Title

The Rapid Rise of Middle-Class Vehicle Ownership in Mumbai

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Publication Date

2012-10-01

UCTC-DISS-2012-01

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2012

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By

Manish Shirgaokar

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

City and Regional Planning

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Elizabeth Deakin, Chair
Professor Robert Cervero
Professor Joan Walker

Fall 2012

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Abstract

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In India, demand for urban mobility is increasing rapidly because of growth in urban populations, establishment of multiple employment sub-centers, suburbanization of households, better education, higher workforce participation rates, and rising incomes. An increase in discretionary spending is leading to higher household transportation budgets. Middle-income households in particular are investing in private vehicles such as motorized two-wheelers (TWs) and cars. At the same time, policies to reduce vehicle ownership through regulations and user costs remain underdeveloped and weakly enforced. This further increases households' willingness to use vehicles, especially for non-discretionary work trips. Higher private vehicle use is affecting other quality of life issues such as time spent commuting, accident rates, noise pollution, and particulate and greenhouse gas emissions.

In part, this higher vehicle ownership and use is driven by land use dynamics in Indian cities, where growth within city municipal boundaries is constrained by regulations limiting floor-area ratios. As a result, much of the new growth has taken place in urban peripheries where land is cheap and building costs are low. In these peripheral areas, existing small and medium towns have become anchors for agglomeration, transforming into bedroom communities for emergent middle-class groups. Urban peripheral areas are usually undersupplied with transportation infrastructure such as roads or bus transit.

This dissertation unpacks the question of why the middle-class in India is driven to owning and using TWs and cars by asking the following: (1) How does work location influence travel by public and private modes? (2) What factors encourage vehicle ownership in middle-class households? (3) What factors drive up vehicle use in middle-class households? The research was conducted using a travel survey dataset from the Greater Mumbai Region (GMR) that represents 1.5% of the households there. The GMR is among the most populated megacity regions in the world, housing over 22 million people. Its growth illustrates the transformation from a monocentric to a polycentric city which is seen in many rapidly growing Indian cities.

In seeking to develop an understanding of how work location affected travel, this research identified employment sub-centers using work destination data. Of all middle-class

home-based work trips, 67 percent ended in a sub-center, while 33 percent did not. Mean travel times and mean travel distances by train, TW and intermediate public transportation (IPT) modes such as rickshaws were longer for work destinations in sub-centers than for work destinations in the urban periphery, but trips made by buses were shorter in sub-centers. Car users traveled longer and farther compared to TW users for home-based work trips in the GMR. Trains were the speediest mode of travel in the GMR, but traveling by a TW or car was speedier than bus or IPT travel—confirming that having a private vehicle has advantages.

This research used a multinomial logit model to analyze households' choice of having no vehicles, only TWs, or at least one car. Results indicated that household utility from both TWs and cars increased with household characteristics such as per capita annual income, living in an independent house or an apartment, number of rooms in the housing unit, housing location farther from a railway station, the presence of children under 5 years, and larger household size. Moreover, vehicle utility for households increased with the primary wage earner's characteristics including college education, employment, being married, making more trips across all modes, traveling during the morning peak, and working in the urban periphery. Household utility from both TWs and cars decreased when the primary wage earner had longer work trips and higher employment density at the work location.

Regression models for vehicle kilometers traveled (VKT) and person kilometers traveled (PKT) for cars and TWs showed that vehicle use increased with number of employed persons in the household, and if the primary wage earner worked in the urban core. Vehicle use decreased if density of housing and jobs went up at either the home or work location. TW use went down with per capita annual household income.

Overall findings indicate that demand for private vehicles is rising due to the following factors: better education, employment, higher incomes, suburbanization, peripheral employment node formation, and lack of public travel options. However, higher density decreases vehicle use. Without changes in policies encouraging higher well-managed densities, jobs-housing balance, and supply of adequate transit and IPT travel options, vehicle ownership and use will likely continue to grow rapidly in India.

