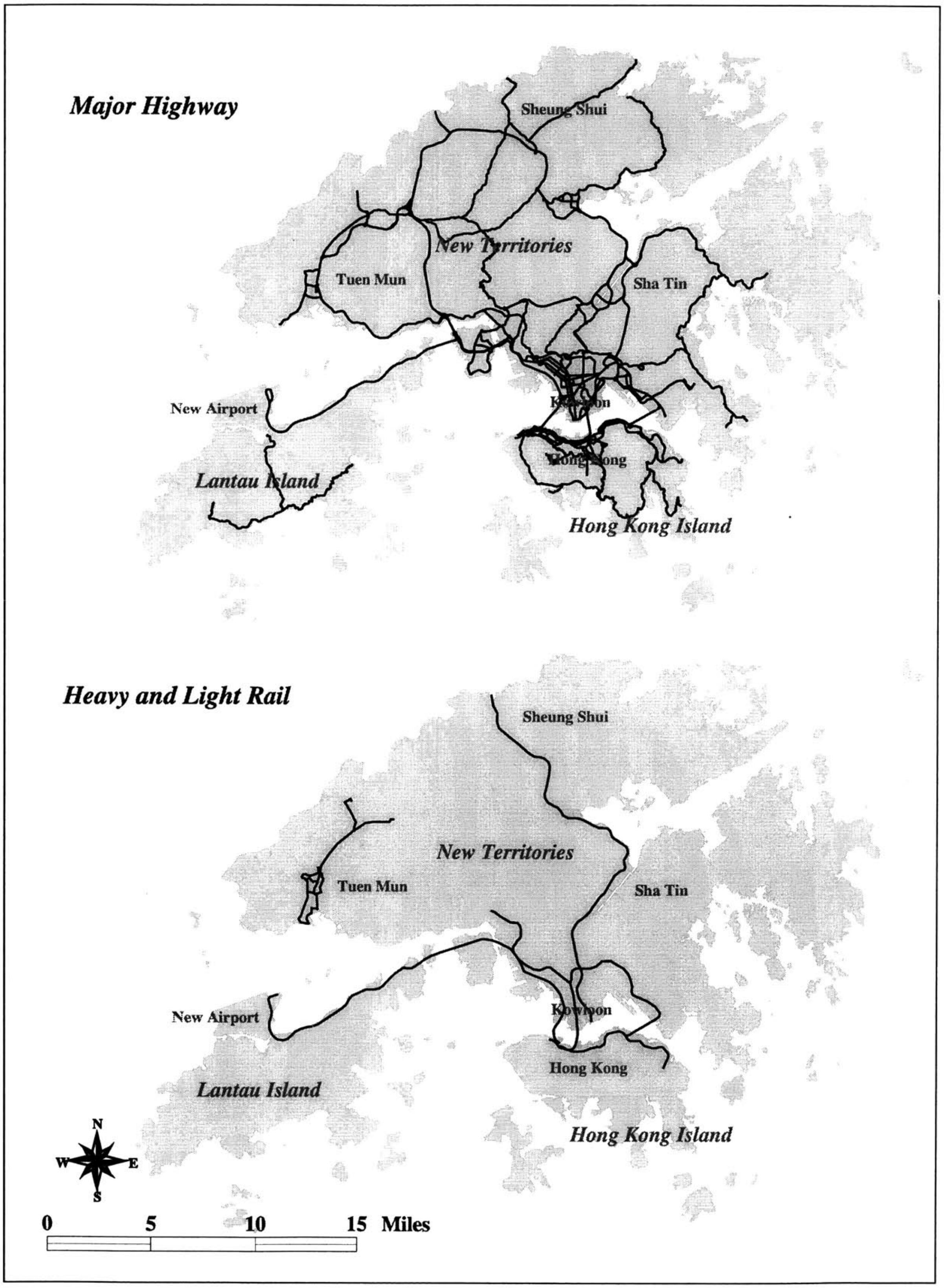


Figure 5.6 Major Highway and Rail Networks in Hong Kong



in other developed countries or regions that are in the same income category. For example, Hong Kong's car ownership of 52 cars per thousand people is only one-tenth of that in the US, although its real income (GDP per capita) is just ten percent less than the US. Compared with other Asian countries, Hong Kong has six-tenths of Japan's real income but a seventh of Japan's car ownership. Hong Kong's motorization and car ownership are less than half of Singapore's. The modal share of public transportation in Hong Kong is as high as 90%. The opposite is true in almost all North American cities where the modal share of private transportation is 80% or higher.

Table 5.3 Vehicle and Private Car Ownership in Selected Developed Countries/Regions, 1996

Country Name	Vehicles (1,000 people)	Cars (1,000 people)	GDP (US$) (per capita)
United States	773	518	27,590
Australia	601	488	20,370
Luxembourg	598	561	45,750
Italy	581	568	19,930
Canada	563	457	19,200
New Zealand	555	470	15,850
Japan	547	373	41,080
Germany	529	498	28,860
Iceland	524	462	26,480
France	523	438	26,290
Switzerland	501	462	43,420
Austria	496	458	27,940
Belgium	469	424	26,440
Norway	469	378	34,780
Spain	455	371	14,200
Sweden	450	411	25,770
Finland	431	378	23,230
Netherlands	409	361	25,850
United Kingdom	398	370	19,810
Denmark	388	332	32,250
Portugal	359	257	10,290
Ireland	305	279	17,450
Singapore	167	116	27,480
Hong Kong	*77*	***52***	***24,760***

Sources: Hau 1999, World Bank 1999

The question that is of special interest to this research is: what factors explain the radical deviation of Hong Kong people's mobility choice and travel patterns from the worldwide trend. One apparent, most frequently cited factor is Hong Kong's quality public transportation services that are made viable by its peculiar geography and by the high concentration of population and jobs. The Hong Kong case has often been mentioned as a distinguished example demonstrating the significant influence of land use on transportation and individuals' travel behavior. In the following we show that land use and transit supply only explain part of the story. The other part is Hong Kong's transportation policies that reflect the government's strong commitment and the public's acceptance to limiting the growth of owning and using private vehicles.

5.4 Explaining the Success

- **Consistent Regional Transportation Strategies**

Hong Kong's policy objective for transportation development has been to "keep Hong Kong moving" – to ensure the most efficient movement of goods and people to meet the region's needs of export-oriented economy and to cope with the great diversity of land use (Transport Department, The Government of HKSAR, 2000). While continuously investing in the transportation infrastructure, the government has also recognized that Hong Kong's topography prevents traffic from growing without bound. The government has therefore exercised its centralized power managing and regulating the transportation sector.

The territory's transportation planning practice and policy strategies find their roots in numerous transportation studies and public consultations in the past decades, and most notably are three Comprehensive Transport Studies completed in 1976, 1987, and 1999, respectively.

The first Hong Kong Comprehensive Transport Study (CTS-1) was commissioned in 1973-76 in responding to that the export-induced economic prosperity had resulted in continuous increase of motor vehicles since 1960s. The main purpose of the study was to determine the measures required to achieve and maintain an acceptable level of mobility for passengers and freight up to 1991. It was the first full review of long-term planning and development of transportation systems and policies in Hong Kong covering both road and public transportation networks. The study found that surprisingly three-quarters of Hong Kong's road space were being used by only a quarter of the traveling population (namely motorists and taxi occupants). Out of concern about the efficient supply and use of the road spaces within the territorial physical constraints, the study recommended a package of policy strategies: to improve the road networks, to expand existing rail transit lines and improve other public transportation systems, and to make more efficient use of existing road space.

One major strategy proposed to enhancing the efficient use of road space was to impose/increase fiscal measures that restrain auto ownership. There are two forms of fiscal measures: First Registration Tax (FRT), i.e. a purchase tax and Annual Licensing Fees (ALF). FRT was increased to the level of 15% of the cost-insurance-freight (c.i.f) value on all private cars and motorcycles (but not on goods vehicles) by March 1974. Annual vehicle license fees (ALF) were roughly trebled, with the high levels targeted primarily at private cars. In December, 1975, the FRT for private cars and motor cycles doubled to 30% and for goods vehicles and taxis the rate was 15%. The most lasting results of CTS-1 were the decision to construct the Mass Transit Rail (MTR) system and the realization that it would be necessary to restrain private car travel.

In 1986, the Hong Kong government decided to conduct the second Comprehensive Transport Study (CTS-2) in response to Hong Kong's rapid expansion, both geographically (due to the further development of the New Territories) and economically (From 1976 to 1986, Hong Kong's real GDP growth averaged 8.4 per cent annually). The purposes were, firstly, to establish detailed road infrastructure and public transportation development programs to support sufficient mobility in Hong Kong up to the year 2001; and secondly, to develop an analytical tool capable of assisting in the formulation of transportation policies able to reflect quickly the effects of changes in policies on the transportation infrastructure of the territory. CTS-2 was later updated in 1990-93. The study recommended construction of three major highways (i.e. Route 3, 7 and extension of the Hung Hom bypass) with a total investment of HK$23 billion. In respect to public transport, a HK$9 billion rail investment program including rolling stock for railways. Extensions to the new towns was recommended. Furthermore, a major rail line within the urban area costing HK$20 billion was recommended for consideration for the late 1990's.

In addition to the positive supply measures, CTS-2 also recommended four policy packages: i) car ownership taxation, i.e. raising FRT by 50%; ii) doubling the fuel tax; iii) goods vehicle taxation from 15% FRT to 70%-90% to reduce the fleet by 15%; and iv) area pricing as a long-term option. A set of supplementary measures including vehicle quotas of minibuses and taxis, parking controls and tunnel tolls are combined with the four packages. (Not all these recommended policy measures were fully implemented due to public objection.)

The third long-term transportation study, CTS-3, was commissioned in August 1997 (the last year under the British colonial rule) and completed in 1999. In the ten years (1988-1998) after the completion of CTS-2, Hong Kong had experienced rapid growth in population (1.9% annually), GDP per capita (1.8% annually in real terms) and private vehicle fleet (6.9% annually). The overall objective of CTS-3 was to determine what should be done to achieve and maintain an acceptable level of mobility for passengers and freight by all transportation modes up to the year 2016 and to enable continued social and economic development in a environmentally sustainable manner as far as possible (The Government of HKSAR, 1999). Continuing to recommend infrastructure expansion as previous CTS studies did, CTS-3 placed greater emphasis on 1) rail-based public transportation, 2) integration of land use/transportation development and environmental sustainability, 3) cross-border link and development between Hong Kong and the mainland, and 4) use of advanced technology such as ITS to monitor road conditions and to manage traffic.

There are three policy principles that are established based on and consistent throughout the CTS-1~3: 1) improve the road system and transportation infrastructure, 2) expand and improve the public transportation system, and 3) make efficient use of road space. In the past decades, these principles have guided the territory's transportation policy making. As noted by Hau (1999), it is the Hong Kong government's comprehensive policy of providing a package of supply enhancements and traffic management measures to date that keeps Hong Kong moving.

- **Diversified Public Transportation Systems**

Over the years, Hong Kong has developed an efficiently operated and financially sustained public transportation system. It has been the government's policy to give priority to public transportation and to allow healthy competition among different modes of public transportation. The purpose is to promote service efficiency and to provide no direct subsidy. An important feature of Hong Kong's public transportation is the diversity of services that cover almost every segment of the market in the region. The services are provided by a multi-modal systems, including buses, minibuses, light and heavy rails and tramways, ferries and taxies.

Buses: Franchised bus services are provided by five major bus companies in Hong Kong. These double-decker buses, which run from 6 AM till 3 after midnight, cover most parts of the territory. (1) Citybus Limited is a franchised operator on Hong Kong Island. It operates about 108 bus routes, including 65 Hong Kong Island routes, 26 cross-harbour routes, and 16 routes to Tung Chung/Airport. It has a licensed fleet of about 960 air-conditioned buses. (2) The New World First Bus Services Limited (NWFB) operates about 61 Hong Kong Island routes and 32 cross-harbour routes, with a licensed fleet of some 730 buses. (3) The Kowloon Motor Bus Company (1933) Limited (KMB) operates about 385 bus routes in Kowloon and the New Territories and 61 routes on cross-harbor services. With a licensed fleet of 4,065 buses, mostly double-deckers, KMB is one of the largest road passenger transportation operators in Southeast Asia. (4) Long Win Bus Company Limited provides bus services to north Lantau and the Airport. It operates 15 routes with a fleet of 159 double-deck air-conditioned buses. (5) The New Lantau Bus Company (1973) Limited operates 18 routes on Lantau Island. The fleet comprises 90 single-deck buses, serving mostly leisure travel especially in the summer and on Sundays and public holidays due to recreational demands.

Minibuses: Public Light Buses (PLBs) are minibuses with no more than 16 seats. The fleet size is fixed at a maximum of 4,350 vehicles territory-wide. Some PLBs are used on scheduled services (the green minibuses) and others on non-scheduled services (the red minibuses). (1) Red minibuses are free to operate anywhere without control over routes or fares, except where special prohibitions apply. There were 2,176 red minibuses by June 1998. (2) Green minibuses operate on fixed routes at fixed fares that are generally higher than those of franchised buses. By June 1998, there were 68 green minibus routes on Hong Kong Island, 66 in Kowloon and 161 in the New Territories, employing a total of 2,174 vehicles. Red minibuses carry about 790,000 passengers a day, while green minibuses carry about 980,000 passengers daily.

Rail: There are three types of rail transit services in Hong Kong, the metro subway Mass Transit Railway (MTR), the Light Rail Transit (LRT) in the new towns, and the suburban commuter rail Kowloon-Canton Railway (KCR). MTR is an underground heavy railway network with five lines and 44 stations over a total route length of 43.2 kilometers (27 miles). It is government-owned and started operating in late 1979. The Tung Chung Line and Airport Express (a route length of 34 kilometers or 21 miles) came into service in mid-1998. The Kowloon-Canton Railway (KCR), completed in 1910, is 34 kilometres long with 13 intermediate stations and runs from Hung Hom in Kowloon up to the border with Shenzhen of mainland China. The double-tracked line was fully electrified in 1983. Through-train services to and from Beijing and Shanghai are also operated on the same track route. The Light Rail Transit (LRT), starting services in 1988, is owned and operated by KCR. The current system serves the new towns in north-west New Territories. The system comprises 31.75 kilometres of double track, 119 single-deck light rail vehicles and 57 stops.

Trams: Electric trams have been running in Hong Kong since 1904. Hongkong Tramways Limited operates eight routes along the north-shore of Hong Kong Island on a 16-kilometre track with a total of 161 double-deck trams. Another Hong Kong' s tramway is a cable-hauled funicular railway, operated by Peak Tramways Company Limited since 1888. The 1.4 kilometres line runs between Central and the Victoria Peak, with four stops en route, serving mainly tourists and local sightseers.

Ferries: There are 14 licensed ferry operators providing 32 regular passenger ferry services in Hong Kong. The Star Ferry, which has connected Hong Kong Island and Kowloon since 1898, runs regularly between 6.30am to 11.30pm. The Hong Kong Ferry (Holdings) Company provides other regular and inexpensive services that connect Hong Kong Island to other parts of the Kowloon Peninsula and to the outlying islands.

Taxis: Providing a convenient, personalized point-to-point transportation service, taxi plays a key role in Hong Kong's public transportation systems. In 2000, there are 18138 taxis in Hong Kong, of which 15250 are urban taxis or the Red taxis, serving Hong Kong Island and Kowloon; 2838 are the Green taxis, serving the New Territories; and 50 are the Blue taxis, serving the Lantau Island.

- **Restrictive Automobile Policies**

Along with the plentiful supply of public transportation services are high charges on owning and use of private vehicles. The after-purchase costs of owning and using private automobiles in Hong Kong are among the highest in the world. These costs include FRT, ALF, insurance, fuel price and parking charges.

Hong Kong does not have its own auto industry. All vehicles are imported. Vehicles, no matter whether it is a company vehicle or private car, brand new or used, imported into Hong Kong are not subject to any customs tax. However, under the Motor Vehicles (First Registration Tax) Ordinance (Chapter 330), no vehicle can be driven or used on public roads unless it is registered and licensed. Table 5.4 lists the first registration tax rates applied to various vehicle types in Hong Kong as of the Year 2000. License fees are charged on the one-year or four-month basis. The fee schedule is shown in Table 5.5. In Hong Kong, car registration tax is, on average, 50% , compared to the 5% sales tax in Boston.

The fuel price in Hong Kong is also high. As of 1998, the unleaded gasoline is HK$10.04 per liter, or US$4.87 per gallon, about four times of the US average.

Table 5.4 Vehicle First Registration Fees in Hong Kong, 2000

Vehicle Class	**First Registration Tax (%) (of vehicle's taxable value)**
Private Cars	40~60%
Motorcycles	40%
Goods Vehicles	18%
Van-type Light Goods Vehicles (<=1.9 tonnes)	40~50%
Van-type Light Goods Vehicles (>1.9 tonnes)	20%
Other vehicles	4%

Sources: Hong Kong Government, 2001

Note:
In general, the taxable value of a vehicle is calculated on the basis of the published retail price of the vehicle or the provisional taxable value assessed by the Customs and Excise Department. However, the value of any exempted accessory (i.e. air-conditioning unit, anti-theft devices or audio equipment) fitted and any warranty other than manufacturer's warranty provided will not be included in the calculation of taxable value of the vehicle.

Table 5.5 Vehicle License Fees in Hong Kong, 2000

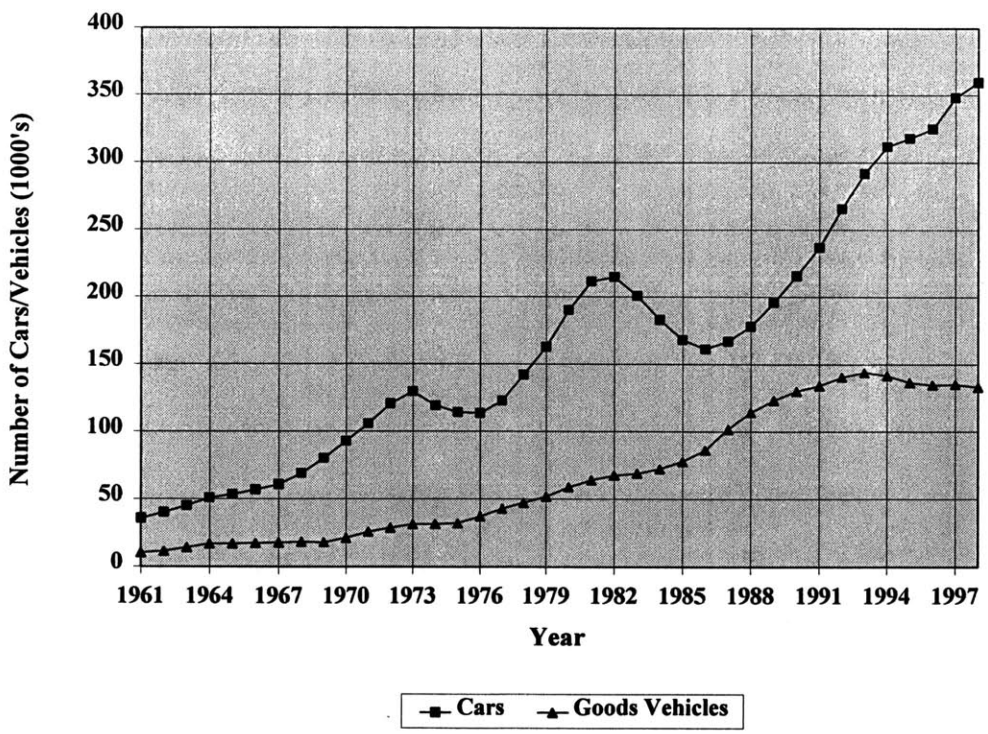
Vehicle Class	Annual(HK$)	4-month(HK$)
Private Car (Petrol)		
Cylinder Capacity:		
(a) not exceeding 1,500c.c.	3,929	1,404
(b) exceeding 1,500 c.c. but not exceeding 2,500 c.c.	5,794	2,056
(c) exceeding 2,500 c.c. but not exceeding 3,500 c.c.	7,664	2,711
(d) exceeding 3,500 c.c. but not exceeding 4,500 c.c.	9,534	3,365
(e) exceeding 4,500 c.c.	11,329	3,994
Private Car (Diesel)		
Cylinder Capacity		
(a) not exceeding 1,500c.c.	5,389	1,915
(b) exceeding 1,500 c.c. but not exceeding 2,500 c.c.	7,254	2,567
(c) exceeding 2,500 c.c. but not exceeding 3,500 c.c.	9,124	3,222
(d) exceeding 3,500 c.c. but not exceeding 4,500 c.c.	10,994	3,876
(e) exceeding 4,500 c.c.	12,789	4,505
Motor Cycle and Motor Tricycle	1,314	488
Goods Vehicle & Special Purpose Vehicle		
(other than Van-Type Light Goods Vehicle)		
Permitted Gross Vehicle Weight:---		
(a) not exceeding 1.9 tonnes	1,289	480
(b) exceeding 1.9 tonnes but not exceeding 5.5 tonnes	2,404	870
(c) exceeding 5.5 tonnes	4,694	1,671
Van-Type Light Goods Vehicle		
Permitted Gross Vehicle Weight:---		
(a) not exceeding 1.9 tonnes	2,229	809
(b) exceeding 1.9 tonnes	4,254	1,517
Public Bus		
(a) for the driver; and	25	$30+35% of Annual Rate
(b) additional fee for each seat for a passenger	50	
Private Bus		
(a) for the driver; and	25	$30+35% of Annual Rate
(b) additional fee for each seat for a passenger	45	
Taxi	3,159	1,134
Public Light Bus	8,429	2,979
Private Light Bus	2,749	991
Electrically Powered Passenger Vehicle		
(a) not exceeding 1 tonne unladen weight; and	440	$30+35% of Annual Rate
(b) an additional fee for each 250 kg unladen weight or part thereof	95	
Trailer For each 250 kg permitted gross vehicle weight or part thereof, excluding any gross vehicle weight of the trailer imposed on the drawing vehicle	30	35% of Annual Rate

Source: Hong Kong Transport Department

Note: Fees are in Hong Kong dollar. US$1=HK$7.8

The effects of the fiscal restraint measures on the ownership of private cars and motorcycles are better seen by plotting out the longitudinal data on number of registered cars over time (Figure 5.7). On the car fleet curve in Figure 5.7, the two humps correspond to year 1974 and 1982 when two major vehicle ownership measures (non applied to goods vehicles) were implemented. In 1974, car fleet started declining and reached the trough in 1976. Thereafter, the downward trend reversed itself and started ascending and did not exceed the past peak of 1973 until 1978. A similar and prolonged effect is observed in 1982 and after. Hong Kong's car fleet declined from its peak in 1982 and did not regain the same level until 1990, eight years after the fiscal restraint measure of 1982. Evidently, it was the two drastic vehicle ownership measures of 1974 and 1982 that were primarily responsible for the interruption of the rising trend in the vehicle fleet of private cars and motorcycles in postwar Hong Kong.

Figure 5.7: Registered Car/Vehicle Growth in Hong Kong



The above observation also suggests that fiscal measures such as FRT and ALF in restraining private car ownership are effective mostly in the short- or mid-term. When income further grows, the impacts of these fiscal measures diminish. In order to maintain their influence, FRT and ALF have to increase along with income. This is what the transportation authorities in Hong Kong have been doing. In addition, dynamic management of road use such as electronic road/area pricing is also in consideration.