To that which is
To that which may yet be

To hope

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ACKNOWLEDGEMENTS

Many forces shape what we are, what we do, and how we do things.

Soyabbhai, Pravinbhai, Manharbhai. Friends, more often guideposts to my moral compass, always men with dignity who gracefully accepted the hand life had dealt them. Sometimes chauffeurs. You helped me understand how the other lives. You shared the hopes and dreams you had for your children with me. I may have never embarked on this journey if you had not been around to drive me from airports to corporate offices, often very early in the morning, sometimes too late at night.

A disaggregate analysis of consumption behaviors is rare in the context of public policy in India. I was lucky to have a series of contacts that led me to MMRDA (Mumbai Metropolitan Region Development Authority) who held an extensive household travel survey dataset – making such an analysis possible. I thank Mr. PRK Murthy (Chief, Transport and Communications Division) for granting me access to this non-public dataset, and Mr. Manoj Dandare for his help at MMRDA. Mr. B. M. Setty of LEA Associates South Asia Private Limited was helpful with other relevant pieces of information.

Elizabeth Deakin (Betty) has helped me evolve into a better policy thinker. She supported me not just by being a mentor during the many years of working together, but also financially through research positions. She constantly challenges me to think critically, and I hope she will keep doing so in the future. Robert Cervero, though busy with travel and other engagements, was supportive with careful critique and encouragement. Joan Walker was helpful with the choice models. I thank her for bringing this elegant technique to those of us interested on the policy applications side. Lee Schipper was an optimist on policy questions in India, and always had a contact person to go to when I was stuck with an issue. His passing on during my dissertation writing phase was saddening.

The University of California Transportation Center's Dissertation Grant and the Dean's Normative Time Fellowship at UC Berkeley provided funding for the analysis and writing phase of my Ph.D. My professors and colleagues have helped me tremendously over the years. However, all opinions, errors or omissions in this work are mine.

Jin Murakami was my sounding board on specifics of research design and strategy. Liming Wang and Sheng Li helped me with questions on database management, statistical and GIS analysis. Ye Kang Ko, Sara Jensen, and Allison Lassiter helped me with the nitty-gritty of GIS analysis. Akshay Vij was my go-to choice modeling guru. Colleagues in the Ph.D. Program at Berkeley – Bruce Appleyard, Gautam Bhan, Andrea Broaddus, Ian Carlton, Asavari Devadiga, Reim El-Zoghbi, Lisa Feldstein, Julie Gamble, Erick Guerra, Sara Hinkley, Carrie Makarewicz, Sergio Montero, Greg Newmark, Wei-Shiuen Ng, Billy Riggs, Renee Roy, James Rubin, Rebecca Sanders, Bob Schneider, Allie Thomas, Jake Wegmann, and Miriam Zuk – were there to talk and share during these years of production. I have learned a lot from them.

In Mumbai, Amita and Amitabh RoyChowdhury opened their home and hearts to me during the months of field work. This family adopted me and made me feel welcome in my case city. They were inquisitive about my research and helpful when I was frazzled.

In Berkeley, Robert Lew was not just my landlord, but also a friend and mentor. He saw me jubilant and stressed during these years. He was always there; for this I thank him. Last but not the least, my parents Anand Shirgaokar and Jyotsna Shirgaokar, my sister Rashmi Vaidya and brother-in-law Sachin Vaidya understood my need to indulge in original research. They were concerned about where my life choices were leading me, but always supported my need to know and do more. I have come to this threshold because of you. I owe you much.

Berkeley, California
December, 2012

Chapter 1

Factors Contributing to the Rapid Rise of Private Vehicles in India: Framing the Issue of Vehicle Ownership and Use

1.1 GROWTH AND CHANGE IN INDIA

Rapidly growing vehicle ownership in India raises anxieties about social, economic and environmental sustainability, but reflects the emergence of a large middle-class with hopes for a comfortable life. This introductory chapter discusses how demand for urban mobility, and in particular mobility based on personal vehicles, is going up because of growth in urban population, suburbanization of housing, increasing sub-centering of employment, and changes in consumer preferences and options resulting from better education and rising incomes. Such growth in vehicle ownership and use has serious implications for safety, emissions, and livability. Whereas in the short-term, the Indian government hopes to let vehicle and fuel standards take care of emissions externalities, it is also looking into cordon and time pricing strategies for major cities to address concerns of congestion. Long term land use changes are also part of policy thinking. However, much of this policy thinking is an assortment of good ideas that need further development and evaluation, and would require regulatory reform to be implemented effectively.

As the middle-class grows in size and affluence, without changes in land use planning, supply of transit options, and thoughtful regulation of intermediate public transportation (IPT) options such as rickshaws, vehicle ownership and use will likely grow in India. This in turn is likely to create tremendous pressures on urban infrastructure, city and state budgets, environmental quality, and public health. A major question is whether the Indian path forward will be like that of so many other emergent economies, with severe congestion and pollution the norm, or more like the paths found in sustainable cities where the automobile is not dominant but rather is a complement to walking, biking and transit use.

Though India is growing economically, there is still a large segment of the population living in deplorable circumstances in cities and villages – many come to cities from rural locations in search of a better life. However, access to opportunities is often challenging since the very poor rely on walking, biking or on collective, mostly public travel modes such as buses. Since transportation investments in India are largely in road space, and not in transit, this group remains underserved in most Indian cities.

Along with poverty, informality in employment and incomes across all segments of society is a dominant condition in Indian cities. Official, formal processes often leave the informal out of the analysis or deal with it in a perfunctory manner. However, even the formal society is often under-studied, with little data gathered or analyzed. Taking these issues together, the result is often a lack of understanding on ground truths, and a lack of robust research on public policy questions.

Congestion and pollution are apparent all over India, particularly in cities like Mumbai, which is wealthy and very densely populated. The city has had a supply of rail and rubber tire transit options for many decades, and a vibrant culture of transit use. Yet similar to many other Indian cities, Mumbai has a growing number of private vehicles. In some ways, Mumbai is a counterfactual to other Indian cities, because most other Indian cities do not have many transit options. Indeed, given such a diverse supply of transit options, why would households in Mumbai choose to own and use a private vehicle? The city thus can serve as an example of what may be the future for other Indian cities, absent a forceful change of policies that look beyond simply providing road space and trunk line transit services such as bus-rapid transit systems and metros. Luckily, Mumbai also has good data on growth patterns and transportation which can support investigations into the motorization phenomenon, allowing for the development of improved understandings of the factors involved, and laying the groundwork for future policy studies.

This chapter frames this dissertation by providing background information on urbanization in India, changes in the middle-class, growth in vehicle ownership, transportation sector supply side government initiatives, and proposed directions in nation transportation policy. The concluding sections highlight gaps in the literature showing the need for research on vehicle ownership and use in the Indian context, and give an outline of the dissertation.

1.1.1 Population, Urbanization and Middle-Class Growth

As more families move into urban areas across India, an increasing percentage of the population is moving from "working poor" into the "middle-class." The key factors for this transition are increasing education in successive generations, a limiting of household size in urban India, greater mobility, and higher buying power. As households move into formal housing and formal jobs, they move farther out from urban cores, which is usually where they can afford to buy housing. At the peripheries of Indian cities, where transportation infrastructure is weakly supplied, but demand for travel is rapidly growing, questions of how to get to work and education are most pressing. This is the setup for the questions that this dissertation grapples with. Households are investing in private vehicles in numbers never before experienced in India; this investment is partly the result of private preferences and new opportunities, and partly the result of the transportation and land use choices that are made available as a result of public policies.

Figure 1.1 shows how the population in India has grown since 1901, along with the increase in urban population. Whereas only 11% of India's population was urban in 1901, after independence 17% was urban in 1951. 23% of the total population was urban in 1981, 25% in 1991, and 28% in 2001. In the 2011 census, the urban population was 31%. Therefore, not only has the population grown, but almost one in three Indians lives in a city currently.