In sum, Hong Kong's low automobile ownership and small share of auto travel are the results of the government's strong commitment to control the private automobile and to promote public transportation. Hong Kong's strong fiscal constraint suppresses to a large extent the demand for owning and using private automobile. The positive supply of the public transportation services serves much of the region's travel needs. The two form a pair of 'push and pull' forces that have maintained a relatively high level of urban mobility and accessibility in the region.

5.5 Mode Choice Modeling and the Role of Land Use

In this section we present an empirical analysis examining the effects of land use and transportation policies on the people of Hong Kong's travel behavior by modeling their travel mode choices. As in the Boston case study, the purposes of modeling mode choice are: (1) to examine how land use characteristics is associated with individual's travel choice decision while controlling for important behavioral variables such as price and taste preferences; (2) to provide a modeling context for analysis of automobile dependency reported in the following section; and 3) to provide empirical results for the simulation analysis of policy effects.

The main data source is the Travel Characteristics Survey commissioned by the Hong Kong Government in preparing for the Third Comprehensive Study (completed in 1999). The survey includes a sample of 23,259 households and 77,271 people who made a total of 97,897 trips at time of survey. Of these, 49,097 (or 63.5%) are work-related trips and 25,460 are home-based work trips.

Again, as in the Boston case study, GIS (Geographic Information System) and RDBM (Relational Database Management) tools are utilized to efficiently organize and process the data sets. Specifically, the following four types of data are used (Refer to Chapter 3 for the structure of the database set up in Sybase for PC):

- 1992 territory-wide Travel Characteristics Survey. It includes seven files: (1) Interview general data profile containing information on dates of interview and street block locations of households. (2) Household profile on household size and income. (3) Household member profile on individual member's gender, age, occupation, and usual mode of travel. (4) Trip making profile on origins, destinations, times of travel and modes used. (5) Mode choice profile on modes used for each segment of trip with detailed information on vehicle occupancy. (6) Vehicle type ownership profile on number of private- and company-owned vehicles in households. (7) Vehicle parking profile on availability of private and public parking and level of subsidies received for parking.

- 1997 Skim Tables on zonal travel time and costs by all modes for the 274 traffic analysis zones (TAZ) in Hong Kong.

- Zonal population, employment and public and private parking supply.

- Transit information (for the Hong Kong Island only) including service capacities and frequencies by all types of transit modes at route level and geographical data such as street networks, transit routes.

Table 5.6 summarizes the descriptive statistics of the major control variables entered into the final choice model. General travel characteristics are highlighted below.

- The number of trips made per weekday in 1992 was 10,298,000, or 1.85 trips per day per person. Total trips have grown by 24% over nine years, from 1981 to 1992, and growth has been mainly in the home-based non-work travel and non-home-based travel. Trip making by public modes is 1.48 trips per capita per day, four times of trip rate by private mode (cars).

- 11.5% of all trips are made by private modes (cars or motorcycles) and 8.3% by taxi. The rest 80% of trips use public transportation. Of the commuting trips, only 6.1% are made by private cars and 2.4% by taxi. Public transportation modes carry 91.5% of all journey-to-work trips.

- Average travel times are shorter in 1992 than in 1981. For public transportation the average travel time is 42 minutes compared with 50 minutes in 1981; and for private modes it has dropped from 30 minutes to 28 minutes. The general decrease in average journey times despite of substantial increase in commuting suggests improvement of transportation services in Hong Kong mainly due to the expansion of the rail subway system MTR, and bus and minibus networks.

Table 5.6: Sample Descriptive Statistics for Home-Based Work Trips

Variables	Mean	Std. Dev.	Min.	Max.
Trip Maker Socio-Demographic Characteristics				
Age (years)	36	11	17	65+
% of Female	36%			
Household Size (persons)	4	1.6	1	13
No. of Kids under Five	0.12	0.38	0	4
Household Income (HK$/Year)	251,872	200,013	12,000	900,000
No. of Vehicles in Household	0.23	0.5	0	7
No. of Vehicles per Person	0.065	0.17	0	5
No. of Company Vehicles in Household	0.06	0.3	0	6
% of Vehicle-owning Households with Parking Subsidy	25%			
Travel Costs				
Rail Time (minutes)	57.0	29.3	3.2	240.3
Bus Time (minutes)	49.3	24.7	2.6	188.9
Car Time (minutes)	43.5	17.7	8.0	173.0
Taxi Time (minutes)	29.2	17.0	4.0	182.0
Rail Costs (HK$, one way)	8.2	4.3	0.4	26.5
Bus Costs (HK$, one way)	7.6	4.7	0.1	33.7
Car Costs (HK$, one way)	46.9	22.5	0.5	131.6
Taxi Costs (HK$, one way)	56.5	43.1	0.5	321.8
% with Parking Subsidy	4.9%	0.22	0	100%
Land Use Attributes				
Job density (jobs/acre)	111	230	0	2293
Population density (persons/acre)	152	181	0	986
Private parking spaces (spaces per 100 person)	5	16	0	214
Public parking spaces (spaces per 100 jobs)	2	4	0	22

In modeling mode choices of home-based work trips, three types of explanatory variables are considered (Table 5.6), which is in contrast to the Boston case where transit supply and boarding information is available at the stop/station levels).

The first one includes variables describing the social and economic characteristics of the travelers and their households. Specifically, these include age, gender, employment status, and driving capability (holding a driving license or not) of individuals, and household income, vehicle ownership, and family structure.

The second one includes price variables related to travel. They are travel time and monetary costs for all modes. Subsidy for vehicle parking is also considered as an important factor influencing people's mode choice decision.

The third type of variables includes the indicators of land use characteristics such as population and job densities. Detailed information on land use by different functions (e.g. commercial, residential, industrial and institutional) is not available for this case study. Therefore indicators characterizing other aspects of land use patterns such as land use mix or balance cannot be derived in the same way as we did in the Boston case. It is well known however, land use activities in Hong Kong are highly mixed with building structures typically having commercial or office use at the lower floors and residential on the upper levels. Except for the affluent residential areas on the southern side of Hong Kong Island and small areas of financial and banking concentrations in the central district, functional segregation of land uses is rarely seen in Hong Kong. Hence, we can reasonably assume that the potential effects of land use mixture on Hong Kong people's travel behavior tend to be uniform across different modes. In a similar reasoning, urban form indicator at the micro level is also ignored.

- **Nested Logit Model Structure**

There are 11 modes aggregated from the original 25 types of travel means recorded in the travel survey (Table 5.7). Nine of the 11 are public in nature. Since our research interest lies at people's travel decisions in choosing public vs. private modes rather than predicting the choices of specific modes, further aggregation of the observed choice outcome into a smaller number of categories is necessary in order to reduce computing costs. However, grouping all public modes into one category is also problematic analytically due to the overwhelming dominance of model share (over 90%) which causes too skewed a distribution.

Table 5.7 Sample Mode Choice Distribution

Public Mode	Observations	Share
Mass Transit Railway (MTR)	7310	29.83%
Kowloon-Canton Railway (KCR)	1330	5.43%
Light Rail Transit (LRT)	451	1.84%
Tramways	464	1.89%
Ferry	542	2.21%
Public Light Bus (PLB)	2634	10.75%
City Bus	8930	36.44%
Special Purpose Bus (SPB)	599	2.44%
Taxi	737	3.01%
Total Public	***22260***	***90.83%***
Private Mode		
Car or Motorcycle	1947	7.94%
Goods Vehicle or Truck	301	1.23%
Total Private	***2248***	***9.17%***
Total	**24508**	**100%**

Aggregated Modal Shares in the sample		
Rail	9093	36.02%
Bus	13167	52.16%
Car	2248	8.90%
Taxi	737	2.92%
Total	**25245**	100.00%

Accordingly, we group all public transportation modes into three types: *rail, bus* and *taxi* based on their service characteristics. Rail contains MTR, KCR, and LRT, whereas bus includes all other public modes excluding taxi. Rail services differ from bus. For example, rail is protected from road congestion as trains run at grade levels, either elevated or under ground, or have operational privilege through traffic signal control. Running along fixed tracks, Tramways are still considered as bus-type because their service features such as running on streets at lower travel speeds and stopping frequently resemble regular bus services more than rail. Taxi differs from rail and bus in that it provides door-to-door services like private automobile. However, taxi differs from private automobile because it is demand-responsive, meaning that users need to wait or have to walk to or from taxi stands. Therefore, for the modeling purpose, taxi is treated as a unique mode, separated from private or other public modes. The aggregated modal shares of home-based work trips are also shown in Table 5.7.

From travelers' perspective, however, rail and bus services do share a number of common characteristics. For example, they do not provide door-to-door service convenience. They only operate on certain routes and schedules, which often require transfer and waiting. Still other intangible factors include comfort, reliability, safety, and privacy. These shared attributes differentiate public travel modes from private ones such as car and motorcycle. They affect people's mode choice decisions with certain degree of correlation. Not all of these attributes, however, can be explicitly accounted for due to data limitations. Our Hong Kong case database, for example, lacks information on out-of-vehicle travel times and number of transfers for trips made by the public modes. We also have no information indicating Hong Kong people's general attitude to public transportation relative to private means. Lack of such information creates an issue concerning the applicability of the multinominal logit (MNL) model to mode choice analysis in this case study due to strict assumptions to be satisfied for the application of MNL (Ben-Akiva and Lerman 1985). Specifically, one of MNL's key properties, Independence from Irrelevant Alternatives (IIA), is likely to fail because of the unaccounted, shared attributes of rail and bus. Similarly, there may be correlation between car and taxi, and between taxi and other public transportation modes as well.

There are basically two approaches to addressing the issues. One is to run a number of statistical tests to test the appropriateness of a pre-specified MNL structure. Known tests include the Small and Hsiao test (1982), and Hausman and McFadden test (1984). If the tests fail, alternative model structures should be sought. The other approach is to directly specify a number of different model structures, including nested logits, based on *a priori* or common knowledge. All these models are then empirically estimated using the same data set. The best model is chosen based on the evaluation of the estimates of variable coefficients and of the structure coefficients. Given the relative small number of choice alternatives (four in our case), we take the second approach.

Figure 5.8 Alternative Model Specifications for Model Choice Modeling

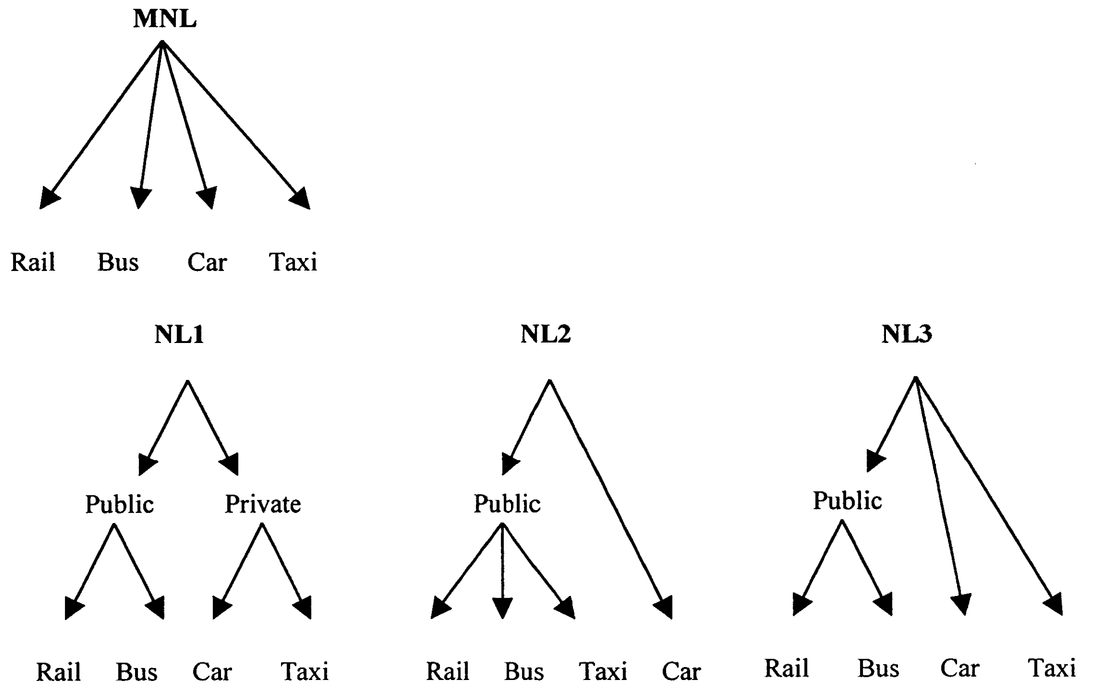


Figure 5.8 show a number of alternative specifications for our Hong Kong's mode choice model based on different assumptions on the relationships in the unobserved attributes among the four modes. It includes a base MNL model and three other nested logit (NL1~3) structures with different groupings of public and private modes. NL1 assumes that rail and bus share common characteristics of public transportation in contrast to Car and Taxi that are similar as private modes. NL2 indicates that rail, bus and taxi share some unobserved attributes and as a group are different from the car mode. NL3 suggests that rail and bus are similar, whereas car and taxi are independent (in the unobserved terms) from each other and from the public transportation.

Empirical tests of the model structures rely on the estimates of the coefficients, namely the structure coefficients of the *public* and *private* mode indicators at the intermediate levels of the nested structures. The null hypothesis is that the structure coefficient of a branch in a nested model is equal to one. If the null hypothesis is accepted, the nested structure collapses into a MNL model, meaning that the MNL specification is appropriate and the effects of the unobserved attributes of modes on individuals' model choices can be ignored statistically. On the other hand, if the null hypothesis is rejected, i.e. the structure coefficient is smaller than one, the nested structure is considered more appropriate. A structure coefficient that is greater than one or less than zero indicates serious model specification errors (Ben-Akiva and Lerman 1985).

- **Estimation Results**

Table 5.8a~d reports estimation results with the four structure specifications. In the MNL model, most land use variables perform poorly with wrong signs. Parking policy-related variables do not enter as statistically significant. In contrast, the explanatory variables in the nested models (NL1~3) generally perform better (in a statistical sense) than in the MNL model. In the model NL1, however, the structure coefficient is significantly greater than one at 99% confidence level, suggesting the inappropriateness of the model specification. NL2 and NL3 are structurally acceptable with the structure coefficient less than one and greater than zero in each specification. In model NL2, the land use variables, i.e. population and job density at trip destinations, and the parking policy variables, i.e. parking subsidy and public parking space supply, are statistically insignificant at 95% level of confidence, but they do in model NL3. Overall, model NL3 offers greater explanatory power, with the value of Rho-squared (equivalent to the R-squared in least square regression) of 0.39957, compared to model NL2 (Rho-squared 0.39736). Accordingly, NL3 is chosen as the final model for our Hong Kong case study.

Table 5.8a MNL Mode Choice Modeling Results

Coefficient	Estimation	Std Error	t ratio
Constant (rail)	-0.21437	0.11079	-1.93497
Constant (bus)	0.74106	0.10776	6.87718
Constant (car)	1.10725	0.13589	8.14838
Travel Time (rail)	-0.00398195	0.00120255	-3.31125
Travel Time (bus)	-0.0320591	0.00144754	-22.1474
Travel Time (car)	-0.0282574	0.002563	-11.0251
Travel Time (taxi)	-0.059915	0.00503711	-11.8947
Travel Cost (rail)	-10886.5	678.076	-16.055
Travel Cost (bus)	-8510.69	711.898	-11.9549
Travel Cost (car)	-1699.21	231.709	-7.33341
Travel Cost (taxi)	-9592.41	496.63	-19.315
Young (rail, bus)	0.32395	0.0511842	6.32911
Female (rail, bus)	0.77144	0.0550656	14.00948
Vehicle Ownership (car)	1.00092	0.15723	6.36599
Population Density at Origins (rail, bus)	0.0011288	0.000151115	7.46979
Job Density at Origins (rail, bus)	-0.00016833	0.000206791	-0.81401
Population Density at Destiations (car)	-9.32508E-05	0.000180273	-0.51727
Job Density at Destinations (car)	-1.37289E-05	6.36696E-05	-0.21563
Parking Subsidy (car)	0.11119	0.072775	1.52789
Public Parking Supply (car)	2.07741	1.45641	1.42639
Number of observations :	25215		
Log-likelihood at Convergence:	-15874		
Initial log-likelihood:	-26352		
Rho squared :	0.39762		
Rho bar squared:	0.39686		

Table 5.8b NL Specification #1 Mode Choice Modeling Results

Coefficient	Estimation	Std Error	t ratio
Constant (rail)	0.6739	0.2834	2.378
Constant (bus)	1.704	0.2857	5.964
Constant (car)	0.9172	0.1159	7.912
Travel Time (rail)	-0.01363	0.001659	-8.214
Travel Time (bus)	-0.045	0.002107	-21.35
Travel Time (car)	-0.0153	0.002052	-7.456
Travel Time (taxi)	-0.04608	0.004199	-10.97
Travel Cost (rail)	-9628	778	-12.38
Travel Cost (bus)	-7117	826.6	-8.61
Travel Cost (car)	-724.7	168.4	-4.304
Travel Cost (taxi)	-6015	495.5	-12.14
Young (rail, bus)	0.7376	0.1366	5.402
Female (rail, bus)	1.787	0.2175	8.218
Vehicle Ownership (car)	0.8519	0.1249	6.821
Population Density at Origins (rail, bus)	0.002801	0.0004631	6.049
Job Density at Origins (rail, bus)	0.0001717	0.0004878	0.352
Population Density at Destiations (car)	-0.0003467	0.0001437	-2.413
Job Density at Destinations (car)	-0.0001359	0.00005187	-2.619
Parking Subsidy (car)	0.1241	0.05703	2.176
Public Parking Supply (car)	2.941	1.159	2.537
Structure Coefficient: Private Transport	1.281	0.04926	5.696
Structure Coefficient: Public Transport	0.4419	0.04339	-12.86
Number of observations :	25245		
Log-likelihood at Convergence:	-15823.9		
Initial log-likelihood:	-26387.5		
Rho squared :	0.40033		
Rho bar squared:	0.39949		

Table 5.8c NL Specification #2 Mode Choice Modeling Results

Coefficient	Estimation	Std Error	t ratio
Constant (rail)	-0.2769	0.1153	-2.401
Constant (bus)	0.6935	0.1113	6.233
Constant (car)	0.884	0.1473	6.0
Travel Time (rail)	-0.005624	0.001381	-4.073
Travel Time (bus)	-0.03441	0.00172	-20.01
Travel Time (car)	-0.02611	0.002549	-10.24
Travel Time (taxi)	-0.06405	0.005278	-12.14
Travel Cost (rail)	-10790	691.3	-15.6
Travel Cost (bus)	-8346	726.2	-11.49
Travel Cost (car)	-1530	232.8	-6.571
Travel Cost (taxi)	-9520	494.7	-19.24
Young (rail, bus)	0.3412	0.05536	6.164
Female (rail, bus)	0.791	0.05973	13.24
Vehicle Ownership (car)	1.017	0.1548	6.567
Population Density at Origins (rail, bus)	0.00127	0.0001698	7.477
Job Density at Origins (rail, bus)	-0.0001469	0.0002178	-0.6746
Population Density at Destiations (car)	-0.0001899	0.0001789	-1.061
Job Density at Destinations (car)	-0.00005266	0.00006353	-0.8289
Parking Subsidy (car)	0.1296	0.07191	1.802
Public Parking Supply (car)	2.47	1.445	1.709
Structure Coefficient: Public Transport	0.8589	0.04686	-3.012
Number of observations :	25245		
Log-likelihood at Convergence:	-15902.2		
Initial log-likelihood:	-26387.5		
Rho squared :	0.39736		
Rho bar squared:	0.39656		

Table 5.8d NL Specification #3 Mode Choice Modeling Results

Coefficient	Estimation	Std Error	t ratio
Constant (rail)	0.5489	0.2679	2.05
Constant (bus)	1.58	0.27	5.85
Constant (car)	1.14	0.1322	8.62
Travel Time (rail)	-0.0137	0.001653	-8.29
Travel Time (bus)	-0.04511	0.002098	-21.50
Travel Time (car)	-0.01937	0.002471	-7.84
Travel Time (taxi)	-0.05007	0.00499	-10.03
Travel Cost (rail)	-9592	775.6	-12.37
Travel Cost (bus)	-7075	823.8	-8.59
Travel Cost (car)	-936.5	209.3	-4.47
Travel Cost (taxi)	-8370	491.5	-17.03
Young (rail, bus)	0.7513	0.1355	5.54
Female (rail, bus)	1.764	0.2127	8.30
Vehicle Ownership (car)	1.019	0.1518	6.72
Population Density at Origins (rail, bus)	0.002911	0.0004646	6.26
Job Density at Origins (rail, bus)	*0.0002069*	*0.0004819*	*0.43*
Population Density at Destiations (car)	-0.0004239	0.0001776	-2.39
Job Density at Destinations (car)	-0.0001709	0.00006353	-2.69
Parking Subsidy (car)	0.1553	0.07052	2.20
Public Parking Supply (car)	3.455	1.438	2.40
Structure Coefficient: Public Transport	0.4399	0.04253	-13.17
Number of observations :	25245		
Log-likelihood at Convergence:	-15843.8		
Initial log-likelihood:	-26387.5		
Rho squared :	0.39957		
Rho bar squared:	0.39878		

Note: The t-statistic for the structure coefficient refers to the null hyphothesis of the coefficient equal to 1 [t=(0.4399-1)/0.04253=-13.17]

Specifically, as shown in Table 5.8d NL3, of the 21 coefficients estimated, all but one are statistically significant at 95% or higher confidence level. The coefficients of the cost (travel times and monetary costs) variables have negative signs as expected, conforming to the common knowledge that, when the price of travel by a mode increases (e.g. longer travel time or more monetary costs of travel), the demand for travel by that mode decreases. Parking subsidy works in the opposite way to cost variables in affecting people's mode choices as it reduces the direct operating costs of vehicles. This is shown by the positive coefficient (0.1553) of parking subsidy variable specific to the car mode, meaning that, when there are vehicle parking subsidies, people tend to choose driving.

The modeling results also suggest that in Hong Kong, female workers without children and young people prefer taking public transportation (buses, subway, light rail or ferry) to driving, a similar behavior to what we found in the Boston case study. On the other hand, when there are more vehicles per person in a household, members of the household are more likely to drive to work than to take transit.

Notably, population densities at trip origins are positively associated with transit use. Employment densities at trip origins, on the other hand, seem irrelevant to people's decisions on travel means to work. The negative estimates of the coefficients of density variables measured at trip destinations suggest that, when travel time, costs, and other factors are controlled, people working in places where employment and population densities are higher are unlikely to commute by driving.

Public parking supply at trip destinations is considered as a spatial constraint to vehicle use. Intuitively, when there is more parking supply, driving mode is more likely to be chosen. The significance of parking supply in influencing people's driving decisions has been examined both theoretically and empirically in the US cities (e.g. Pickrell and Shoup 1975, Wilson 1995, and Shoup 1999). This is also proved by our Hong Kong case, as shown by the positive, significant coefficient (3.455) of public parking spaces available at trip destinations.

5.6 Automobile Dependency in Hong Kong?

- **Measuring Automobile Dependency: Single Coefficient Captivity Logit Modeling**

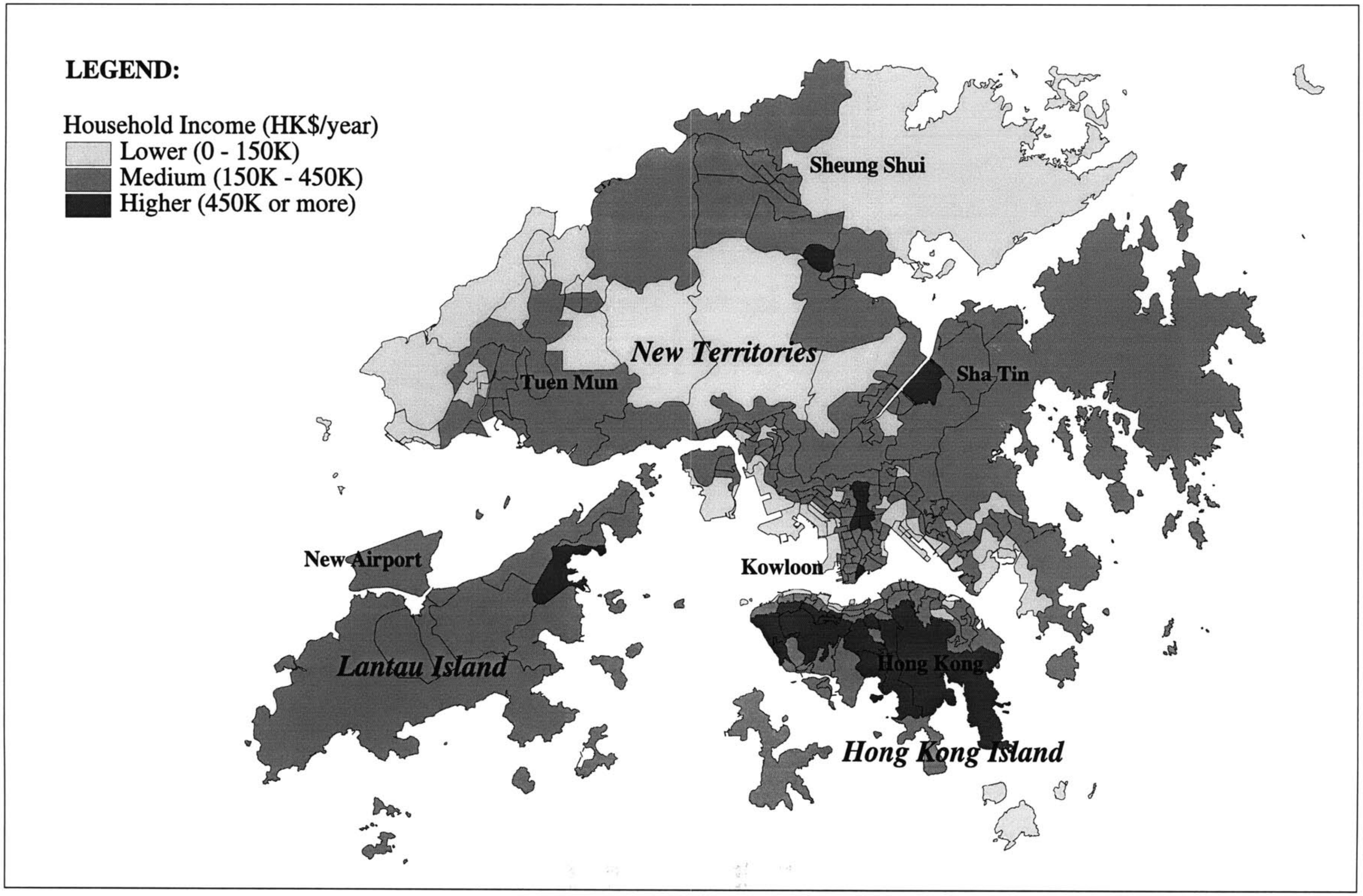
In this section we apply the same method as in the Boston case to measure automobile dependency in Hong Kong. Given the availability of a large variety of transit services territory-wide, one may expect that no individuals in Hong Kong be captive to driving for their daily work and non-work activities.

To test this hypothesis and to provide a reference case to the Boston study, we estimate the same set of 18 single-coefficient captivity logit models, each using wither the entire sample or a subset of the sample stratified by locations and by income groups. Only 11 of the 18 models are reported here with an emphasis on the home-based non-work trips. Home-based works trips are omitted here because none of them appear identifiable or significant in the estimated captivity coefficients.

Spatially, Hong Kong has developed a pattern of high density clusters. There is not such an obvious urban vs. suburb characterization as we see in Boston or other American cities. Accordingly, we stratify the sample by Hong Kong Islanders vs. the rest. Hong Kong Islanders are those who live on the Hong Kong Island. The southern side of the Hong Kong Island is where most affluent people live, and has much lower density than other places (Figure 5.9). The income classifications of the population are as follows: The higher income group includes those with annual household income over HK$450,000 in 1992 (~US$70,000); the medium income group has an income level between HK$150,000 and HK$450,000 (US$20,000~70,000); and the lower income less than HK$150,000.

Table 5.9 reports the modeling results for the entire sample (Model #B1) and for non-work trips only (Model #N1). The estimated auto captivity coefficient in Model #B1 is negative, meaning that no captive driving behavior is identifiable. We may then

Figure 5.9 Spatial Distribution of Income Groups in Hong Kong (1997)



conclude that in Hong Kong, overall, there is no observable automobile dependency, confirming our expectation.

However, this is not the case for the non-work trip making. The captivity coefficient has an estimated value of 0.029 and is statistically significant at 95% confidence level, suggesting that about three percent of those Hong Kong people who either have valid driver's license or own motorized vehicles in the household tend to be dependent on private vehicles for their non-work activities.

To find out whether different income groups behave differently in (not) relying on automobile in their daily life, we estimate one model for each income group for the all-trip purpose. The results are reported in Table 5.10. None of the three income groups appears captive to driving. This leads us to suspect that it is the non-work travel for which some Hong Kong people are likely to depend on private transportation means, a similar behavior to Bostonians. The modeling results by different income groups for non-work trips are shown in Table 5.11. The medium and low income people do not appear dependent on driving for non-work activities. Only the higher income has a chance of 21% of being captive to driving.

Three more models are estimated and reported in Table 5.12 aiming to learn more about the geographic variation of the captive driving behavior. Model #L1 is for those who do not live on the Hong Kong Island. There is 1% chance that they are auto captive for non-work activities, but the estimate does not show statistical significance at the conventional level. On average, those who live on the Hong Kong Island are not auto dependent. Only the higher income on the Island has a probability of 24% being captive to driving for their non-work activities. These people are mostly affluent businessmen, pop singers and movie stars. It is very likely that they rely on private travel means because of attitudinal reasons. To some degree, they are probably perfectly price inelastic—they can afford almost any levels of vehicle use charges that government policies can practically impose.

Table 5.9: Automobile Dependency Estimation: Region-wide

	B1: All Trips		N1: Non-Work Trips	
	Coef.	*z-test*	*Coef.*	*z-test*
Driving				
Driving Time	-0.0009	-3.84	-0.0022	-0.59
Driving Cost	-0.0045	-3.10	-0.3139	-5.83
Parking Subsidy	0.0668	3.95	-0.1306	-1.53
Vehicles per HH Member	1.3887	45.00	3.6461	16.84
Public Parking at Destination	0.5771	5.77	-1.3816	-1.04
Population Density at Destination	-0.0014	-6.17	-0.0294	-4.95
Job Density at Destination	0.0006	2.29	-0.0032	-0.69
Constant	3.8347	.	-0.4340	-2.60
Non-Driving				
Trip Time	-0.0007	-4.77	-0.0097	-4.50
Trip Cost	-0.0161	-2.17	-0.2973	-2.20
Female	0.0172	5.00	0.2864	3.72
Age 30 or Younger	0.0047	1.28	0.8939	10.09
Population Density at Origin	0.0006	2.72	0.0522	6.20
Job Density at Origin	0.0009	2.32	-0.0110	-0.97
Captivity Coefficient	-0.9777	-5400.12	**0.0291**	**2.80**
Number of obs		16501		5744
Wald chi-squared		3032.86		340.48
Prob > chi-squared		0		0
Log likelihood		-6715.62		-2800.92

Table 5.10: Automobile Dependency Estimation: All Trips, by Income Groups

	B4: High Income		B5: Med. Income		B6: Low Income	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.0044	-3.84	-0.0006	-1.90	-0.0004	-0.56
Driving Cost	-0.3292	-8.42	-0.0113	-4.30	-0.0030	-1.06
Parking Subsidy	0.0626	2.23	0.0688	3.07	-0.0518	-1.52
Vehicles per HH Member	1.9116	22.01	1.2239	31.04	1.4107	16.26
Public Parking at Destination	0.2774	0.36	0.0806	0.75	2.8683	7.20
Population Density at Destination	-0.0054	-3.19	-0.0015	-5.11	-0.0115	-8.85
Job Density at Destination	0.0051	3.45	-0.0009	-1.56	-0.0011	-1.11
Constant	6.1503	.	2.3802	.	5.1197	.
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Non-Driving						
Trip Time	-0.0054	-6.93	-0.0010	-4.27	-0.0021	-4.30
Trip Cost	-0.1990	-0.69	0.0500	2.03	0.0027	0.19
Female	-0.0045	-0.21	0.0297	4.09	-0.0634	-3.25
Age 30 or Younger	0.1633	6.97	0.0277	3.92	-0.0487	-3.53
Population Density at Origin	0.0177	5.97	-0.0002	-0.41	-0.0004	-0.40
Job Density at Origin	-0.0094	-2.74	0.0012	1.56	0.0000	0.02
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Captivity Coefficient	-0.9970	-5650.8	-0.9058	-639.7	-0.9940	-8649.2
Number of obs		3528		10071		2902
Wald chi-squared		734.16		1664.98		326.86
Prob > chi-squared		0		0		0
Log likelihood		-1959		-3733.9		-748.96

Table 5.11
Automobile Dependency Estimation: Non-Work Trips by Income Groups

	N1: High Income		N2: Med. Income		N3: Low Income	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.0233	-2.13	-0.0033	-1.07	0.0010	0.62
Driving Cost	-0.5079	-1.21	-0.1256	-2.57	-0.0076	-2.54
Parking Subsidy	-0.2664	-1.24	-0.1393	-1.90	0.0096	0.25
Vehicles per HH Member	3.6915	6.97	2.7326	5.15	1.2317	8.99
Public Parking at Destination	3.6126	0.82	-0.1302	-0.14	-1.9196	-3.05
Population Density at Destination	-0.0808	-3.92	-0.0137	-2.45	0.0110	4.26
Job Density at Destination	-0.0235	-1.71	0.0003	0.06	-0.0047	-1.65
Constant	0.8941	1.92	-0.5760	-2.35	5.8689	.
Non-Driving						
Trip Time	-0.0095	-1.57	-0.0057	-3.06	-0.0012	-1.80
Trip Cost	-5.2013	-2.23	-0.1849	-0.74	-0.0342	-1.81
Female	0.0827	0.39	0.2598	2.47	-0.1262	-3.91
Age 30 or Younger	2.2255	5.47	0.2868	2.23	-0.0766	-2.27
Population Density at Origin	0.0886	3.24	0.0195	2.55	0.0047	1.95
Job Density at Origin	-0.0230	-0.79	-0.0027	-0.29	0.0031	0.68
Captivity Coefficient	**0.2667**	**5.11**	**-0.1457**	**-1.79**	**-0.9977**	**-7699.6**
Number of obs		1631		3169		944
Wald chi-squared		50.04		41.16		90.55
Prob > chi-squared		0		0		0
Log likelihood		-968.892		-1436.1		-288.355

Table 5.12: Automobile Dependency Estimation: By Locations

	L1:Non-HK Islanders Non-Work		L2: HK Islanders All Trips		L3: HK Islanders, High Income,Non-Work	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.0068	-1.35	-0.0026	-3.24	-0.0247	-1.79
Driving Cost	-0.3482	-6.75	-0.0050	-2.50	-0.3626	-0.73
Parking Subsidy	-0.1805	-1.58	0.0610	2.08	-0.3402	-1.23
Vehicles per HH Member	3.8749	13.53	1.3817	29.21	3.3973	5.33
Public Parking at Destination	-1.2382	-0.85	2.5782	4.81	14.3912	1.71
Population Density at Destination	-0.0086	-1.05	-0.0106	-13.21	-0.0811	-3.17
Job Density at Destination	-0.0090	-0.97	-0.0029	-3.50	-0.0306	-1.91
Constant	-0.9327	-4.49	5.2104	.	1.0163	1.74
Non-Driving						
Trip Time	-0.0144	-4.92	-0.0028	-5.13	-0.0034	-0.47
Trip Cost	-0.3827	-2.62	0.0690	2.72	-6.0132	-1.89
Female	0.5899	5.88	-0.0044	-0.38	-0.3246	-1.26
Age 30 or Younger	0.7343	6.94	0.0246	2.52	2.2579	5.14
Population Density at Origin	0.0462	5.02	0.0060	8.71	0.1046	1.89
Job Density at Origin	-0.0394	-2.87	0.0026	1.72	-0.0380	-0.60
Captivity Coefficient	**0.0109**	**1.48**	**-0.9926**	**-3551**	**0.3146**	**4.81**
Number of obs		3510		5475		1131
Wald chi-squared		231.81		1166.1		31.92
Prob > chi-squared		0		0		0
Log likelihood		-1562		-2414		-683.6

- **Explaining Automobile Dependency: Parametrized Captivity Logit Modeling**

To explain the observed automobile dependent behavior of some Hong Kong travelers, we estimate the parametrized captivity logit models as we did in the Boston case. Reported below (Table 5.13) include only those models in which the single captivity coefficients estimated in preceding section have been identified and shown statistical significance. They are the models for all non-work trips, for non-work trips made by high income people, and non-work trips by those high income people living on the Hong Kong Island. As in the previous case, our interpretation of the results is focused on the variables entered in the auto captivity functions.

Across all three models, motorization measured as number of vehicles per household member shows consistent, significant influence on automobile dependence for non-work trip making. The explanation is the same as in Boston. When there are more vehicles available, people are likely to use them more. Trip distance as a cost factor discourages auto travel and therefore shows negative sign in the all non-work trip model. However, it has no measurable effects to the high income group and to those living on the Hong Kong Island. Young travelers (i.e. those at age of 30 or younger) are flexible in mode choices; older people are more likely to rely on cars. Higher population and employment densities at trip destinations are associated with lower levels of automobile dependence, most likely because of the inconvenience of driving in the high density places, for instance, lack of parking, and because of the convenience of alternative travel modes to driving.

These results are consistent to those we obtain in the Boston case. In Hong Kong, only a small portion of the population own automobile and their measurable dependence on automobile for non-work trips is relatively low. It therefore does not generate such significant social and environmental concerns as it does in the US cities. The challenge to Hong Kong policy makers is to maintain the low level of motorization under the pressure of rising income and growing demand for private mobility.

Table 5.13 Parametrized Automobile Dependence Model: Non-Work Trips

	N1: All Non-Work		N2: High Income		L3: HK Islanders, High Income	
	Coef.	*z-test*	*Coef.*	*z-test*	*Coef.*	*z-test*
Driving						
Driving Time	-0.0046	-1.00	-0.0121	-1.56	-0.0053	-0.59
Driving Cost	-0.2678	-4.31	-0.0395	-0.16	0.0716	0.25
Parking Subsidy	-0.1573	-1.71	-0.1577	-1.14	-0.1493	-0.93
Vehicles per HH Member	3.3192	13.60	2.5133	6.03	2.2422	4.80
Public Parking at Destination	-1.2729	-0.88	-0.6994	-0.21	7.0208	1.25
Population Density at Destination	-0.0059	-0.79	-0.0079	-0.51	-0.0232	-1.78
Job Density at Destination	0.0135	2.13	0.0128	1.16	0.0036	0.37
Constant	-1.4556	-5.59	-0.7860	-1.59	-0.6136	-1.18
Non-Driving						
Trip Time	-0.0138	-4.16	-0.0006	-0.13	0.0064	1.30
Trip Cost	-0.2823	-1.99	-3.8974	-2.33	-3.9861	-1.97
Female	0.2795	3.42	0.0009	0.01	-0.2237	-1.43
Age 30 or Younger	0.3313	2.22	0.3094	1.25	0.1300	0.33
Population Density at Origin	0.0495	5.77	0.0580	3.37	0.0319	0.97
Job Density at Origin	-0.0089	-0.75	-0.0089	-0.42	0.0385	0.83
Auto Captivity Function						
Vehicles per HH Member	2.8503	6.04	3.0716	3.32	2.3407	2.18
Trip Distance	-0.0151	-2.30	0.0024	0.39	0.0000	0.00
Age 30 or Younger	-2.3502	-3.86	-3.8027	-2.54	-14.4629	-0.04
Population Density at Destination	-0.1094	-4.53	-0.1146	-2.88	-0.0632	-1.46
Job Density at Destination	-0.0695	-2.99	-0.1461	-2.93	-0.1194	-2.35
Constant	0.2258	0.54	0.9354	1.56	0.8728	1.41
Number of obs		5744		1631		1131
Wald chi-squared		262.43		46.58		27.38
Prob > chi-squared		0.00		0.00		0.00
Log likelihood		-2791.9		-954.5		-674.8

5.7 Simulations of Pricing and Land Use Policy Effects

A series of simulation and policy effect analyses similar to those in the Boston case study are conducted. These include analysis of the relative importance of price and land use policies to individuals' mode choice behavior, the effects of density, parking supply, and travel costs on individuals' accessibility (as measured by the total utility associated with all available travel modes) and mode choice probabilities. Specifically, following six simulations are run:

- Simulation #5.1: Driving Costs, Vehicle Ownership on Accessibility
- Simulation #5.2: Population Density, Public Parking Supply on Accessibility
- Simulation #5.3: Driving Costs vs. Population Density with Accessibility Held Constant
- Simulation #5.4: Population Density, Public Parking Supply on Mode Choice Probabilities
- Simulation #5.5: Driving Costs, Vehicle Ownership on Mode Choice Probabilities
- Simulation #5.6: Combination of Density, Public Parking Supply, Costs and Vehicle Ownership on Mode Choice Probabilities with Accessibility Held Constant

The relative importance of price and land use policies to explaining individuals' mode choice behavior is indicated by the pseudo-beta coefficients reported in Table 5.14 (see previous chapter for explanation on how they are computed.) From the table a rather different picture from that in the Boston case is observed, although in general price variables, i.e. travel time and monetary costs, are observed having strong influence on mode choice. For example, for the rail mode, the pseudo-beta for gender variable is the largest, suggesting its greatest explanatory power in choosing rail in comparison to other variables. The influence of bus cost (with a pseudo-beta of 0.39) is not as strong as gender (0.85) and population density (0.53). For the car mode, vehicle ownership and public parking supply show stronger influence on car use than do parking subsidy and densities (both job and population).

Table 5.14 Pseudo-Beta Coefficients of NL Mode Choice Model

Coefficient Estimates by Mode	Estimation	Sample SDV	Pseudo-Beta
Rail			
Female	1.764	0.48	**0.85**
Travel Cost	-9592	0.0000572	**0.55**
Population Density at Origins	0.002911	181	**0.53**
Travel Time	-0.0137	29.30	**0.40**
Young	0.7513	0.5	**0.38**
Job Density at Origins	0.0002069	230	**0.05**
Bus			
Travel Time	-0.04511	24.70	**1.11**
Female	1.764	0.48	**0.85**
Population Density at Origins	0.002911	181	**0.53**
Young	0.7513	0.5	**0.38**
Travel Cost	-7075	0.000055	**0.39**
Job Density at Origins	0.0002069	230	**0.05**
Car			
Travel Time	-0.01937	17.70	**0.34**
Travel Cost	-936.5	0.000284	**0.27**
Vehicle Ownership	1.019	0.17	**0.17**
Public Parking Supply at Destinations	3.455	0.04	**0.14**
Population Density at Destiations	-0.0004239	181	**0.08**
Job Density at Destinations	-0.0001709	230	**0.04**
Parking Subsidy	0.1553	0.22	**0.03**
Taxi			
Travel Cost	-8370	0.000479	**4.01**
Travel Time	-0.05007	17.00	**0.85**

- **Simulation #5.10: Driving Costs, Vehicle Ownership and Accessibility**

Figure 5.10 Driving Cost and Accessibility

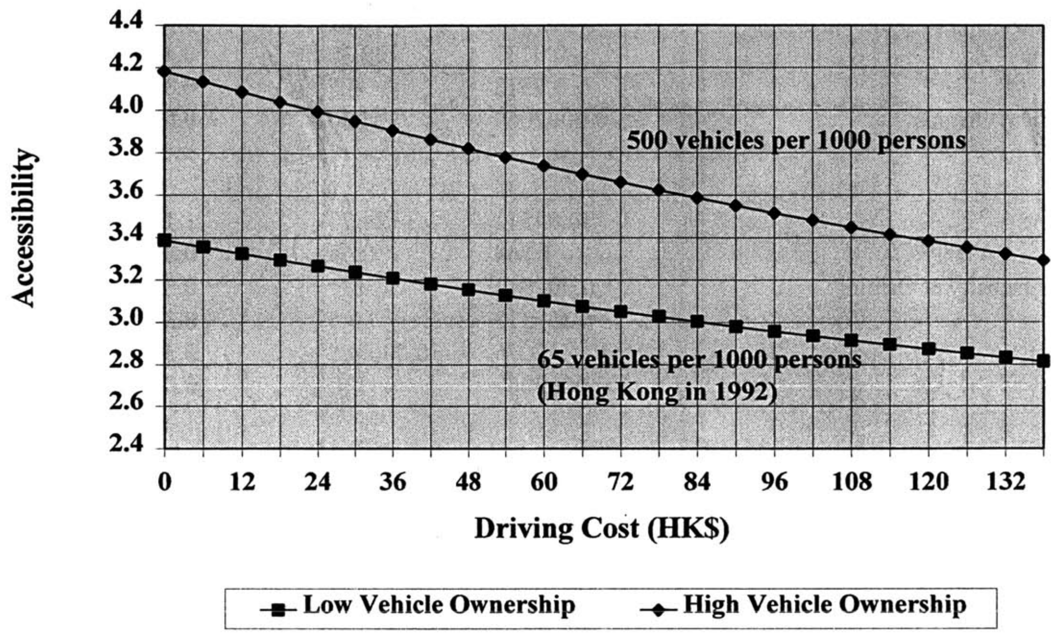
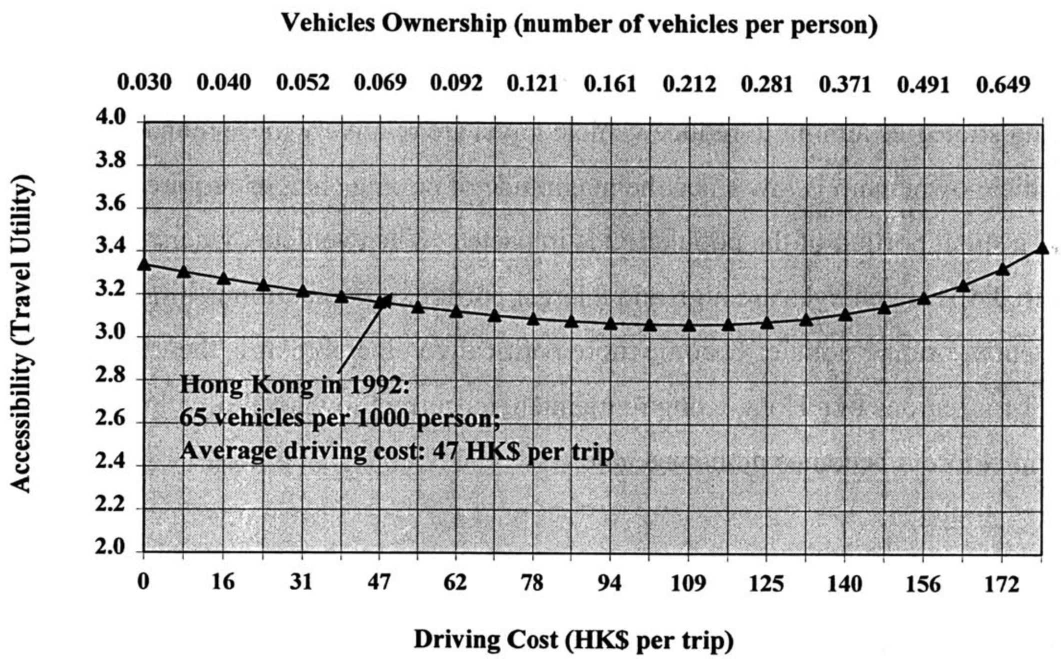


Figure 5.10 graphs the relationships between driving costs and accessibility with two different, fixed levels of vehicle ownership. The lower curve simulates such relationship at a vehicle ownership level of 65 vehicles per 1000 persons (i.e. Hong Kong's motorization level in 1992), whereas the upper curve represents a vehicle ownership of 500 vehicles per 1000 persons (similar to the automobile ownership in Boston), all else being equal. The relative positions of the two graphs suggest that, when travel time, costs per trip and all other factors are held constant, higher vehicle ownership leads to higher level of accessibility. This is true because of the higher individual mobility resulting from increased motorization. The downward slopes of the curves are consistent with the common knowledge that increasing driving costs will reduce utility associated with driving mode and thus, all else being equal, decrease the individuals' accessibility.