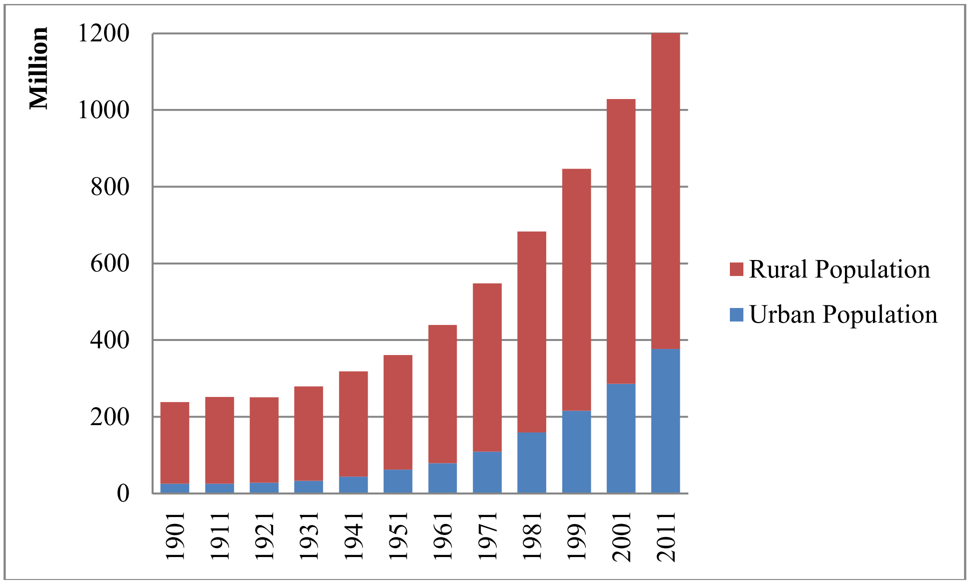

FIGURE 1.1 Population growth in India.
Source: Govt. of India, Report on Indian Urban Infrastructure and Services, March 2011, table A4, pg. 170.

The government of India classifies cities based on their population. Figure 1.2 shows how many cities fell in each class over the census years. Small cities (class IV+) were 89% of the total cities in India in 1901, but this class had shrunk to 55% in 2001. The largest growth was in class III cities which went from 7% of the total in 1901 to 27% in 2001. Very large cities (classes II and I) have also grown in numbers. Growth in smaller cities creates specific challenges for sustainability given their limited institutional capacity (Dimitriou, 2006).