The above observation suggests an interactive relationship between driving costs and vehicle ownership in affecting individuals' accessibility and consequently their demand for travel. This is better illustrated by graphing the relationships between accessibility and driving cost while vehicle ownership is *increasing* (Figure 5.11).

Figure 5.11 Driving Cost, Motorization and Accessibility



The convex curve indicates that, when motorization is at the lower range (for example, at less than 140 vehicles per 1000 persons as shown in Figure 5.11), the impact of increasing driving cost dominates that of rising motorization, causing decrease in vehicle-based travel utility and thus decrease in overall accessibility. On the other hand, when motorization is at the higher range (for example, at more than 100 vehicles per 1000 persons as shown in Figure 5.11), travel utility increases even though driving cost continues to grow. This is because the effects of increasing driving cost on travel are off set and exceeded by the increasing level of motorization. Of course, the actual shape of the curve and the trend it points to for a specific city depends on: 1) the starting levels of vehicle ownership and travel costs, and 2) the relative magnitude and rate of increase in vehicle ownership and travel costs (Figure 5.11 assumes a HK$7.8 or US$1.0 increment starting from zero in car cost and 15% vehicle ownership growth rate at an initial level of 30 vehicles per 1000 persons).

Important policy implications can be drawn from the above observation.

(1) Unless driving costs increase faster than or at least proportionally to the growth of vehicle ownership, the effect of pricing policies on vehicle travel demand diminishes and eventually become negligible as vehicle ownership increases.

(2) Pricing strategies aiming to reduce vehicle travel are relatively more manageable when vehicle ownership is low since the magnitude of pricing charges required is small and only a small portion of the population is impacted. When vehicle ownership is high, the required driving charges are high and a larger portion of population is impacted. Consequently, pricing policies become more politically vulnerable. It is therefore important for regions like Hong Kong to maintain its current low level of vehicle ownership before it becomes unmanageable.

- **Simulation #5.2: Population Density, Parking Supply and Accessibility**

Similar simulation analysis is done on the relationships between land use attributes (density and public parking spaces) and accessibility. As noted earlier, increase in the supply of public parking spaces makes driving better off, leading to higher accessibility. The effect of densification on accessibility, on the other hand, is rather complicated as it tends to impact public and private modes in the opposite direction. The positive coefficients of density variables associated with public transportation suggest a positive relationship between density and accessibility. As density increases, the utility associated with transit modes increases, which gives transit riders a higher level of accessibility, all else being equal. Density increase, however, creates disutility to private vehicle users. To private vehicle users, there are many disamenities associated with high density, for example, congestion, inconvenience of parking, high risk of accident, and psychological effects such as anxiety about delay. Here we simulate how density affects accessibility in conjunction with the level of public parking supply while controlling for travel cost and travel time (that is, controlling for congestion and delay).

Figure 5.12 simulates the relationship between population/job density and accessibility with two different, fixed levels of public parking supply. The first is at the supply level of one space for every 50 jobs, which is also Hong Kong's average zonal public parking supply in 1992. The second has parking supply of one space for every two jobs. Two curves are graphed in Figure 5.12. All else being equal, more parking supply means higher accessibility and less parking lower accessibility.

Different shapes and sloping of the two curves in Figure 5.12 suggests an interesting story: within the same range of density variation, densification affects accessibility in a different way when there are different levels of parking supply. When parking supply is high (the upper curve), accessibility declines first when density increases, and then levels off and increases when density further increases. When parking supply is low (the lower curve), densification increases accessibility continuously. The explanation to this observation is as follows:

Accessibility in this study measures the total travel utility that contains components for both private and public travel modes. Densification increases transit-utility and decreases vehicle-based utility, as explained above. The net effect on total utility (i.e. accessibility) depends on the magnitude of changes of the two components. When there is plenty of public parking spaces available, vehicle utility is already high whereas the transit utility is low. The utility gain from densification for transit is smaller than the utility loss for the vehicle mode. The net is therefore a loss in total utility, that is, the decrease of accessibility. The opposite is true when density is at the higher range.

When parking space is rare, vehicle utility is already low and transit utility is high. Densification further reduces vehicle utility and increases transit utility, leading to an upward sloping curve we have seen in Figure 5.12.

A more revealing picture is shown in Figure 5.13 in which public parking supply decreases as density increases. This is more realistic than assuming fixed parking supply at any density. In general, the amount of parking spaces is inversely related to density; parking is more difficult to find in denser areas.

Figure 5.12 Density and Accessibility (with fixed levels of parking supply)

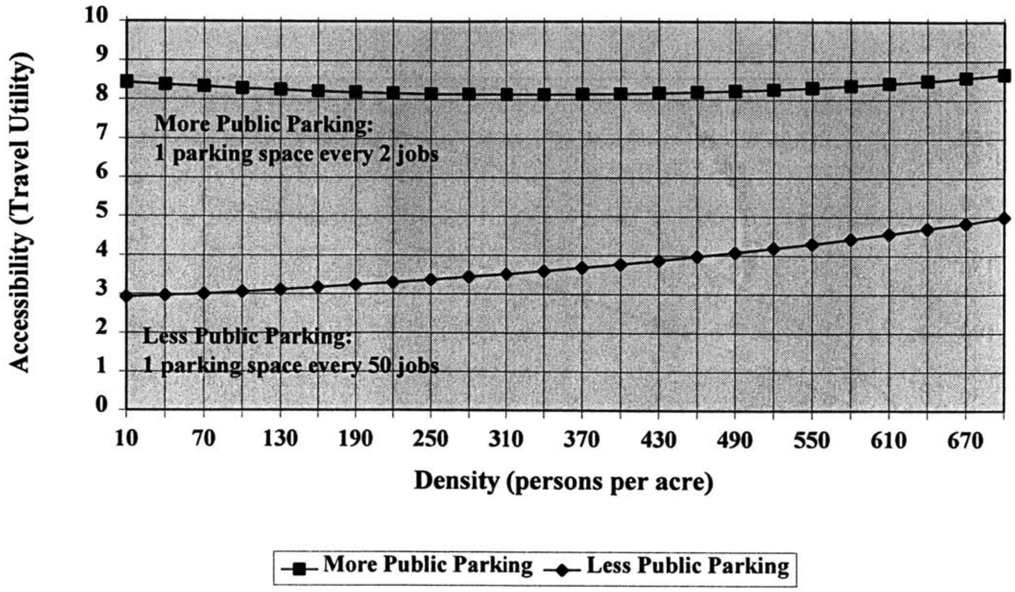
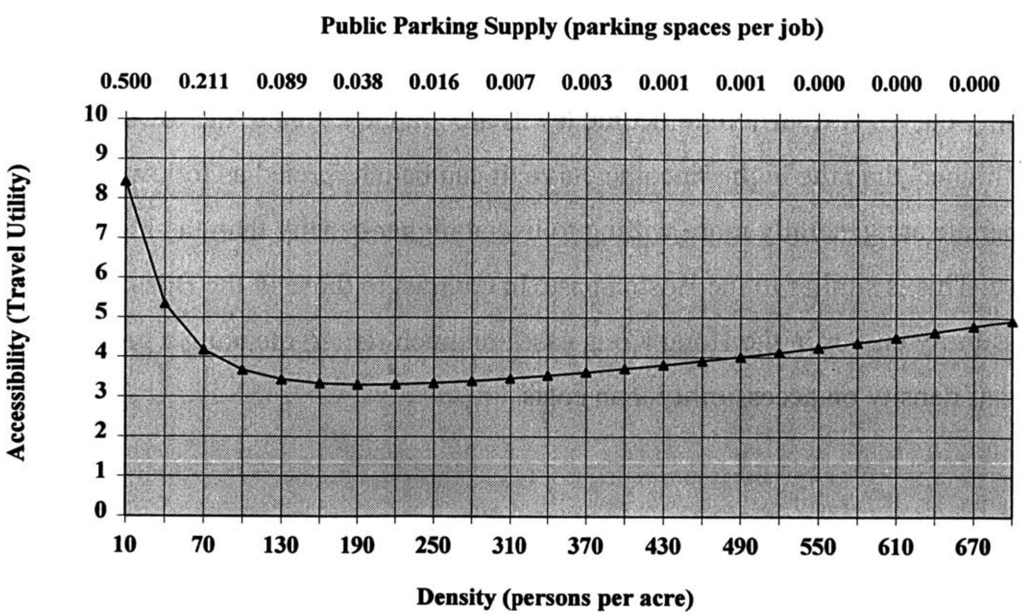
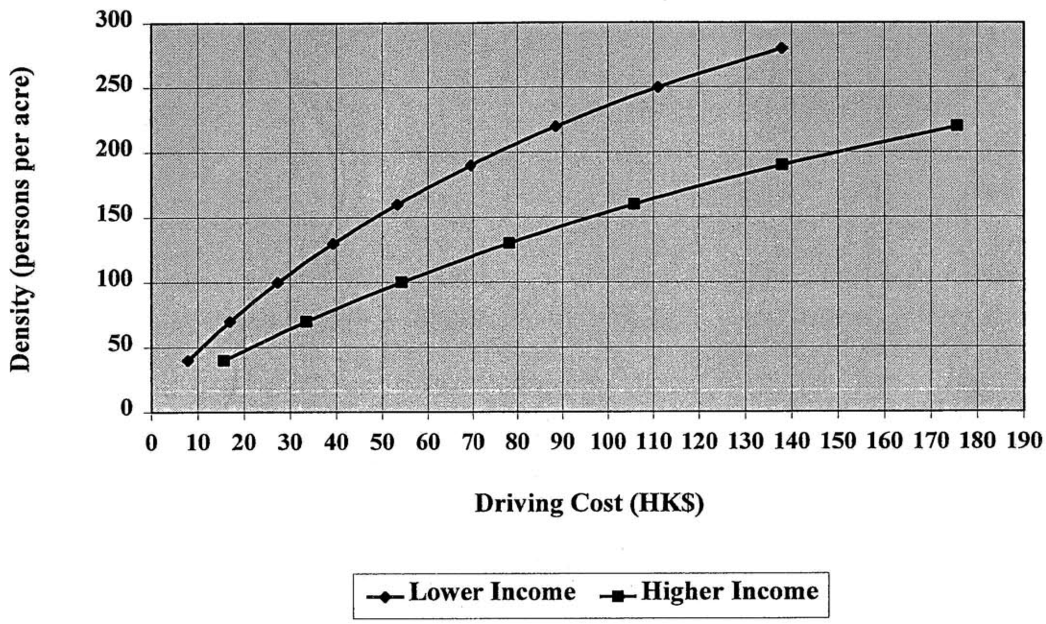


Figure 5.13 Density and Accessibility (with varying level of parking supply)



- **Simulation #5.3: Driving Costs vs. Population Density with Accessibility Held Constant**

Figure 5.14 Iso-Accessibility Curves



In parallel to our Boston case study, Figure 5.14 shows the iso-accessbility curves by graphing density against driving costs while *holding accessibility constant*. Two such iso-accessibility curves with different income levels are graphed. Again, the lower income curve is 'higher' than the higher income curve. It can be interpreted as follows: lower income people are generally more willing to live at higher density than the higher income people are. This is similar to the Boston case. In contrast to those in the Boston case, the iso-accessibility curves in the Hong Kong case are much flatter, meaning a greater influence of density on accessibility than costs.

- **Simulation #5.4: Population Density, Public Parking Supply on Mode Choice Probabilities**

Figure 5.15, 5.16, and 5.17 simulate the mode choice outcome measured as the probabilities of these modes are chosen when population and job density increase, given that public parking supply is, respectively, 1) fixed at a low level of one space every 50 jobs, 2) fixed at a higher level of one space every two jobs, and 3) decreasing as density increases. In aggregate, the mode choice probabilities may be interpreted as modal shares. To make the graphs more illustrative, we combine rail and bus into a single public transportation mode.

As shown in Figure 5.15, when density decreases (from right to left on the graph), the probability of transit being chosen decreases, whereas the probability of driving increases. However, because of lack of public parking supply, driving is still inferior to taking transit even when density is as low as 10 people/jobs per acre (close to the Boston density). The chance that taxi mode is chosen is not very sensitive to density changes.

To the other extreme, assuming there is always plenty of public parking regardless what density, we see that driving becomes preferred to transit (Figure 5.16). When density is as low as about in the Boston area (8 people/jobs per acre on average), we see roughly a 20% share of transit and 80% of driving, *nearly the same modal split for commuting trips as in Boston!*

Figure 5.17 combines previous two extremes and allows parking supply changes along with density. It shows that when at a density of about 110 people per acre and at a parking supply level of 13 spaces per 100 jobs, transit share is equal to driving.

Figure 5.15
Effects of Density on Mode Choice (20 parking per 1000 jobs)

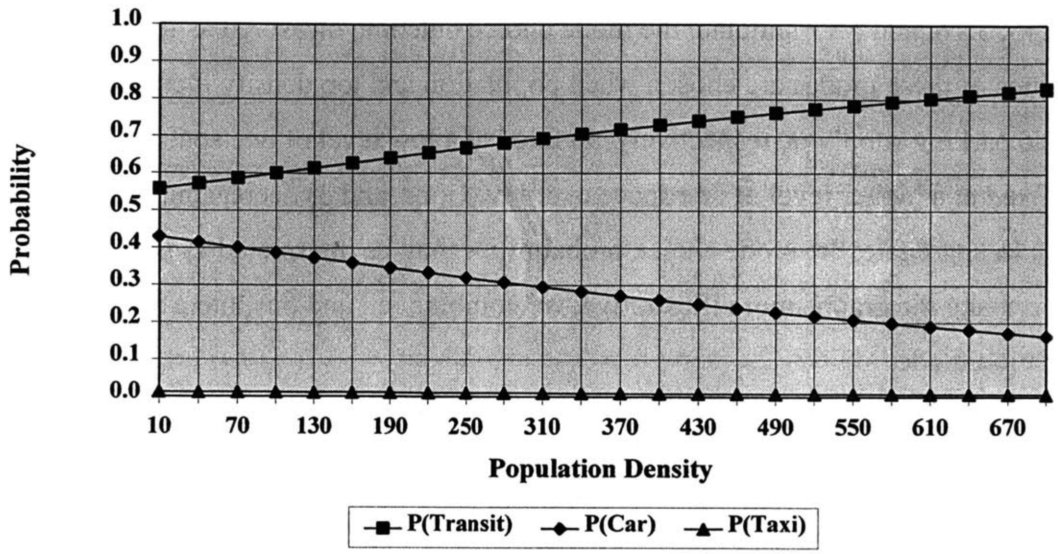


Figure 5.16
Effects of Density on Mode Choice (500 parking per 1000 jobs)

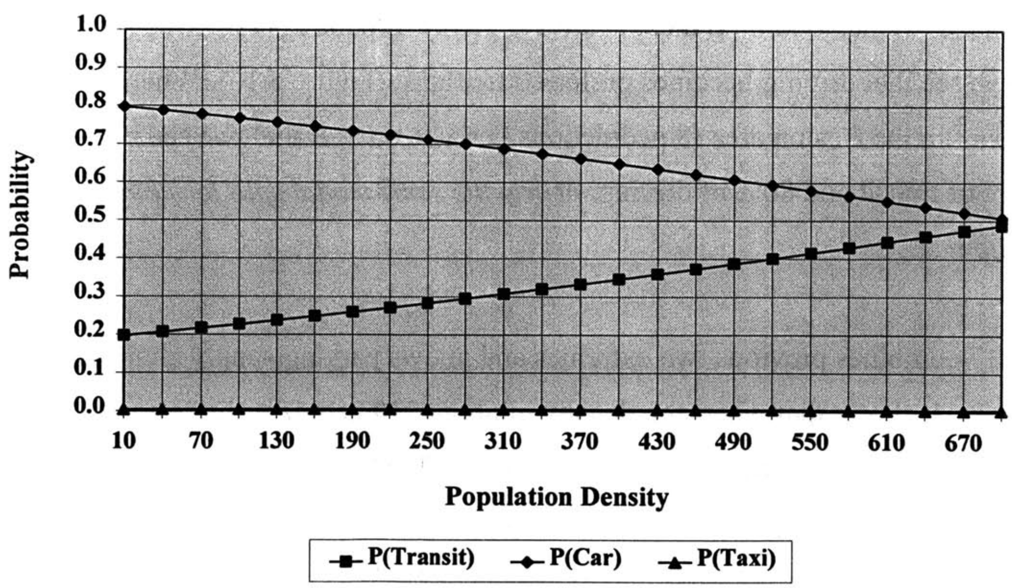
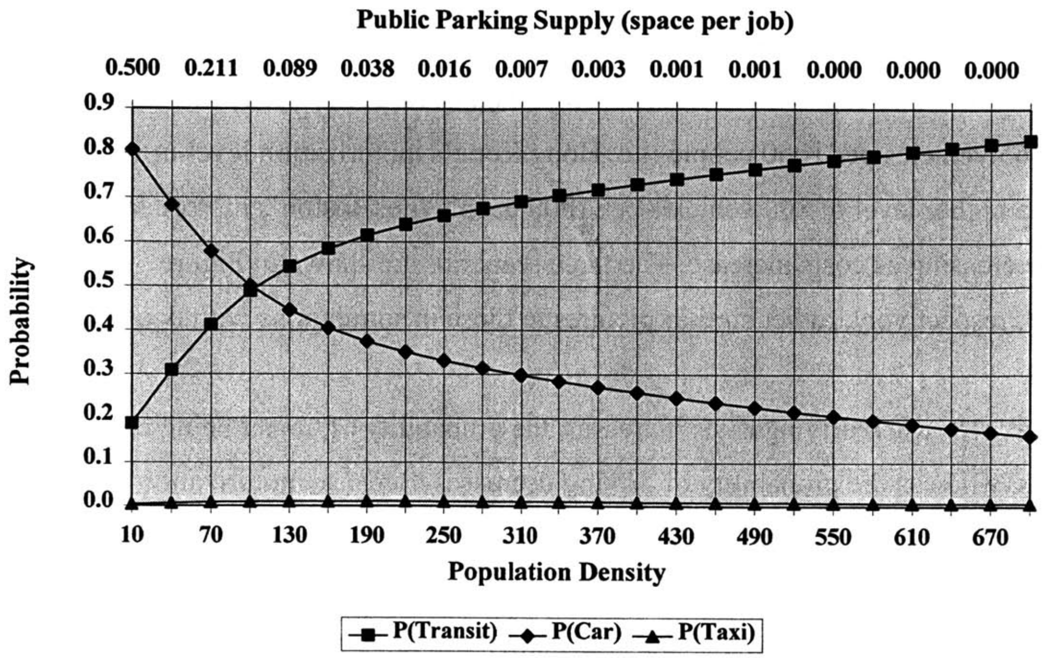


Figure 5.17
Effects of Density on Mode Choice (varying parking supply)



- **Simulation #5.5: Driving Costs, Vehicle Ownership on Mode Choice Probabilities**

A similar set of simulations are done on changes in mode choice probabilities when driving costs increase, given that vehicle ownership is, respectively, 1) fixed at a low level of 65 vehicles per 1000 people (i.e. Hong Kong's motorization level in 1992), 2) fixed at a higher level of 800 vehicles per 1000 people (i.e. Boston's motorization level), and 3) decreasing as costs increase. The three scenarios are shown in Figure 5.18, 5.19, and 5.20, respectively, rather similar pictures to those in simulations with density effects.

In Figure 5.18, when driving costs increases, the probability of transit being chosen increases, whereas the probability of driving decreases. Because motorization is held very low, the share of driving is still smaller than that of transit even when driving is cheap.

On the other hand, when vehicle ownership is high (Figure 5.19), transit and driving become equally attractive at a price of HK$120 per trip. When vehicle ownership decreases as driving cost increases, transit mode dominates when driving cost is about HK$25, sooner than in previous scenario (Figure 5.20).

Note that even when cost of driving is zero (technically) and vehicle ownership is as high as in the US (800 vehicles per 1000 people), transit still has a market share of as high as 40%! Does it mean that Hong Kong people are so much attached to transit that 40% of them would still use transit regardless how cheap driving is? This is unlikely the case, as shown by the following simulation in which all land use and pricing factors (i.e. density, parking supply, driving cost and vehicle ownership) are combined,

Figure 5.18 Effects of Driving Cost on Mode Choice (low motorization: 65 vehicles per 1000 people)

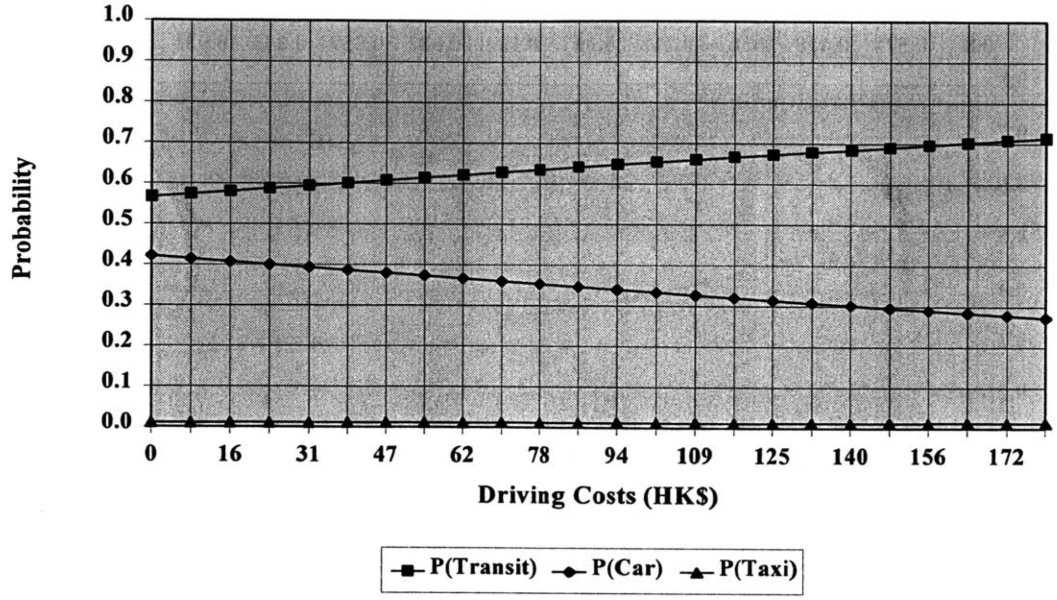


Figure 5.19 Effects of Driving Cost on Mode Choice (high motorization: 800 vehicles per 1000 people)

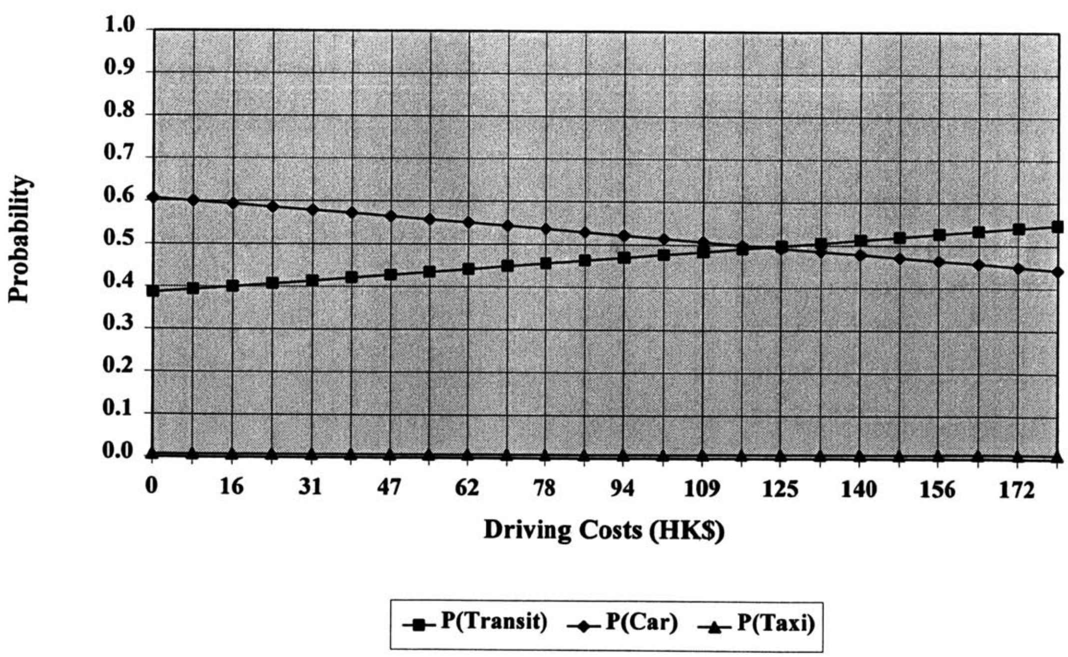
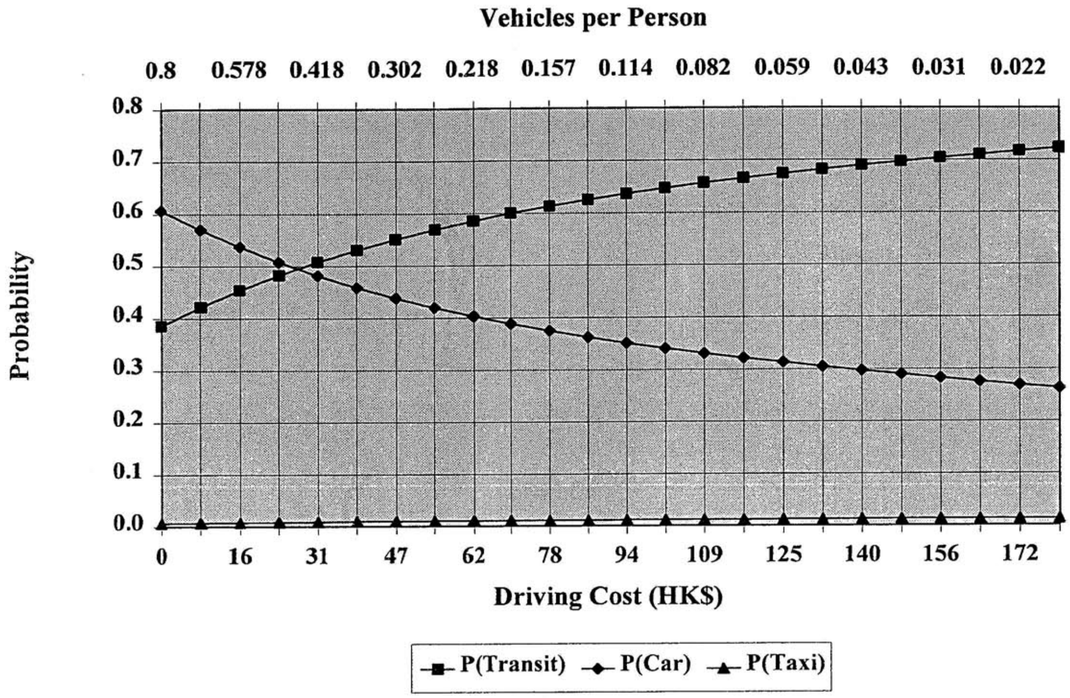


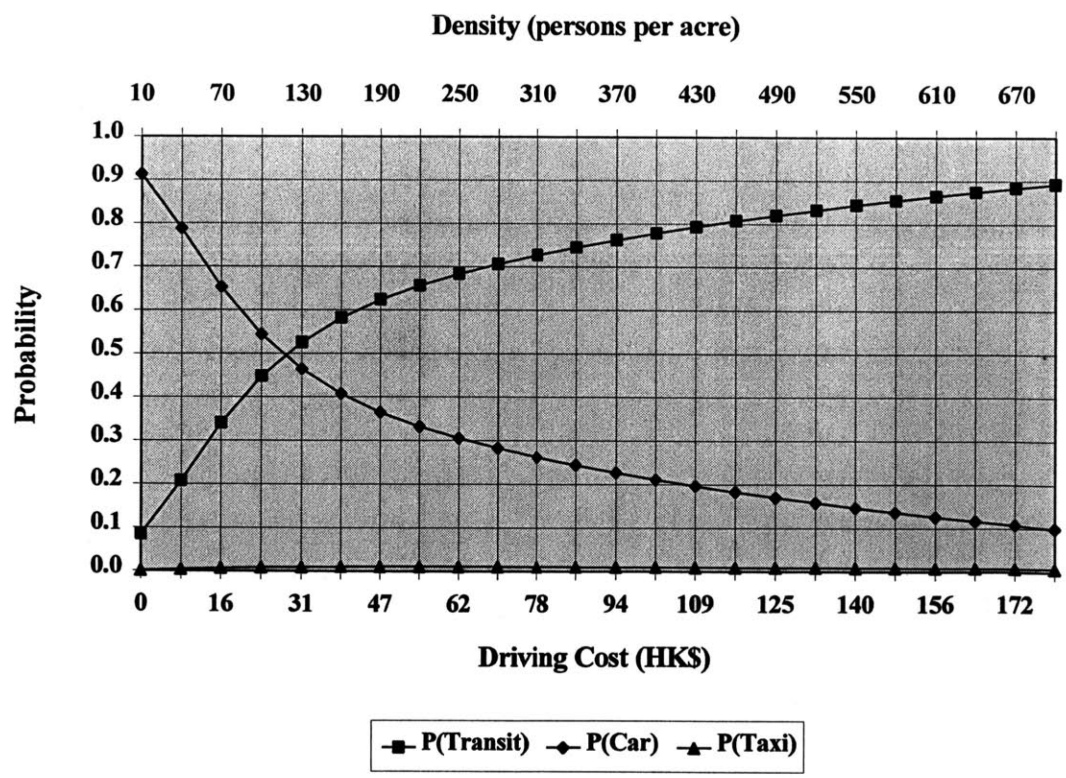
Figure 5.20
Effects of Driving Cost on Mode Choice (varying motorization)



- **Simulation #5.6: Combination of Density, Public Parking Supply, Costs and Vehicle Ownership on Mode Choice Probabilities with Accessibility Held Constant**

This simulation combines the effects of density, public parking supply, driving cost and vehicle ownership. It shows that land use plays a key role in supporting transit and in restricting driving (by limiting parking). Figure 5.21 suggests that, on average, a Hong Kong person is indifferent between taking transit and driving when the person has an annual household income HK$252,000 and one vehicle for every five people, lives in areas where density is 120 persons per acre, and at a cost of HK$25 per trip, commutes to work in places where employment density is 120 jobs per acre and one public parking space for every ten jobs is provided.

Figure 5.21
Combined Effects of Driving Cost and Density on Mode Choice



5.8 Chapter Conclusion

There is no reason to believe that Hong Kong people dislike cars. Their behavioral responses to transportation policies are similar to others: as income grows, demand for travel and demand for private mobility increase. The low automobile ownership and extensive use of public transportation are the results of drastic financial measures to the owning and use of private automobile, and of positive supply of efficient transit systems, which in turn is made viable by Hong Kong's peculiar geography and settlement patterns. In Hong Kong, both the government or policy makers and the general public are aware of that private-automobile-based mobility strategy is unfeasible. This shared consciousness guided Hong Kong to ride on transit. Auto control policies, although severe, have received relatively large acceptance as only a small portion of the population is affected. Land use provides unique, favorable conditions to support viable, diversified public transportation services differentiated by service quality, routes, operating hours, scheduling flexibility.

Chapter 6

Conclusions

Having contrasting patterns in land use and travel, the metropolitan Boston and Hong Kong offer a pair of mirror cases representing two different development paths and policy strategies to supply urban mobility and accessibility. In previous two chapters we present in detail our empirical studies on these two cases of world cities, addressing the questions of the conditions and effectiveness of land use as a mobility tool to influence people's mode choice, trip frequency, and automobile dependence.

In this concluding chapter we shall draw implications pertaining to transportation policy making from the empirical findings. First we summarize the results of the Boston and Hong Kong case study. We then discuss on the implications suggested by the results. The discussion starts with remarks on general lessons learned from the two cases. Next, we revisit and comment on the land use-based mobility strategies mentioned in Chapter 2 in light of the research findings. Further discussions are presented specifically on automobile dependence, as it is of critical concern to the public and the policy makers, and a research focus of this dissertation. The following section highlights the contributions of this research to the field and identifies the areas for future study. The chapter ends with concluding remarks.

6.1 Summary of Empirical Findings

- **The Boston Case Study**

Figure 6.1 The Birdseye View of the Metropolitan Boston

Source: Col-East, Inc. (http://webs.ii.ca/nalyd/skyscrapers/aerials/)

Boston is one of the few US metropolises that offer a variety of travel choices, mostly within its urban area. The public transportation network and biking- and walking-friendly environment are supported by relatively dense and mixed land use patterns in the centrally located cities and towns. The majority of the population and geography, however, is still auto-oriented. Region-wide, the average density is eight persons per acre of built-up area. Approximately 80% of the total trips are made by the private vehicles.

The empirical study on the Boston case has focused on three aspects of travel behavior: mode choice, trip frequency, and automobile dependence. The main findings are summarized below.

1) Mode choice The empirical tests show that most land use attributes are statistically significantly associated with people's mode choices *after* the common behavioral variables such as travel time, monetary costs and individuals' socioeconomic characteristics are controlled for. Land use variables generally demonstrate important explanatory power to people's commuting and driving behavior. For the non-driving, non-commuting trips, however, these land use variables perform rather poorly. The results imply that land use strategies may be effective in influencing commuting trips, which exhibit certain spatial and temporal regularities, but less so in dealing with non-commuting trips, unless the entire metropolitan area is re-configured.

2) Trip frequency In addition to the cost factors such as trip time and distance, individual and household characteristics are the most important factors generating more frequent trips. Females with children five years or younger tend to make more car-trips because she needs to visit daycare centers, health care, or shopping areas to fulfill the needs of the children. A person in a larger household tends to make more trips. For non-driving travel, supplying 'park-n-ride' spaces has positive effects on travel demand. More transit supply in terms of daily seats available in the immediate vicinity of trip origins is associated with larger demand of non-driving travel. Higher densities at destinations consistently discourage driving for total trips and for non-work trips as well. Urban form indicators do not enter statistically significant for non-work travel demand, although they do appear important in the all-trip model.

3) Automobile dependence Defined as the likelihood of an individual being captive to driving, automobile dependence in the Boston region displays certain patterns in the spatial, social and activity dimensions. Firstly, the suburban residents are overwhelmingly more dependent on the automobile than the urban residents. There are 86% chances that suburban Bostonians are captive to automobiles for their daily activities. On the other hand, there are 16% chances that the urban Bostonians depend on automobiles for their daily activities. Secondly, the lower income drivers are more dependent on the automobile than the higher income. For the non-work activities, the medium income group relies on the automobile more than other population groups. Thirdly and finally, the non-work travel is generally more auto dependent than commute. In aggregate, 23% of some four million people in the metropolitan Boston area are automobile dependent.

The sources of automobile dependence are diverse. Greater household mobility in terms of vehicle ownership contributes to a higher degree of automobile dependence. Family structure also plays a role in causing auto dependent travel. Females who have small children at five or younger tend to rely more on private transportation, particularly in the suburb. Less transit supply decreases the level of services and makes transit less likely to be considered as a substitute for driving, and hence increases automobile dependence. For longer travel, the automobile is preferred to other modes; when the toll and parking charges are negligible, driving is further encouraged. Finally, lower density is associated with higher level of automobile dependence, although overall the explanatory power of the land use variables is mixed.

Policy simulation analysis indicates that current land use patterns or pricing policies, when implemented alone, have to change dramatically before any significant difference in people's travel behavior can be seen. For example, the net population density has to increase by over 20 fold, from 8 to 180 persons per acre, to break even between the choice probabilities of driving alone and taking other modes. Similarly, for pricing approach to have significant effects at a regional scale, economic measures such as tolls and parking fees need to be significantly large. The simulation indicates that toll and parking costs have to increase by about seven fold, from 1.72 to 12 dollars (one way) on average, to make the modal split of work trips similar to the European level (about half of the work trips made by private cars [Newman and Kenworthy 1999]). When the two factors, driving costs and population density, are combined, however, they become more practical. To reach the point where probabilities of driving and taking transit are equal, driving costs only need to raise to about $4.00 one way and density at 140 people per acre.

Still, 140 people per acre is an extrapolation far out of the US experience. Such a high density requires changes in most Americans' perceptions and attitude about mobility, space, privacy, or basically, their value system. Nevertheless, the purpose of this analysis is not to find optimal or acceptable level of density in the US cities. Rather, we illustrate that the bundling of pricing and land use strategies are more effectual and practical than they are implemented separately.

- **The Hong Kong Case Study**

Figure 6.2 The Birdseye View of Hong Kong

Source: Hong Kong Polytechnic University
(http://www.sdalpha.polyu.edu.hk/intercol/sdic_hkmap.html)

The extrapolated large share of transit trips and the exceptionally high density shown in the Boston case study are inconceivable in the US practice, but they are the reality in Hong Kong. The Hong Kong experience makes a live example of the simulated analysis on the Boston case. Therefore, studying Hong Kong sheds light on the understanding of the potential and limit of land use-based mobility strategies in affecting travel.

Hong Kong is the densest metropolis in the world, with a population density in the built-up area of approximately 160 persons per acre (1996). The unique characteristics of Hong Kong's natural and built environment play a significant role in the region's mobility supply. The region contains basically all the desirable attributes, namely higher densities, greater mix of different uses, and with a pedestrian-friendly walking environment that are favorable to non-auto-based transport services. In fact, Hong Kong is known as a transit-oriented city; less than 10% of commuting is made by private vehicles.

Vehicle ownership in Hong Kong has been increasing since 1960's, along with income growth. However, it has been kept at a low level of 77 vehicles per 1000 people (1996), only a small fraction of those in most countries that have comparable income. The low vehicle ownership and small share of auto travel are the results of the government's strong commitment to control ownership of the private automobile and to promote public transportation. In Hong Kong, car registration tax is, on average, 50%, compared to the 5% sales tax in Boston. The annual license fee for a medium sized car (i.e. 2.5 ~ 3.5 liter in cylinder capacity) is HK$7,664 (US$982) in 2000, and increasing every year. In the Boston region, fees including plate, annual inspection and city tax (specific only to certain cities or towns) are less than US$100 in total. Hong Kong's strong fiscal constraint suppresses to a large extent the demand for owning and using private automobile.

The nested logit modeling of mode choice in Hong Kong produces results as expected. Specifically, longer travel times and higher monetary costs reduce the demand for travel by all modes. Parking subsidy works in the opposite way to cost variables in affecting people's mode choices as it reduces the direct operating costs of vehicles. In Hong Kong, female workers without children and young people prefer taking public transportation (buses, subway, light rail or ferry) to driving, a similar behavior to what we found in the Boston case study. When there are more vehicles per person in a household, members of the household are more likely to drive to work than to take transit. Population densities at trip origins are positively associated with transit use. Employment densities at trip origins, on the other hand, seem irrelevant to people's decisions on travel means to work. When travel time, costs, and other factors are controlled, people working in places where employment and population densities are higher are unlikely to commute by driving. Public parking supply at trip destinations is considered as a spatial constraint to vehicle use. When there is more parking supply, driving mode is more likely to be chosen.

There is still a small portion of Hong Kong people who are automobile dependent for the non-work travel. Not surprisingly, these are the people with higher income and higher vehicle ownership. Of the people whose annual household income was more than HK$540,000 in 1992 (about US$70,000), approximately 21% of them were captive car users for leisure, shopping, or other non-work purposes. These people live mostly on the southern side of Hong Kong Island, where densities are relatively low.

The simulation analysis suggests that Hong Kong people are not much different from Bostonians in terms of fundamental behavior in demanding more personal mobility when income grows, and in adjusting to different spatial and economic constraints. If population and job densities and costs of owning and using automobile in Hong Kong were at the same level as in Boston, and if there were ample public parking available territory-wide, 80% of Hong Kong people would drive to work, just like what Boston workers are currently doing.

6.2 Policy Implications

- **General Lessons Learned from the Boston and the Hong Kong Case Study**

Governmental policies play a crucial role in determining long run urban travel outcome and in affecting individuals' travel behavior. During the post-war period, at least up to early 1980, the mobility supply strategy in the US cities may be characterized as a combination of private motorization and public supply of road infrastructure. Growing income and availability of land made this strategy feasible, and cheap gas and low cost of owning and operating private vehicles made it attractive. It is reasonable to say that in such an environment favorable to automobile, most American people, including Bostonians, have made an economically rational choice, that is, to drive. Hong Kong, on the other hand, has followed a different mobility supply strategy. In spite of income increase and rising demand for the acquisition of private vehicles, the government has placed major emphasis on the development of efficient public transportation system. The outcome of the two different mobility strategy is 10%-90% in Boston but 90%-10% in Hong Kong in terms of transit vs. auto modal split.

Exogenous factors such as availability of land resource is obviously another important factor affecting mobility choice and travel behavior. In Hong Kong, many households can afford a car but not a parking spot. Hong Kong's extremely high density, created by default, provides favorable conditions for financially self-sustainable public transportation operation. The awareness of the scarcity of the land resource by both the public and the government in Hong Kong guided the region to make a conscious mobility choice. On the other hand, in the US, land has never been thought as such a scarce resource as in Hong Kong. It is perhaps the awareness of the availability of vast land that guided the government and the individuals to create a low density, driving lifestyle.

Economic measures and land use initiatives are necessary but not sufficient conditions to influencing travel if they are formulated and implemented independently, or as substitutes as has been largely suggested. This is because individuals' behavioral responses to policy actions may not be in the expected directions. In responding to local traffic measures such as congestion pricing, motorists much likely behave in ways that make the pricing efforts to reducing traffic largely in vain.

For example, as Neale (1995) has noted, motorists may drive exactly as they always have if the congestion charge is not high enough relative to their income, or is subsidized by their employers. They may drive more as they shift to 'rat running' through alternative roads to avoid priced routes. In the longer term, they may shift shopping, recreation, and even work destinations to other locations that are not being charged, resulting in more driving. One may argue that spatial and temporal diffusion of traffic flows is beneficial as congestion in bottleneck places can be relieved. From the societal perspective, however, it is of little help as the overall travel outcome is unaffected or even becomes worse.

Use-based pricing strategies such as higher fuel tax or charges based on odometer readings are relatively more effective in curbing motor vehicle travel. Those who are price-elastic may be pressed to drive less or to shift to other modes. However, if other alternatives are not attractive enough or unfeasible, people would still have to drive as usual, ending up with a larger portion of household income spent in travel. As illustrated in this study, the reduction of auto use resulting from price increase alone is at the expenses of travelers' accessibility or welfare. Plus equity issues associated with pricing, transport-pricing policies that aim to reduce auto use at a large scale are generally politically vulnerable.

The Hong Kong experience indicates that good transit services supported by 'good' land use patterns are still not 'good enough' to persuade people to stop buying and using private automobiles. The demand induced by rising income to achieve higher personal mobility through private motorization is too strong; the pull force from the transit supply side appears weak. Due to its service characteristics, transit is usually in a competitively disadvantageous position, as it generally cannot provide the same levels of flexibility and privacy as car does. In a purely free market (without any public intervention), perhaps the best transit can do in competing with cars is to break even—which is likely to happen only when both of them are stuck in traffic. This is to say that the demand side must be checked, through policy intervention for example, before the supply-side strategies, including land use based strategies, can be sufficiently effective. The contribution and importance of Hong Kong's strong auto control policy is that it has prevented the majority of the trip makers, mostly the middle income, from becoming part of the driving population. If this portion of the population became motorized and started driving, traveling in Hong Kong would be a nightmare, for both car drivers and transit riders.

In order for both transport pricing policies and land use initiatives to be practical and effective, they need to be designed and implemented jointly. The two approaches form a pair of complementary 'pull and push' forces to influence people's travel behavior. Land use initiatives become more effective because possible substitution of higher trip frequency for longer trip distance is discouraged by punitive pricing policies. Welfare loss resulting from increasing driving costs can be compensated by the improved alternative transport services. Overall, the required changes in land use patterns and pricing are much less dramatic to achieve the same objectives than if they acted alone.

In urban America, land use and transport cost factors have been historically acting as complements to produce the current land use and travel patterns. The decrease in costs of travel (relative to income) allows people to travel farther and faster in the same amount of time and costs as before and enables them to consume more space in more distant locations. Everybody's living in larger spaces results in a greater spatial separation. In turn, it further demands faster travel means and better infrastructure to facilitate travel by that means. In the past four or five decades, both the transport/land use markets and the governmental policies have responded to such demand recursively, which has produced today's travel and land use patterns.

- **Land Use-Based Mobility Strategies Revisited**

Our case studies have shown that land use does play a significant role in shaping urban mobility and therefore offers important potential in influencing individual's travel behavior. Land use as a mobility tool affects travel from the supply side. How land space is allocated, composed, and designed has differentiated impacts on the supply quantity, quality and costs of different travel modes, namely private automobile, mass transit, and non-motorized means. Nevertheless, since land use attributes are surrogates of many physical elements related to transportation, their effects on travel are also multi-dimensional. Caution should be exercised when policy recommendations are made based on land use indicators' statistical performance.

Densification reduces spatial separation, meaning lower costs of travel for all modes as opportunities or services that people are traveling to reach become closer. However, it benefits walking, biking, and other non-motorized modes more than driving because of their greater sensitivity to distance changes. Densification also makes transit better off more than driving due to the combined benefit of reduced distance and increased pool of potential transit riders in a given area. This is why in our empirical tests most land use attributes are still statistically significantly associated with people's mode choices *after* the common behavioral variables are controlled for. Of course, whether or not densification will actually make a person switch from driving to non-driving depends on the magnitude of density increase and the corresponding improvement of the non-driving services such as transit supply.

Land use mix increases the attractiveness of the destination opportunities because of increased diversity, and it makes travel more efficient--one trip serves multiple purposes. Saving a trip means saving time and cost. In other words, more balanced land use improves the quality and reduce the cost of travel. Nonetheless, as we see in our travel demand analysis, higher degree of land use mix (measured as the entropy of different land uses) tends to induce more frequent trip making including driving trips, particularly for non-work trip purposes. Consequently, the net transportation benefit in terms of total driving reduction from higher land use mix is unclear.

The effect of urban form in terms of network configuration (e.g. cul-de-sac and curve-linear vs. gridiron pattern) on travel behavior is more subtle. Consistent with many other empirical studies, this research has also found statistically significant effects of the urban form factor as measured by the proportion of cul-de-sac intersections on driving. That is, a larger proportion of cul-de-sac intersections is positively associated with automobile uses. Many have therefore concluded that, to reduce driving and encourage walking, biking or taking transit, the built environment should be configured in gridiron fashion instead of in the widespread cul-de-sac and curve-linear patterns. We argue that this is rather a misinterpretation of urban form's effect on travel. At the micro scale, the effects of urban form on travel relate more closely to the quality design of a variety of travel choices than to the geometric form per se, i.e., cul-de-sac and curve-linear vs. gridiron pattern. Simply converting cul-de-sac/curve-linear networks to grid patterns may bring back the old problems that many urban design pioneers tried to solve early in the century while the current problems of excessive auto use remain unsolved. A brief review of the history of cul-de-sac/curve-linearity helps explain why this might be the case.

The cul-de-sac/curve-linear pattern as a design vocabulary originated with the Garden City movement in the 1920's. Reacting to the increasing motor traffic's destruction of urban life and the monotonous, lifeless gridiron suburbanization in the early twentieth century, a group of pioneering urban planners and designers sought to design a new generation of American settlements. Their efforts were strongly influenced by the Garden City model that Ebenezer Howard and Raymond Unwin created and implemented in England. Most representative of these efforts are the conceptualization of 'Neighborhood Unit' by Clarence Perry and the construction of Radburn, New Jersey, planned and designed by Clarence Stein and Henry Wright in the 1920's (Levy 1991). The very basic design vocabularies include (1) superblocks, (2) separation of pedestrian and automobile traffic, and (3) hierarchical road systems featured with cul-de-sacs and curve-linear alignment.

The design purpose of cul-de-sacs was to protect the neighborhood from through traffic and to provide quiet and safety. The curvilinear streets were used to provide variety and changing street vistas. The use of cul-de-sac/curve-linear model should be together with the provision of parallel, separated circulation systems designated for pedestrians or bikers. Unfortunately, in the following decades of suburban subdivision and development, only part of the Radburn language was institutionalized and spread. The dogmatic application of the cul-de-sacs/curve-linearity have replaced the monotony of gridiron settlements in early suburbanization with another type of monotony. The other central component of neighborhood design, the pedestrian circulation system linking public space and facilities, has largely been neglected. It is not the inherent characteristics of cul-de-sac/curve-linearity (nor of gridiron) that created suburban distress and dependence on the automobile, but the lack of options. A living environment with auto-only design leaves residents no other viable choices but driving. It is in this regard that the current neotraditional design movement makes an important contribution, with its emphasis on the design of a coherent neighborhood unit and accommodation of pedestrian, biking and transit, in addition to autos.

Due to the multi-dimensional effects of land use on travel and its mobility role as a supply input, supplemental policies are extremely important to make all land use factors work in the same directions towards achieving specific policy objectives. Lack of supplemental policies is likely to weaken the effectiveness of land use as a mobility tool. For example, if the policy objective is to reduce driving, positive strategies in improving alternative supply such as more transit services, more friendly bike and walk paths are necessary. In the mean time, restrictive policies to auto use such as higher charges or less parking spaces should also be in place. Simply increasing density, land use mix, or changing the network configuration tend to have mixed effects on driving; some of them are offset with each other.

It is important to identify and to design policy instruments that more directly relate land use to travel than density, land use mix and urban form do. Densification, higher degree of land use mix, and better design of the street network suggest the principles of land use-based mobility strategies. They themselves are difficult to serve as policy measures because the evaluation of these indicators are often too ambiguous and subjective. For example, it is unclear what level of land use mix is most appropriate to a specific location or an area. It is also a subjective judgment that cul-de-sacs are better or worse than gridirons. Densification is easier to quantify. However, density is largely perceived as an undesirable 'good', especially in the US. The term itself tends to generate significant public resistance before it can be implemented as a policy strategy at the regional scale.

One potentially effective instrument that relates land use to travel is parking. From both the Boston and the Hong Kong cases we have seen that parking costs as part of vehicle operating costs and availability of parking spaces have very significant effects on driving. Parking policy also has important implication on land use density as more ground parking spaces usually relates to lower density. For example, in subdivision design, eliminating on-street parking lanes may increase density to a great extent without reducing the lot size of individual homes. This is illustrated by the following hypothetical example. Assume that a suburban residential block is encircled by a four-lane road on each side. Also assume that the block is 300x600 feet between the road center lines and the road is 48 feet wide, with one lane (12 feet) used for on-street parking on each side of the block. If we keep the lot size for each home unchanged but eliminate the parking lane along four sides of the block, we would increase the residential density by about 12% without reducing the size of individual properties.

- **Overcoming Automobile dependence**

Two main conclusions and policy implications can be drawn from the study findings specifically on the issue of automobile dependence. First, for effective transportation policy making to overcome automobile dependence, it is essential to distinguish between the use of the automobile and the dependence on it. The policy objectives in dealing with the two issues may overlap, for example, achieving the reduction of vehicle travel and thus the relief of the associated problems such as congestion and pollution. Distinguishing between the two, however, suggests a different policy strategy. From the individuals' travel perspective, overcoming automobile dependence should start from providing more travel options. Without the presence of viable travel alternatives, policies imposed to reduce vehicle travel are likely to meet strong public resistance as these policies tend to be interpreted as limiting personal mobility. Even though these policies can be implemented with strong political forces, the issue of automobile dependence still remains as long as there is no travel alternative in place.

For example, the Boston case study has shown that the suburban Bostonians are overwhelmingly more dependent on private vehicles than urban residents. To reduce the suburban Bostonians' dependence on the automobile, one may recommend a pricing policy. That is, to increase the costs of driving through increased tolls, higher parking charges, and larger fuel taxes. To what extent will the pricing reduce automobile dependence? It is unlikely to have significant effects unless desirable travel (or location) alternatives exist. As mentioned earlier, the public transportation system in the Boston region has been historically developed in a radial network pattern, better serving the suburb-to-downtown travel. The suburb-to-suburb transit service is rather rare (Figure 4.8, 4.9a and 4.9b). Walking and biking are apparently infeasible for the long suburban commute trips. When there are no viable alternatives, the suburban residents have no choice but driving. Responding to higher costs of driving imposed by the pricing, people may drive less by making travel more efficient, for instance, by combing trips. It is also very likely that, as noted earlier, they continue to drive but taking the no-toll routes, negotiating with the employers for parking subsidies, or using more fuel-efficient vehicles. From the travel choice perspective, when there are no alternatives, they will still have to depend on their automobiles in their daily life, possibly ending up with even a larger portion of income (and time) spent in driving.

Another finding from the Boston case study is that, among those who have access to the private motor vehicles, the lower income is more dependent on the automobile than the higher income. This finding does not contradict to other studies showing that income growth generally leads to increase in motorization and vehicle travel (e.g. Ingram and Liu, 1999). In fact, in the Boston sample, the higher income group has an ownership of 2.41 vehicles per household, higher than the lower income group, which has 1.65 vehicles per household. The average trip length for the higher income group is also longer than that of the lower income. The measured lower level of automobile dependence for the higher income group is attributable to the flexibilities the higher income people have in mobility, residential and even job location choices. This finding poses another challenge to the policy of relying on economic disincentives to reduce automobile dependence, because the lower income group who lacks travel and location flexibilities is most likely to be affected first, raising more concerns on transportation inequity associated with existing automobile dependence.

Of course, this is not to dismiss the role of economic policies in overcoming automobile dependence. Rather, it is to emphasize the importance of providing travel choices as the starting point. In conforming to individual's two-stage choice behavior discussed in the earlier section, public policies aiming to overcome automobile dependence should first focus on expanding individual's feasible choice sets as a necessary condition, and then employ (dis)incentives to encourage non-driving to achieve environmental and social objectives of transportation. The key is to overcome automobile dependence while mobility and accessibility are preserved and quality of life is maintained or improved (Dupuy, 1999).

The challenge to implementing the strategy of providing more travel choices is that the current suburban land use patterns do not offer favorable conditions to providing alternative transportation services. For example, the suburban density is too low to enable transit services to be efficient and cost-effective; health care and other services are so scattered that driving is the only feasible choice for a working mother; roads and streets are designed for swift vehicle movement, making biking and walking unsafe.

Hence, the precondition of overcoming automobile dependence is to re-plan and re-design the suburban built environment to make alternative travel supply more viable. This is the rationale on which many planners have recommended the land use-based strategies such as densification, mixed development, and pedestrian-friendly design to overcome automobile dependence. To this end, the role of land use as a mobility tool is to facilitate alternative travel supply, which in turn help reduce dependence on vehicle travel.

Obviously, same questions may be asked to the land use-based policy strategies: to what extent the automobile dependence can be reduced through land use reconfiguration? Even if travel alternatives are provided, can one guarantee that people switch from driving to non-driving, or drive less? The answer is it depends: some may and some may not. This leads to the second major conclusion and policy implication drawn from the study.

This study has shown that automobile dependence displays certain patterns in the spatial, social and activity dimensions. The sources of automobile dependence, however, are complex and diverse, varying among people differing in travel purposes, income, family structure, and residential locations. Automobile dependence is not a static state of vehicle use, but a dynamic process that has been driven by the societal changes in economic and technological development, in demographic and labor market compositions, and in the physical and institutional settings. It is a process that has been historically modified, more often than not, reinforced, by decades' land use development and transportation pricing practice. *This means that overcoming automobile dependence should take an incremental approach, target on particular portions of the driving market, and start from the trips with potential travel flexibilities.* One example of this kind of incremental, targeted policy strategies is to aim at reducing short driving trips via design-based strategies such as pedestrian- or biking-friendly environmental design. In the Boston sample, 11 percent of the total trips are within half a mile and 58 percent of them are driving trips. There are 12 percent of trips are between half a mile and one mile and 83 percent of which are by automobiles. These short trips, which are as large as six to ten percent of total driving trips, are potentially substitutable by walking or biking and should be targeted by the design-based mobility strategies. This policy recommendation offers two implications. First, the design-based strategies to improve the viability of walking and biking should target on reducing automobile dependent travel by the amount of about ten percent of total driving trips. Second, the ten percent reduction in driving trips through design strategies is close to the maximum since not all short driving trips can be substituted by non-driving. (This does not consider possible increase in transit trips resulting from improved walking and biking as access modes.) Therefore, expecting the urban design-based strategies to achieve more dramatic travel benefit in driving reduction is neither practical nor fare, at least in the near future when the regional physical structure remain largely unchanged.

In conclusion of this discussion, overcoming automobile dependence requires a package of policies from within and beyond transportation sector. Land use, transportation supply, and automobile pricing policies should act as complements. Each is designed to deal with one or more aspects of the automobile dependent travel while all need to work together. Land use and alternative travel supply are necessary conditions, whereas pricing makes them sufficient to overcome automobile dependence.

6.3 Contributions of the Research

This dissertation research has made a number of contributions to the field:

- Firstly, building the empirical analysis on the economic choice theory, this research offers a plausible explanation to the question of how land use 'causes' changes in travel behavior. Due to data limitations for testing the causality, many researchers have found themselves less than confident in explaining the observed empirical findings on the built environment/travel behavior connections, and therefore are cautious in making stronger policy recommendations. The notion of causation has also been used as the base on which the opponents question the potential of land use as an effective mobility tool. In this research, we have explained that land use influences travel demand and mode choice by having differentiated impacts on modal supply.
- Secondly, the research emphasizes the complementarities between land use initiatives and economic measures in affecting travel. It shows that either is necessary but not sufficient to achieve the environmental and social objectives of transportation. For both policy strategies to be effective and practical, the two should act together as complements. The mobility role of land use is to modify transportation supply and to support expansion of travel choices, whereas pricing is to manage and redirect vehicle travel demand. This research thus fills a research gap since in the literature the two are largely treated as substitutes.
- Thirdly, the modeling and quantification of automobile dependency explore uncharted waters. This paper has presented a disaggregate analytical framework to investigate automobile dependence from the perspective of individual's travel choice. Defining automobile dependence as the likelihood of an individual being captive to driving, the framework enables explicit modeling of and account for the intensity of the automobile dependent travel. Through two case studies, the single coefficient automobile dependence model has demonstrated the empirical advantages in quantifying automobile dependence. The relatively simple model formulation makes it convenient to compare and contrast the varying degrees of

the automobile dependent travel by different population groups and for different trip purposes. The parameterized automobile dependence model allows simultaneous control for the effects of various factors on travel choice decisions, and therefore helps identify the sources of automobile dependence. The findings of the study offer important insights into the understanding of the nature and causes of automobile dependence.

- Fourthly and finally, the examination of two contrasting international cases, Boston and Hong Kong, at the disaggregate level is a unique contribution of this research. It helps promote international learning in search for sustainable transport policy in an increasingly globalize world. In studying the two cases, we have also demonstrated the applications and robustness of a set of disaggregate modeling techniques. These techniques and methods provide sharpened tools for policy analysts to improve policy analysis.

6.4 Future Research

One important expansion of this research is to study other world cases, particularly those cities falling in between Boston and Hong Kong in terms of spatial and travel characteristics. These cities are mostly found in the Europe and other Asian countries. Analyzing a full range of international cases is important since issues like automobile dependency, decentralization, sustainable transportation are no longer city-specific, but increasingly global in nature.

The modeling of automobile dependence warrant further research. In this study, due to data limitations, we are not able to examine to what extent automobile dependence is caused 1) by the lack of alternative transport supply, 2) by the lack of information about the availability of alternatives, or 3) by individuals' attitudinal reasons. Therefore, more specific policy recommendations aiming to reduce people's dependence cannot be made. To improve the analysis, additional information needs to be collected on individuals' perceptions of or attitudes to alternative travel modes. This information can be obtained through surveys, for example, by asking respondents/travelers to rate on a scale the statements such as "The bus is available when I need to go to work or shopping" or "I don't care how frequently the train runs every day because I am going to drive anyway". Factor analysis can then be done to understand individuals' perceptions of and attitudes to different modes and to develop a "preference index" (e.g. Koppelman and Lyon, 1981), which can be used as an explanatory variable in modeling automobile dependence.

For computational convenience, the automobile dependence modeling in this research is simplified into a binary situation in both the Boston and the Hong Kong cases, that is, driving vs. non-driving. The analysis can be expended into three or more modes to better examine the captive travel behavior associated with transit or other modes. Doing so requires more computational capability as the complexity of model estimation increase exponentially as the number of modes increases.

The study can also be extended with more detailed analysis on particular segments of the population differentiated by income, age, or location characteristics so that the distributional effects of land use and transport pricing policies can be better examined. Moreover, effects of specific land use instruments such as parking requirements, minimum lot size, etc. should also be examined in greater detail.

Another direction to improve the research is to refine the measurement of land use and transit supply. For both the Boston and the Hong Kong case study, land use characteristics are measured at the zonal level. As TAZ's are generally defined to maintain equal population sizes among zones, the spatial extents of the zones vary from the inner city to the outer suburb. In the inner city, a TAZ may only contain a few city blocks, whereas in the suburb it is not rare that an entire town is a single TAZ. Large spatial variation among the TAZ's may generate measurement errors as the average zonal land use attributes may not necessarily reflect the characteristics of the specific locations where individual trip making takes place. The potential measurement errors partly explain the poor performance of the entropy measure of land use mix in mode choice modeling in the Boston case study. A possible solution to this problem is to rasterize the study area and compute the land use attributes based on the equal-size grid cells rather than TAZ's. Again, it requires significant computational resources given the size of the Boston metropolitan area and Hong Kong.

The issue of simultaneity exists in trip frequency modeling and in transit supply measures, and it is not dealt with in this study. In the trip frequency modeling reported in the Boston case study, the likelihood of higher trip rates is considered as a function of trip distance, trip time, and other independent variables. What is not considered is that trip distance in turn affects trip rates. There is a similar mutual causality issue in transit demand and supply: the level of transit supply directly affects people's demand for transit services. In the mean time, the decision in the level of transit supply (e.g. bus service frequencies) is affected by how large the demand is. The issue of mutual causality can be resolved by using a simultaneous equations technique, which requires different sets of empirical data.

6.5 Concluding Remarks

This dissertation research has shown that land use, in addition to economic measures, can play an important mobility role to influence travel and to achieve the multi-dimensional objectives of transportation. The issue is not whether land use *can* serve as an effective mobility tool, but *how* the tool is to be used. When the tool is used to ensure sufficient parking spaces, to mandate that a lot is no smaller than a certain size, and to guarantee the swiftness of auto travel with more vehicle lanes, driving will be naturally the most desirable travel mode to choose. When the land use is configured in such a way primarily to accommodate auto use, services by alternative modes such as transit become less viable. More often than not, to many suburban families, driving is not the best but often the only feasible choice. On the other hand, if the build environment is designed to be more friendly for walking or biking, and if land is developed such that better transit services can be provided, the attractiveness of these modes would increase. People would have more feasible and desirable options to choose from. Increased mobility choices means increased accessibility and improved quality of life.

For both land use and pricing policies to be effective in affecting people's travel, they should be designed and implemented together. The historical formation of land use and travel patterns through the interactive process of land use and transportation pricing practice in the US reveals that expecting either approach alone to become remedies to the current transport problems is unrealistic. Policy design aiming to reduce automobile dependence and to improve accessibility should have both in the same equation.

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Appendix

Technical Documentation

A.1 The Boston Case
A.2 The Hong Kong Case

This appendix contains working notes and programming codes that were written for data processing and empirical modeling for the Boston and Hong Kong case study. Several computing packages are utilized to take advantages of individual package's special capabilities.

- *Sybase for PC* (MetaVersion 6.0) for organizing and managing the data sets for both the Boston and the Hong Kong case. Detailed below.

- *ArcInfo 8.02* and *ArcView 3.2* for UNIX for geocoding trip origins and destinations at the city block level (represented by block centroids) for the Boston case; digitizing and creating Hong Kong road/rail networks and TAZ boundaries; generating thematic maps for both cities.

- *Statistical Software Tools*, or *SST* 3.0 by Dubin and Rivers Associates for MNL mode choice modeling for the Boston case.

- *HieLow* by Michel Bierlaire at Groupe de Recherche sur les Transports, Belgium for nested logit modeling in the Hong Kong case study.

- *Stata 7.0 for UNIX* for ordered logit and generalized ordered logit modeling for travel demand analysis. Captivity Logit modeling requires the use of Maximum Likelihood estimator which is also provided with Stata.

This appendix serves as references and road maps that will be useful for future research on the two cases.

A.1 The Boston Case

A.1.1 Data Management

- **Create the Database *BOSCASE.DB* in Sybase**

03-22-2000
Create a new database named BOSCASE with server named BOSCASE
from Adaptive Serve Anywhere/Manage Adaptive Serve Anywhere/
Sybase Central/utility/create database

Database "C:\MY_DOC~1\ZIPDISK1\DISSER~1\BOSTRI~1\BOSCASE.DB"
created successfully

To access the database in Interactive SQL: User ID: dbf ; Password: sql

Data Loading, Processing and Query

The data loading process is recorded in file *Phdthesis_loaddata.sql* (not included in this documentation). Data sets are linked as shown in the chart in Figure 3.4.

Code file *Phdthesis_runalltrips.sql* (not included here) records the data query procedures that generate a set of 'related' data for mode choice modeling in SST and for travel demand and automobile dependence analysis in Stata.

A.1.2 MNL Mode Choice Modeling with SST

Following SST code is written for the Boston MNL mode choice modeling.

File Name: run1009.cmd

```
spool file[run1009.out]
config more[off]

REM read to[tripodid seatsbus seatssub seatsrai hbwdist \
REM trip_id personid omdpwz dmdpwz triptime tripmode mode1 mode2 mode3 mode4 \
REM mode5 numothr carpakd pktype pkcost0 pkcost monthday cashfare passcst
bookcst \
REM iva24 ivaam ivaconge ivapm dist toll ivtrtran ivtrauto ovtrwait ovtrwalk fare \
REM pnrfee per_id id biryr sex drive hhsize numvehrc hhincrc hhincdd empfl ownrent \
REM over5 under5 workers luzone opkcost opoptot ohhtot oemptot ozoneinc olandind \
REM olandcom olandrec olandres olandtot dpkcost dpoptot dhhtot demptot dzoneinc \
REM dlandind dlandcom dlandrec dlandres dlandtot ototstr dtotstr ostops dstops \
REM obussup dbussup osubsup dsubsup orailsup drailsup oparking dparking \
REM oxingall odeadend oxing3wa oxing4wa dxingall ddeadend dxing3wa dxing4wa] \
REM file[logitdat.txt]
```

```
REM The input file, logitdat.txt, should be in tab-delimited form

REM save file[logitdat.sav]

clear
load file[logitdat.sav]

REM ***********************************************
REM * CHOICE ALTERNATIVES                         *
REM ***********************************************

set one = 1
set zero = 0

REM Four alternatives of mode choice

set choice = 1
REM non-motor mode = walk(tripmode==119), bike(98), or others(111)
set choice = 2; if[tripmode == 116]
REM transit mode = rail, bus, taxi
set choice = 3; if[tripmode==99]
REM shared ride private mode
set choice = 4; if[tripmode==100]
REM drive-alone


REM ***********************************************
REM * TRAVELER CHARACTERISTICS                    *
REM ***********************************************

set age = 91 - biryr
        REM The survey was done in 1991
set elder = 0
set elder = 1; if[age>=60]

set young = 0;
set young=1; if[age<=30]

set female = 0
set female = 1; if[sex==2]

set empfull = 0
set empfull = 1; if[empfl==1]


REM ***********************************************
REM * HOUSEHOLD CHARACTERISTICS *
REM ***********************************************

REM set income variables in US$
REM use TAZ median household income for those observations with missing values
```

```
set hhinc = ozoneinc
set hhinc = 15000; if[hhincdd == 1]
set hhinc = 30000; if[hhincdd == 2]
set hhinc = 50000; if[hhincdd == 3]
set hhinc = 70000; if[hhincdd == 4]
set hhinc = 90000; if[hhincdd == 5]
set hhinc = 120000; if[hhincdd == 6]

set vehown = numvehrc/workers; if[workers > 0]

set withkids = 0
set withkids = 1; if[under5 >=1]
set femnokid = female*(1-withkids)

set owner = 0
set owner = 1; if[ownrent == 1]

REM ********************************************
REM * COST VARIABLES                           *
REM ********************************************

REM TIME COSTS (UNIT: MINUTES)
set wkdist = hbwdist
set wkdist = (dist/10)*1609; if[hbwdist==0]
set walktime = ((1/(1+abs(age-30)/30))*wkdist/80)

set ttimetr = (ovtrwait + ivtrtran + ovtrwalk)/100
set ttimetr = triptime; if[ttimetr==0]

set ivtimedr = triptime
set ivtimedr=ivaam; if[ivtimedr==0]

set ivtimecp = triptime
set ivtimecp=ivaam; if[ivtimecp==0]

REM MONETARY COSTS (UNIT: US CENTS)
set faretr = (fare+pnrfee)/hhinc
set faretr = (cashfare*100+pnrfee+(passcst*100)/30)/hhinc; if[faretr==0]
set faretr = 150/hhinc; if[faretr==0 && (omdpwz<=400 && dmdpwz<=400)]
set faretr = 350/hhinc; if[faretr==0]
REM $1.5 is the average fare cost for trip O/D <= TAZ#400
REM $3.5 is the average fare cost for trip O/D > TAZ#400

set ttcostcp = (dpkcost+toll)/(numothr+1)/hhinc

set ttcostdr = (dpkcost+toll)/hhinc

REM ********************************************
REM * LAND USE VARIABLES                       *
REM ********************************************
```

```
REM NET LAND USE DENSITY
set obuiltup = olandcom+olandind+olandres+olandrec
set dbuiltup = dlandcom+dlandind+dlandres+dlandrec

REM UNIT: PERSONS OR JOBS PER ACRE
 set odenpop = opoptot/(obuiltup*640)
 set odenemp = oemptot/(obuiltup*640)
 set ddenpop = dpoptot/(dbuiltup*640)
 set ddenemp = demptot/(dbuiltup*640)

REM LAND USE MIX
set opctcom = olandcom/obuiltup; if[obuiltup>0]
set opctind = olandind/obuiltup; if[obuiltup>0]
set opctres = olandres/obuiltup; if[obuiltup>0]
set opctrec = olandrec/obuiltup; if[obuiltup>0]

set otmpcom = 0
set otmpcom = opctcom*log(opctcom); if[opctcom>0]
set otmpind = 0
set otmpind = opctind*log(opctind); if[opctind>0]
set otmpres = 0
set otmpres = opctres*log(opctres); if[opctres>0]
set otmprec = 0
set otmprec = opctrec*log(opctrec); if[opctrec>0]

set oentropy = - (otmpcom + otmpind +otmpres + otmprec)

set dpctcom = dlandcom/dbuiltup; if[dbuiltup>0]
set dpctind = dlandind/dbuiltup; if[dbuiltup>0]
set dpctres = dlandres/dbuiltup; if[dbuiltup>0]
set dpctrec = dlandrec/dbuiltup; if[dbuiltup>0]

set dtmpcom = 0
set dtmpcom = dpctcom*log(dpctcom); if[dpctcom>0]
set dtmpind = 0
set dtmpind = dpctind*log(dpctind); if[dpctind>0]
set dtmpres = 0
set dtmpres = dpctres*log(dpctres); if[dpctres>0]
set dtmprec = 0
set dtmprec = dpctrec*log(dpctrec); if[dpctrec>0]

set dentropy = - (dtmpcom + dtmpind +dtmpres + dtmprec)

REM INTERSECTION TYPES (UNIT: %)
set opct1way = odeadend/oxingall
set opct4way = oxing4wa/oxingall
set opct3wup = (oxing3wa+oxing4wa)/oxingall
set dpct1way = ddeadend/dxingall
set dpct4way = dxing4wa/dxingall
set dpct3wup = (dxing4wa + dxing3wa)/dxingall
```

```
REM ***********************************************
REM * TRANSPORT SUPPLY VARIABLES *
REM ***********************************************

REM INCLUDE TRANSIT STOP AND ROAD DENSITY INFO IN MODELS
REM Areas are measured in acres.

set olanepc = 0
set olanepc = ototstr/(opoptot); if[opoptot>0]
set odenstp = ostops/(obuiltup*640)
set odenrd = ototstr/(opoptot*obuiltup*640); if[opoptot>0 && obuiltup>0]

set dlanepc = 0
set dlanepc = dtotstr/(dpoptot); if[dpoptot>0]
set ddenstp = dstops/(dbuiltup*640)
set ddenrd = dtotstr/(dpoptot*dbuiltup*640); if[dpoptot>0 && dbuiltup>0]

set odenseat = 0
set odenseat = (obussup + osubsup + orailsup)/(obuiltup*640)
REM transit seats supplied per acre (per day) at origin zone

set ddenseat = 0
set ddenseat = (dbussup + dsubsup + drailsup)/(dbuiltup*640)
REM transit seats supplied per acre (per day) at destination zone

set parkride = 0
set parkride = 1; if[oparking>0]

set trseats = seatsbus + seatssub + seatsrai
set trseats = (566/17.5)*ostops; if[trseats==0 && choice==2]

REM 566 is the total number of seats in 100,000's in Boston at trip origns.
REM 17.5 is the total number of stops in 1000's in Boston at trip origins.
REM (566/17.5) is then the average seats-supplied (in 100's) per day per stop
REM at origins.
REM This helps fix the missing data (i.e. trseats==0 while choice==2)

REM ***********************************************
REM * DESTINATION CONTROL              *
REM ***********************************************

set CBD = 0
set CBD = 1; if[dmdpwz <= 80]

REM ***********************************************
REM * MODE AVAILABILITY                *
REM ***********************************************
REM Decision rules for setting mode availability
set avail_wk=0
set avail_wk = 1; if[wkdist <= 8000 ]
```

```
set avail_tr = 0
set avail_tr = 1; if[dstops > 0 || choice == 2]

set avail_cp = 1

set avail_dr = 0
set avail_dr = 1; if [numvehrc >= 1 ]

mnl dep[choice] ivalt[                                                   \
        walkbike:       one             zero            zero            zero    \
        transit:        zero            one             zero            zero    \
        carpool:        zero            zero            one             zero    \
        \
        wktime:         walktime        zero            zero            zero    \
        ttimetr:        zero            ttimetr         zero            zero    \
        ivtimecp:       zero            zero            ivtimecp        zero    \
        ivtimedr:       zero            zero            zero            ivtimedr \
        \
        faretr:         zero            faretr          zero            zero    \
        ttcostcp:       zero            zero            ttcostcp        zero    \
        ttcostdr:       zero            zero            zero            ttcostdr \
        \
        youngwk:        young           zero            zero            zero    \
        empfulldr:      zero            zero            zero            empfull\
        ownerdr:        zero            zero            zero            owner \
        femnokitr:      zero            femnokid        zero            zero    \
        vehowndr:       zero            zero            zero            vehown          \
        vehowncp:       zero            zero            vehown          zero    \
        \
        CBDtr:          zero            CBD             zero            zero    \
        CBDcp:          zero            zero            CBD             zero    \
        \
        odenpop:        odenpop         odenpop         zero            zero    \
        odenemp:        odenemp         odenemp         zero            zero    \
        ddenpop:        ddenpop         ddenpop         zero            zero    \
        ddenemp:        ddenemp         ddenemp         zero            zero    \
        \
        opct1waydr:     zero            zero            zero            opct1way \
        dpct3wupdr:     zero            zero            zero            dpct3wup \
        \
        oentropywktr:   oentropy        oentropy        zero            zero    \
        dentropywktr:   dentropy        dentropy        zero            zero    \
        \
        odenseattr:     zero            odenseat        zero            zero    \
        ddenseattr:     zero            ddenseat        zero            zero    \
        trseatstr:      zero            trseats         zero            zero    \
        ] coef[beta2]   \
        censor[avail_wk avail_tr avail_cp avail_dr]
```

```
REM *********************************************************************************
REM * LOOKING AT THE AVERAGE CASE: ALL VAR's
REM * TAKE THEIR MEAN VALUES
REM * This is for the calculation of the relationships between two
REM * variables (e.g. cost and land use) while holding logsum
REM * i.e. accessibility constant.
REM *********************************************************************************

set u1mean = beta2[1] + beta2[4]*mean(walktime) + beta2[12]*mean(young) \
        + beta2[19]*mean(odenpop) + beta2[20]*mean(odenemp) \
        + beta2[21]*mean(ddenpop) \
        + beta2[22]*mean(ddenemp) + beta2[25]*mean(oentropy) \
        + beta2[26]*mean(dentropy)

set u2mean = beta2[2] + beta2[5]*mean(ttimetr) + beta2[8]*mean(faretr) \
        + beta2[14]*mean(femnokid) + beta2[17]*mean(CBD) \
        + beta2[19]*mean(odenpop) + beta2[20]*mean(odenemp) \
        + beta2[21]*mean(ddenpop) + beta2[22]*mean(ddenemp) \
        + beta2[25]*mean(oentropy) + beta2[26]*mean(dentropy) \
        + beta2[27]*mean(odenseat) + beta2[28]*mean(ddenseat) \
        + beta2[29]*mean(trseats)

set u3mean = beta2[3] + beta2[6]*mean(ivtimecp) + beta2[9]*mean(ttcostcp) \
        + beta2[16]*mean(vehown) + beta2[18]*mean(CBD)

set u4mean = beta2[7]*mean(ivtimedr) + beta2[10]*mean(ttcostdr) \
        + beta2[12]*mean(empfull) + beta2[13]*mean(owner) \
        + beta2[15]*mean(vehown) + beta2[23]*mean(opct1way) \
        + beta2[24]*mean(dpct3wup)


set u3meantc = beta2[3] + beta2[6]*mean(ivtimecp) + beta2[9]*mean(ttcostcp)*1.01 \
        + beta2[16]*mean(vehown) + beta2[18]*mean(CBD)

set u4meantc = beta2[7]*mean(ivtimedr) + beta2[10]*mean(ttcostdr)*1.01 \
        + beta2[12]*mean(empfull) + beta2[13]*mean(owner) \
        + beta2[15]*mean(vehown) + beta2[23]*mean(opct1way) \
        + beta2[24]*mean(dpct3wup)

set umean = mean(avail_wk)*exp(u1mean) + mean(avail_tr)*exp(u2mean) \
        + mean(avail_cp)*exp(u3mean) + mean(avail_dr)*exp(u4mean)

set umeantc = mean(avail_wk)*exp(u1mean) + mean(avail_tr)*exp(u2mean) \
        + mean(avail_cp)*exp(u3meantc) + mean(avail_dr)*exp(u4meantc)

REM Calc the logsum
set lsmean = log(umean)
set lsmetc = log(umeantc)

set ptrmean = mean(avail_tr)*exp(u2mean)/umean
set pcpmean = mean(avail_cp)*exp(u3mean)/umean
```

```
set pdrmean = mean(avail_dr)*exp(u4mean)/umean
set pwkmean = 1-ptrmean-pcpmean-pdrmean

set ptrmetc = mean(avail_tr)*exp(u2mean)/umeantc
set pcpmetc = mean(avail_cp)*exp(u3meantc)/umeantc
set pdrmetc = mean(avail_dr)*exp(u4meantc)/umeantc
set pwkmetc = 1-ptrmetc-pcpmetc-pdrmetc

set etrmtc = 100*((ptrmetc-ptrmean)/ptrmean); if[ptrmean>0]
set ecpmtc = 100*((pcpmetc-pcpmean)/pcpmean); if[pcpmean>0]
set edrmtc = 100*((pdrmetc-pdrmean)/pdrmean); if[pdrmean>0]
set ewkmtc = 100*((pwkmetc-pwkmean)/pwkmean); if[pwkmean>0]


REM ********** Schedule One
REM ********** SETTING UP TO CALC DRIVE COST/DENSITY TRADE-OFFS
REM ********** WHILE HOLDING ACCESSIBILITY CONSTANT

REM *** travel cost (toll and parking) vs. pop density *****
REM Five items needed: (1)logsum (accessibility) at the mean LSMEAN;
REM (see 2-5 below) Four utility functions associated with the alternatives.

REM First calc the total utility level by excluding transit supply variable.
REM and then combine them in the final logsum equation.

REM (2)u1mean: This will change due to odenpop appeared in the utility function

set u1nopop = beta2[1] + beta2[4]*mean(walktime) + beta2[12]*mean(young) \
        + beta2[20]*mean(odenemp) + beta2[21]*mean(ddenpop) \
        + beta2[22]*mean(ddenemp) + beta2[25]*mean(oentropy) \
        + beta2[26]*mean(dentropy)

REM (3) u2mean will change as in u1mean.

set u2nopop = beta2[2] + beta2[5]*mean(ttimetr) + beta2[8]*mean(faretr) \
        + beta2[14]*mean(femnokid) + beta2[17]*mean(CBD) \
        + beta2[20]*mean(odenemp) + beta2[21]*mean(ddenpop) \
        + beta2[22]*mean(ddenemp) + beta2[25]*mean(oentropy) \
        + beta2[26]*mean(dentropy)  + beta2[27]*mean(odenseat) \
        + beta2[28]*mean(ddenseat) + beta2[29]*mean(trseats)

REM (4) u3mean will change because car poolers are also affected
REM by toll or parking fees

set u3nocost = beta2[3] + beta2[6]*mean(ivtimecp)  \
        + beta2[16]*mean(vehown) + beta2[18]*mean(CBD)

REM (5) u4mean will change
set u4nocost = beta2[7]*mean(ivtimedr)      \
        + beta2[12]*mean(empfull) + beta2[13]*mean(owner) \
        + beta2[15]*mean(vehown) + beta2[23]*mean(opct1way) \
```

```
        + beta2[24]*mean(dpct3wup)

REM Final logsum equation ready for analysis of density/driving cost trade-offs:

REM   lsmean = log(mean(avail_wk)*exp(u1nopop + beta2[19]*mean(odenpop)) \
REM             + mean(avail_tr)*exp(u2nopop+beta2[19]*mean(odenpop)) \
REM             + mean(avail_cp)*exp(u3nocost+beta2[9]*mean(ttcostcp)) \
REM             + mean(avail_dr)*exp(u4nocost+beta2[10]*mean(ttcostdr)))

REM the following is for simulating density/ttcost while holding accessibility constant.

REM   -0.83102 = log(0.51119*exp(-6.52592 + 0.0102212*odenpop) \
REM                   + 0.76864*exp(-3.20516 + 0.0102212*odenpop) \
REM                   + 1.0*exp(-2.33131-168.373*(ttcostdr/1.15336)) \
REM                   + 0.93284*exp(-0.56516-106.223*ttcostdr) )

REM Note here for ttcostcp=ttcostdr/avg(numothr) =ttcostdr/1.15336

REM To verify, do the following:

calc log(0.51119*exp(-6.52592 + 0.0102212*mean(odenpop)) \
                   + 0.76864*exp(-3.20516 + 0.0102212*mean(odenpop)) \
                   + 1.0*exp(-2.33131-168.373*mean(ttcostcp)) \
                   + 0.93284*exp(-0.56516-106.223*mean(ttcostdr)) )

REM which should be equal to lsmean. Verified!!

REM the simulation and graphing job can be better done in Excel.
REM Following numbers are needed
print var[lsmean] obs[1]

print var[u1nopop] obs[1]
calc mean(avail_wk)

print var[u2nopop] obs[1]
calc mean(avail_tr)
matrix beta2[19]

print var[u3nocost] obs[1]
calc mean(numothr+1)
calc mean(avail_cp)
matrix beta2[9]

print var[u4nocost] obs[1]
calc mean(avail_dr)
matrix beta2[10]
REM With above data, I should now be able to graph ttcost against pop density
REM with iso-accessibility. See Excel file MNLACSPMODEL.XLS
```

```
REM ****************** SIMULATION 1
REM Probabilities of all mode choices resulting from driving costs increase,
REM all else being equal.

REM (1) utility of walkbike: u1mean = -6.30633
REM (2) utility of transit: u2mean = -2.98557

REM (3) utility of carpool: u3nocost+beta2[9]*mean(ttcostcp)
REM                         = -2.33131-168.373*(ttcostdr/1.15336)

REM (4) utility of driving: u4nocost+beta2[10]*mean(ttcostdr)
REM                         = -0.56516-106.223*ttcostdr

REM Now move to Excel to do the simulation. Remember to include mode availability
values


REM ****************** SIMULATION 2
REM *** Probabilities of all mode choices resulting from population density at origin
REM increase, all else being equal.

REM (1) utility of walkbike: u1nopop + beta2[19]*mean(odenpop)
REM                         = -6.52592 + 0.0102212*odenpop

REM (2) utility of transit: u2nopop+beta2[19]*mean(odenpop)
REM                         = -3.20516 + 0.0102212*odenpop

REM (3) utility of carpool: u3mean = -2.97650

REM (4) utility of driving: u4mean = -0.99503

REM Now move to Excel to do the simulation. Remember to include mode availability
values


REM ****************** SIMULATION 3
REM *** Probabilities of all mode choices resulting from population density at
REM BOTH origin and destonation increase, all else being equal.

set u1noodpp = beta2[1] + beta2[4]*mean(walktime) + beta2[12]*mean(young) \
                        + beta2[20]*mean(odenemp)  \
        + beta2[22]*mean(ddenemp) + beta2[25]*mean(oentropy) +
beta2[26]*mean(dentropy)

set u2noodpp = beta2[2] + beta2[5]*mean(ttimetr) + beta2[8]*mean(faretr) \
        + beta2[14]*mean(femnokid) + beta2[17]*mean(CBD) \
        + beta2[20]*mean(odenemp) +  beta2[22]*mean(ddenemp) \
        + beta2[25]*mean(oentropy) + beta2[26]*mean(dentropy) \
        + beta2[27]*mean(odenseat) + beta2[28]*mean(ddenseat) \
        + beta2[29]*mean(trseats)
```

```
REM (1) utility of walkbike: u1noodpp + beta2[19]*mean(odenpop) +
                        beta2[21]*mean(ddenpop)
REM   = -6.61164 + 0.0102212*odenpop + 0.00390478*mean(ddenpop)

REM (2) utility of transit: u2noodpp + beta2[19]*mean(odenpop)+
                        beta2[21]*mean(ddenpop)
REM   = -3.29088 + 0.0102212*odenpop+ 0.00390478*ddenpop

REM (3) utility of carpool: u3mean = -2.97650

REM (4) utility of driving: u4mean = -0.99503

REM Now move to Excel to do the simulation. Remember to include mode availability
values


REM ****************** SIMULATION 4
REM Probabilities of all mode choices resulting from population density increase AND
REM driving costs increase, while holding accessibility constant,
REM all else being equal.

REM (1) utility of walkbike: u1nopop + beta2[19]*mean(odenpop)
REM                             = -6.52592 + 0.0102212*odenpop

REM (2) utility of transit: u2nopop+beta2[19]*mean(odenpop)
REM                             = -3.20516 + 0.0102212*odenpop

REM (3) utility of carpool: u3nocost+beta2[9]*mean(ttcostcp)
REM                             = -2.33131-168.373*(ttcostdr/1.15336)

REM (4) utility of driving: u4nocost+beta2[10]*mean(ttcostdr)
REM                             = -0.56516-106.223*ttcostdr


REM ********** Schedule Two
REM ********** SETTING UP TO CALC DRIVE COST/TRANSIT SUPPLY TRADE-OFFS
REM ********** WHILE HOLDING ACCESSIBILITY CONSTANT

REM *** travel cost (toll and parking) vs. transit supply *****
REM Five items needed: (1)logsum (accessibility) at the mean LSMEAN;
REM (see 2-5 below) Four utility functions associated with the alternatives.

REM First calc the total utility level by excluding transit supply variable.
REM and then combine them in the final logsum equation.

REM (2)u1mean: No change

REM (3) u2mean will change as in u1mean.

set u2noseat = beta2[2] + beta2[5]*mean(ttimetr) + beta2[8]*mean(faretr) \
```

```
        + beta2[14]*mean(femnokid) + beta2[17]*mean(CBD) +
beta2[19]*mean(odenpop) \
        + beta2[20]*mean(odenemp) + beta2[21]*mean(ddenpop) +
beta2[22]*mean(ddenemp) \
        + beta2[25]*mean(oentropy) + beta2[26]*mean(dentropy) \
        + beta2[27]*mean(odenseat) + beta2[28]*mean(ddenseat)

REM (4) u3mean will change because car poolers are also affected by toll or parking
fees

set u3nocost = beta2[3] + beta2[6]*mean(ivtimecp)                    \
        + beta2[16]*mean(vehown) + beta2[18]*mean(CBD)

REM (5) u4mean will change
set u4nocost = beta2[7]*mean(ivtimedr) \
        + beta2[12]*mean(empfull) + beta2[13]*mean(owner) \
        + beta2[15]*mean(vehown) + beta2[23]*mean(opct1way) \
        + beta2[24]*mean(dpct3wup)

REM Final logsum equation ready for analysis of driving cost/transit supply trade-offs:

REM   lsmean = log(mean(avail_wk)*exp(u1mean) \
REM            + mean(avail_tr)*exp(u2noseat+beta2[29]*mean(trseats)) \
REM            + mean(avail_cp)*exp(u3nocost+beta2[9]*mean(ttcostcp)) \
REM            + mean(avail_dr)*exp(u4nocost+beta2[10]*mean(ttcostdr)))

REM the following is for simulating density/ttcost while holding accessibility constant.

REM   -0.83102 = log(0.51119*exp(-6.30633) \
REM                   + 0.76864*exp(-3.06352 + 0.00040732*trseats) \
REM                   + 1.0*exp(-2.33131-168.373*(ttcostdr/1.15336)) \
REM                   + 0.93284*exp(-0.56516-106.223*ttcostdr) )

REM Note here for ttcostcp=ttcostdr/avg(numothr) =ttcostdr/1.15336

REM To verify, do the following:

calc log(0.51119*exp(-6.30633) \
                  + 0.76864*exp(-3.06352 + 0.00040732*mean(trseats)) \
                  + 1.0*exp(-2.33131-168.373*mean(ttcostcp)) \
                  + 0.93284*exp(-0.56516-106.223*mean(ttcostdr)) )

REM which should be equal to lsmean. Verified!!

REM the simulation and graphing job can be better done in Excel.


REM ***********************************************
REM * COMPUTING LOGSUM: Base Case*
REM ***********************************************
```

```
set u1 = beta2[1] + beta2[4]*walktime + beta2[12]*young \
        + beta2[19]*odenpop + beta2[20]*odenemp + beta2[21]*ddenpop \
        + beta2[22]*ddenemp + beta2[25]*oentropy + beta2[26]*dentropy

set u2 = beta2[2] + beta2[5]*ttimetr + beta2[8]*faretr \
        + beta2[14]*femnokid + beta2[17]*CBD + beta2[19]*odenpop \
        + beta2[20]*odenemp + beta2[21]*ddenpop + beta2[22]*ddenemp \
        + beta2[25]*oentropy + beta2[26]*dentropy \
        + beta2[27]*odenseat + beta2[28]*ddenseat + beta2[29]*trseats

set u3 = beta2[3] + beta2[6]*ivtimecp + beta2[9]*ttcostcp \
        + beta2[16]*vehown + beta2[18]*CBD \

set u4 = beta2[7]*ivtimedr + beta2[10]*ttcostdr \
        + beta2[12]*empfull + beta2[13]*owner + beta2[15]*vehown \
        + beta2[23]*opct1way + beta2[24]*dpct3wup

set ubase = avail_wk*exp(u1) + avail_tr*exp(u2) + avail_cp*exp(u3) + avail_dr*exp(u4)
set lsbase = log(ubase)

set ptr = avail_tr*exp(u2)/ubase
set pcp = avail_cp*exp(u3)/ubase
set pdr = avail_dr*exp(u4)/ubase
set pwk = 1-ptr-pcp-pdr


REM ***************************************************************************************
REM * COMPUTING ELASTICITY OF PROBABILITY_DRIVE_ALONE                                      *
REM ***************************************************************************************

REM ************ Effect of travel costs (parking & toll) increase by 1%.
REM ************ Note that two utility functions are affected:
REM ************ Drive and Car-pool (TTCOSTDR; TTCOSTCP)

set u4ttcost = beta2[7]*ivtimedr + beta2[10]*ttcostdr*1.01 \
        + beta2[12]*empfull + beta2[13]*owner + beta2[15]*vehown \
        + beta2[23]*opct1way + beta2[24]*dpct3wup

set u3ttcost = beta2[3] + beta2[6]*ivtimecp + beta2[9]*ttcostcp*1.01 \
        + beta2[16]*vehown + beta2[18]*CBD \

set uttcost = avail_wk*exp(u1)+avail_tr*exp(u2)+avail_cp*exp(u3ttcost) \
        + avail_dr*exp(u4ttcost)
set lsttcost = log(uttcost)

REM NEW MODE CHOICE PROBABILITIES WITH NEW ttcost

set ptrtcost = avail_tr*exp(u2)/uttcost
set pcptcost = avail_cp*exp(u3ttcost)/uttcost
set pdrtcost = avail_dr*exp(u4ttcost)/uttcost
set pwktcost = 1-ptrtcost-pcptcost-pdrtcost
```

```
REM ELASTICITIES OF CHOICE PROB WRT ttcost

REM Point-elasticities
set etrtcost = 100*((ptrtcost-ptr)/ptr); if[ptr>0]
set ecptcost = 100*((pcptcost-pcp)/pcp); if[pcp>0]
set edrtcost = 100*((pdrtcost-pdr)/pdr); if[pdr>0]
set ewktcost = 100*((pwktcost-pwk)/pwk); if[pwk>0]


REM Probability-weighted average elasticity

REM How to calc the aggregate elasticity? Moshe has a formula on P.113.
REM But it's not clear the weights should be the before-ttcost probabilities or after-ttcost.
REM Three ways to calc elasiticity: 1) using before-prob; 2) using after-prob
REM 3) using the average of the before- and after-prob. This is arc-elasticity values.

REM Also note that, each individual has four elasticities (one for each choice in the
choice set)
REM numbers.

REM

calc mean(etrtcost)
calc mean(ecptcost)
calc mean(edrtcost)
calc mean(ewktcost)


REM Above way to calc average elasticity gives most resonable results
REM 09-25-00

REM ACCESSIBILITY (I.E. LOGSUM) ELASTICITY WRT ttcost
set elstcost = -100*abs((lsttcost-lsbase)/lsbase)
REM Note here 'abs' is necessary because some lsbase < 0 and some > 0
REM It creates problems when calculate the mean.
REM By common knowledge we know the elasticity should be a negetive number.

calc mean(elstcost)


REM ************ Effect of population density at BOTH O/D's increase by 1%.
REM ************ Note that two utility functions are affected: WALK and TRANSIT
REM ************

set u1odpop = beta2[1] + beta2[4]*walktime + beta2[12]*young \
        + beta2[19]*odenpop*1.01 + beta2[20]*odenemp + beta2[21]*ddenpop*1.01 \
        + beta2[22]*ddenemp + beta2[25]*oentropy + beta2[26]*dentropy


set u2odpop = beta2[2] + beta2[5]*ttimetr + beta2[8]*faretr \
```

```
        + beta2[14]*femnokid + beta2[17]*CBD + beta2[19]*odenpop*1.01 \
        + beta2[20]*odenemp + beta2[21]*ddenpop*1.01 + beta2[22]*ddenemp \
        + beta2[25]*oentropy + beta2[26]*dentropy \
        + beta2[27]*odenseat + beta2[28]*ddenseat + beta2[29]*trseats

set uodpop = avail_wk*exp(u1odpop) + avail_tr*exp(u2odpop) + avail_cp*exp(u3) +
avail_dr*exp(u4)
set lsodpop = log(uodpop)


REM NEW MODE CHOICE PROBABILITIES WITH NEW odpop

set pwkodpop = avail_wk*exp(u1odpop)/uodpop
set ptrodpop = avail_tr*exp(u2odpop)/uodpop
set pcpodpop = avail_cp*exp(u3)/uodpop
REM set pdrodpp1 = avail_dr*exp(u4)/uodpop
set pdrodpop = 1-ptrodpop-pcpodpop-pwkodpop

REM ELASTICITIES OF CHOICE PROB WRT opop

REM Point-elasticities
set etrodpop = 100*((ptrodpop-ptr)/ptr); if[ptr>0]
set ecpodpop = 100*((pcpodpop-pcp)/pcp); if[pcp>0]
set edrodpop = 100*((pdrodpop-pdr)/pdr); if[pdr>0]
set ewkodpop = 100*((pwkodpop-pwk)/pwk); if[pwk>0]

calc mean(etrodpop)
calc mean(ecpodpop)
calc mean(edrodpop)
calc mean(ewkodpop)

REM ACCESSIBILITY (I.E. LOGSUM) ELASTICITY WRT odpop
set elsodpop = -100*abs((lsodpop-lsbase)/lsbase)
REM Note here 'abs' is necessary because some lsbase < 0 and some > 0
REM It creates problems when calculate the mean.
REM By common knowledge we know the elasticity should be a negetive number.

calc mean(elsodpop)

REM Output results to calc the mean values considering mode availability
REM the mean function in SST does not allow me to select specific sub-group of
REM records.
REM
REM Three INC categories:
REM LOW: 0 < INC <= 35000
REM MID: 35000 < INC <= 70000
REM HIGH: 70000 < INC

set probetrt = ptr*etrtcost
set probecpt = pcp*ecptcost
set probedrt = pdr*edrtcost
```

```
set probewkt = pwk*ewktcost

set probetrd = ptr*etrodpop
set probecpd = pcp*ecpodpop
set probedrd = pdr*edrodpop
set probewkd = pwk*ewkodpop

REM write var[hhinc ptr pcp pdr pwk \
        probetrt probecpt probedrt probewkt \
        etrtcost ecptcost edrtcost ewktcost \
        probetrd probecpd probedrd probewkd \
        etrodpop ecpodpop edrodpop ewkodpop ] \
        file[acspout.dat]

set fareraw = faretr*hhinc
set tcostcp = ttcostcp*hhinc
set tcostdr = ttcostdr*hhinc

REM write var[choice hhinc avail_wk avail_tr avail_cp avail_dr \
        sex hhsize numvehrc over5 under5 workers dist \
        walktime ttimetr ivtimecp ivtimedr fareraw tcostcp tcostdr \
        age empfull owner femnokid vehown CBD \
        odenpop odenemp ddenpop ddenemp     opct1way dpct3wup \
        oentropy dentropy odenseat ddenseat trseats ] \
        file[acspvar.dat]

REM write var[trip_id choice omdpwz dmdpwz oentropy dentropy ] \
        file[acspstat.dat]


REM *****************************************************
REM * COMPUTING VALUE OF TIME       $/hr   *
REM *****************************************************

REM HHINC = 52000
set vottr2 = (60*52000*(beta2[5,1]/(beta2[8,1])))/100
set votcp2 = (60*52000*(beta2[6,1]/(beta2[9,1])))/100
set votdr2 = (60*52000*(beta2[7,1]/(beta2[10,1])))/100


config more[on]
spool off
```

A.1.3 Captivity Logit for Automobile Dependence Modeling

These Stata macros (i.e. *.do* files) are for estimating the single coefficient and the parametrized captivity logit models of automobile dependence for the base case: all observations. Same model specifications apply to specific market segments when case selection conditions are specified.

- **Single Coefficient Captivity Logit Modeling of Automobile Dependence**

File Name: dogitbos_run.do

```
log using dogitbos_out_new.log, replace
* Dogit model  for the Boston case
* By Ming Zhang 06-05-2001
* This is a Stata .do file. To run this model, input data and variables
* should be set by running dogitbos_data_recode.do
*
* To run this model:
* athena% add stata
* athena% stata
* . do dogitbos_data_recode.do
* . do dogitbos_run.do
*

program drop _all
set more off

* ---------------------------------------------------------------------
* Model #0 Base model: all observations, no market segmentation

program define dogitbos0
   args lnf theta1 theta2 theta3
   quietly replace `lnf' = ln(`theta3'+1/(1+exp(`theta2'-`theta1'))) /*
                 */ -ln(1+`theta3') if $ML_y1==1
   quietly replace `lnf' = -ln(1+exp(`theta1'-`theta2')) /*
                 */ -ln(1+`theta3') if $ML_y1==0
end

ml model lf dogitbos0 (bicar = /*
        */ ivtimedr ttcostdr CBD  vehown owner oentropy dentropy /*
        */ opct1way opct3wup dpct1way dpct3wup) /*
        */ (ttimetr faretr femnokid trseats odenpop ddenemp young, /*
        */ nocons ) /capti if vehown>0

quietly ml search capti 0 100
quietly ml maximize, difficult
ml display
* ----------------------------------------------------------------------
```

- **Parametrized Coefficient Captivity Logit Modeling of Automobile Dependence**

File Name: palogitbos_run.do

```
log using palogitbos_out.log, replace
* Parameterized logit model  for the Boston case. It evolves from the
* dogit model 'dogitbos.do', with the same input data file.
*
* By Ming Zhang 06-09-2001
* This is a Stata .do file. To run this model, input data and variables
* should be set by running dogitbos_data_recode.do
*
* To run this model:
* athena% add stata
* athena% stata
* . do dogitbos_data_recode.do
* . do palogitbos_run.do
*

program drop _all
set more off

* ------------------------------------------------------------------
* Model #0 Base model: all observations, no market segmentation

program define dogitbos0
    args lnf uvc uvb dvc
    quietly replace `lnf' = ln(exp(`dvc')+1/(1+exp(`uvb'-`uvc'))) /*
                                */ -ln(1+exp(`dvc')) if $ML_y1==1
    quietly replace `lnf' = ln(1/(1+exp(`uvc'-`uvb'))) /*
                                */ -ln(1+exp(`dvc')) if $ML_y1==0
end

ml model lf dogitbos0 (CarUtil: bicar = ivtimedr ttcostdr tripdist /*
        */ vehown empfull owner opct3wup dpct3wup opct1way dpct1way)  /*
        */ (TransitUtil: ttimetr faretr seats femnokid young /*
        */ dppden oppden ojbden djbden oentropy dentropy, nocons )  /*
        */ (CarCapt: vehown  dppden oppden ojbden djbden oentropy /*
        */ dentropy opct3wup dpct3wup opct1way dpct1way tripdist)

quietly ml search
quietly ml maximize, difficult
ml display
* ------------------------------------------------------------------
```

A.1.4 Trip Frequency Modeling with Ordered Logit and Generalized Ordered Logit

This code is for modeling of all non-work trips. For modeling of other purposes, similar codes apply but with separate input data files as the dependent variables will be different.

File Name: tripallhnw_run.do

```
log using tripallhnw.log, replace
* Ordered logit model of trip frequensy for the Boston case
* By Ming Zhang 06-06-2001
* This is a Stata .do file. To run this model, input data and variables
* should be set by running tripallhnw.do
*
* To run this model:
* athena% add stata
* athena% stata
* . do tripallhnw.do
* . do tripallhnw_run.do

set more off

#delimit ;
set matsize 150;

ologit tripfreq ivtimedr tripdist parkride owner hhsize femkid
opct1way dpct1way  odenpop  ddenpop  odenemp ddenemp
oentropy dentropy ;

gologit tripfreq ivtimedr tripdist parkride owner hhsize femkid
opct1way dpct1way  odenpop  ddenpop  odenemp ddenemp
oentropy dentropy ;

#delimit cr

log close
```

A.2 The Hong Kong Case

A.2.1 Data Management

- **Create the Database HKCASE.DB in Sybase**

11-24-2000
Create a new database named HKCASE with server named HKSCASE
from Adaptive Serve Anywhere/Manage Adaptive Serve Anywhere/
Sybase Central/utility/create database
Database "C:\PHD\HONGKONG\HKCASE.DB" created successfully
To access the database in Interactive SQL: User ID: dbf ; Password: sql

- **Data Loading, Processing and Query**

The data loading process is recorded in file *hk_loaddata.sql* (not included in this documentation). Data sets are linked as shown in the chart in Figure 3.5.

Code file *hk_run.sql* (not included here) records the data query procedures that generate a set of 'related' data for mode choice modeling in HieLow and for automobile dependence analysis in Stata.

A.2.2 Nested Logit with HieLow for Mode Choice Modeling

Following notes are for the nested logit modeling of mode choice for the Hong Kong case.

Steps of Using Hielow for NL modeling:

1. Define model tree (model structure). Numbering all the modes/nodes in the same order as coded in Choice of the data file.

2. Specify a utility function for each mode.
-- specify coefficient names for all explanatory variables;
-- specify names corresponding to the variables
-- pairing coefficient names with the variable names
-- add corresponding pairs of coefficient*variable to utility functions.

3. Match variable names in above 2. with the corresponding variables in the data file.

4. Check data characteristics and Process data, all steps in Data menu

5. Set initial values to zero in Estimation menu and run the model.

NL Working Notes

Final Estimation results with three model structure specification.

05-28-2001

Ming Zhang, Hong Kong Case Study
Using Hielow to test the nested logit structure:

(0) Reference Specification: The MNL Model

```
-----> | Car
       | Taxi
       | Rail
       | Bus
```

(1) Specification One

```
----->  Private Transport ---->| Car
                               | Taxi
        Public Transport  ---->| Rail
                               | Bus
```

Description of the hierarchical structure

```
-----------------------------------------
        6 Private Transportation (ThetaPri)
                3 Car
                4 Taxi
        5 public transport (ThetaPub)
                2 Bus
                1 Rail
```

Node available if...

```
--------------------
Rail : Node available if... ((orailacc == 1) && (drailacc == 1)) || (choice == 1)
Bus : Always available
public transport : Always available
Taxi : Always available
Car : Node available if... (vehown > 0) || (choice == 3)
Private Transportation : Always available
```

List of utility functions

```
-------------------------
1 Rail
  odenjob-Bus * odenjob + odenpop-Bus * odenpop + one-Rail * one + railtime * time_rail
+ railcost * cost_rail + female-Bus * female + young-Bus * young
2 Bus
  odenjob-Bus * odenjob + odenpop-Bus * odenpop + one-Bus * one + bustime *
time_bus + buscost-Bus * cost_bus + female-Bus * female + young-Bus * young
5 public transport (ThetaPub)

4 Taxi
  taxicost * cost_taxi + taxitime * time_taxi
3 Car
```

```
 dpublot * dpublot + vehown * vehown + carcost-Car * cost_car + cartime-Car * time_car
+ one-Car * one + parking * parksub + ddenjb * ddenjob + ddenpp * ddenpop
6 Private Transportation (ThetaPri)
```

(2) Specification Two

```
----->   | Car
         | PublicTransport ----->| Rail
                                 | Bus
                                 | Taxi

--> Tue May 29 21:49:30 2001

Model description
=================

hk mode choice
04/26
         c:\phd\hongkong\hielowhk\nl_comp.str
         c:\phd\hongkong\hielowhk\hkskim6.dat

Description of the hierarchical structure
-----------------------------------------
         3 Car
         5 public transport (Theta0)
                  2 Bus
                  1 Rail
                  4 Taxi
Node available if...
--------------------
Taxi : Always available
Rail : Node available if... ((orailacc == 1) && (drailacc == 1)) || (choice == 1)
Bus : Always available
public transport : Always available
Car : Node available if... (vehown > 0) || (choice == 3)

List of utility functions
-------------------------
4 Taxi
  co-taxitime * time_taxi + co-taxicost * cost_taxi
1 Rail
  railcost * cost_rail + railtime * time_rail + one-Rail * one + odenpop-Bus * ch-odenpop +
odenjob-Bus * ch-odenjob + female-Bus * ch-female + young-Bus * ch-young
2 Bus
  odenjob-Bus * ch-odenjob + odenpop-Bus * ch-odenpop + female-Bus * ch-female +
young-Bus * ch-young + buscost * cost_bus + bustime * time_bus + one-Bus * one
5 public transport (Theta0)
```

3 Car
  co-ddenjob * ch-ddenjob + co-ddenpop * ch-ddenpop + co-pksub * ch-pksub + co-dpublot * ch-dpublot + co-vehown * ch-vehown + carcost * cost_car + cartime * time_car + one-Car * one

(3) Specification Three

```
----->  | Car
        | Taxi
        | PublicTransport ----->| Rail
                                | Bus
```

Model description
================

hk mode choice
04/26
c:\phd\hongkong\hielowhk\nl0523.str
c:\phd\hongkong\hielowhk\hkskim6.dat

Description of the hierarchical structure

```
    4 Taxi
    3 Car
    5 public transport (Theta0)
        2 Bus
        1 Rail
```

Node available if...

Rail : Node available if... ((orailacc == 1) && (drailacc == 1)) || (choice == 1)
Bus : Always available
public transport : Always available
Car : Node available if... (vehown > 0) || (choice == 3)
Taxi : Always available

List of utility functions
----
1 Rail
  young-Bus * young + female-Bus * female + railcost * cost rail + railtime * time rail + one-Rail * one + odenpop-Bus * odenpop + odenjob-Bus * odenjob
2 Bus
  young-Bus * young + female-Bus * female + buscost-Bus * cost bus + bustime * time bus + one-Bus * one + odenpop-Bus * odenpop + odenjob-Bus * odenjob
5 public transport (Theta0)

3 Car
  dpublot * dpublot + vehown * vehown + carcost-Car * cost car + cartime-Car * time car + one-Car * one + parking * parksub + ddenjb * ddenjob + ddenpp * ddenpop
4 Taxi
  taxicost * cost taxi + taxitime * time taxi

A.2.3 Captivity Logit for Automobile Dependence Modeling

These Stata macros (i.e. *.do* files) are for estimating the single coefficient and the parametrized captivity logit models of automobile dependence for the base case: all observations. Same model specifications apply to specific market segments when case selection conditions are specified.

- **Single Coefficient Captivity Logit Modeling of Automobile Dependence**

File Name: dogithk_run.do

```
log using dogithk_out_0622.log, replace
* Dogit model  for the HK case
* By Ming Zhang 06-20-2001
* This is a Stata .do file. To run this model, input data and variables
* should be set by running dogithk_data_recode.do
*
* To run this model:
* athena% add stata
* athena% stata
* . do dogithk_data_recode.do
* . do dogithk_run.do
*
program drop _all
set more off
use using hkloghba if (dlh==1 | vehtot>0)
* use using hkloghba if (dlh==1 | vehtot>0) & hkside==1
* use using hkloghba if (dlh==1 | vehtot>0) & hkside==1 & dpur > 3

* The Program -----------------------------------------------------------
program define dogithk
       args lnf theta1 theta2 theta3
        quietly replace `lnf' = ln(`theta3'+1/(1+exp(`theta2'-`theta1'))) /*
                                */ -ln(1+`theta3') if $ML_y1==1
        quietly replace `lnf' = -ln(1+exp(`theta1'-`theta2')) /*
                                */ -ln(1+`theta3') if $ML_y1==0
end
* -------------------------------------------------------------------------

* -------------------------------------------------------------------------
* Model #0 Base model: all observations, no market segmentation

ml model lf dogithk (choice = /*
        */ cartime carhinc parksub vehown dpublot dppden djbden) /*
        */ (transitt transitc female young oppden  ojbden , nocons ) /captivity

 ml search captivity 0 100
 ml maximize, difficult
ml display
---------------------------------------------------------------------------
```

- **Parametrized Coefficient Captivity Logit Modeling of Automobile Dependence**

File Name: palogithk_run.do

```
log using palogithk_out_0723.log, replace
* Dogit model  for the HK case
* By Ming Zhang 07-23-2001
* This is a Stata .do file. To run this model, input data and variables
* should be set by running dogithk_data_recode.do
*
* To run this model:
* athena% add stata
* athena% stata
* . do dogithk_data_recode.do
* . do palogithk_run.do
*

program drop _all
set more off
* use using hkloghba if (dlh==1 | vehtot>0)
* use using hkloghba if (dlh==1 | vehtot>0) & hkside==1
use using hkloghba if (dlh==1 | vehtot>0) & hkside==1 & dpur > 3


* The Program -----------------------------------------------------------
program define palogithk
        args lnf uvc uvb dvc
         quietly replace `lnf' = ln(exp(`dvc')+1/(1+exp(`uvb'-`uvc'))) /*
                                 */ -ln(1+exp(`dvc')) if $ML_y1==1
         quietly replace `lnf' = ln(1/(1+exp(`uvc'-`uvb'))) /*
                                 */ -ln(1+exp(`dvc')) if $ML_y1==0
end

* -----------------------------------------------------------------------

* -----------------------------------------------------------------------
* Model #1: all observations, non-work trips

ml model lf palogithk (CarUtil: choice = /*
         */ cartime carhinc  parksub vehown dpublot dppden djbden) /*
         */ (TransitUtil: transitt transitc female young oppden ojbden , nocons ) /*
         */ (CarCaptivity: vehown tripdistsq young dppden djbden)

quietly ml search
quietly ml maximize, difficult
ml display
* -----------------------------------------------------------------------
```