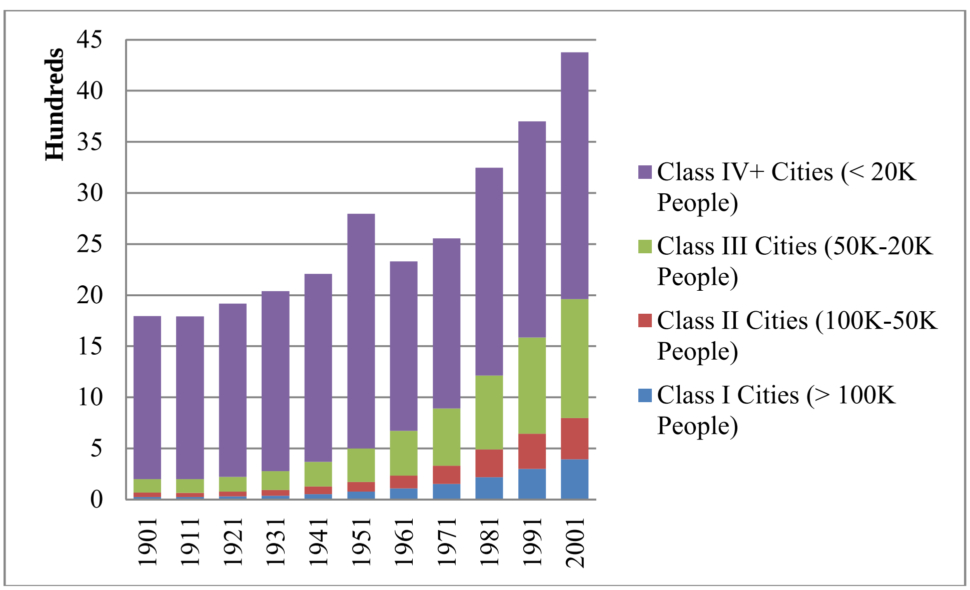

FIGURE 1.2 Growth in cities by category.
Source: Govt. of India, Report on Indian Urban Infrastructure and Services, March 2011, table A5, pg. 171.

Figure 1.3 shows what percentage of the urban Indian population is housed in each city class since 1901. Whereas only 26% of urban India lived in class I cities in 1901, by 2001 this number had grown to 69%. Therefore, two out of three urban Indians lived in very large cities with populations of over a hundred thousand people. In 2001, 38% of urban India lived in cities over a million, whereas 21% lived in cities over five million (calculations based on figure 1.4). The growth of populations in class II and III cities has gone down slightly over the 100 year time span, whereas the number of people moving into very small cities (class IV+) has shrunk down from 46% to 9%. Evidently, big cities hold promise for Indians, who tend to migrate to large cities rather than move into comparably smaller cities or towns.

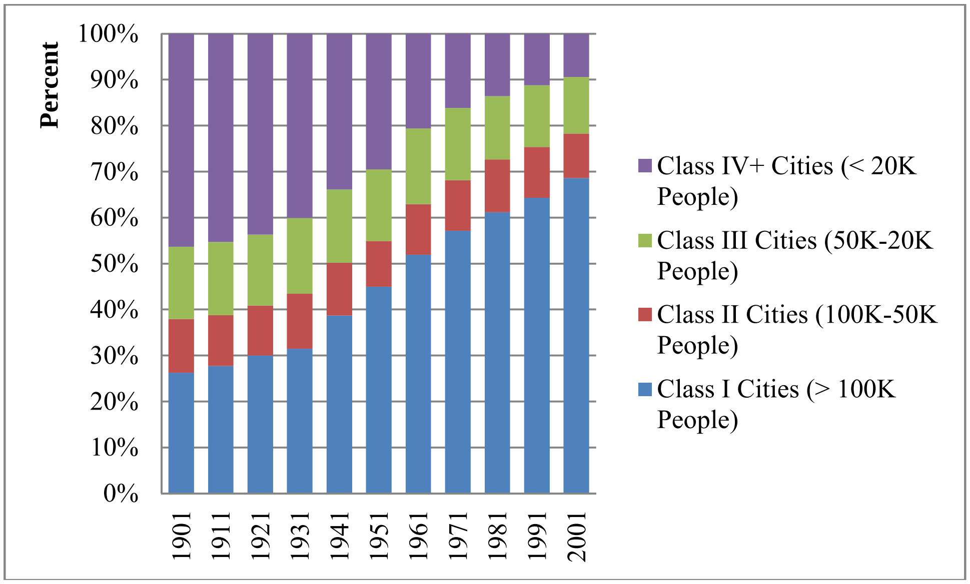

FIGURE 1.3 Population change by city categories.
Source: Govt. of India, Report on Indian Urban Infrastructure and Services, March 2011, table A6, pg. 172.

Based on government projections, figure 1.4 shows how the cities in each class might grow. For this analysis, the authors (see figure source) used a finer grain by splitting class I into three sub-classes. Note how cities in class IC (1 million to 100,000) are expected to grow at the fastest rate. A similar dynamic is projected for class IB cities, whereas the truly large cities in class IA are projected to slow down a little in terms of population growth. This graph is only part of the story since the question of growth has to do with both the numbers and kinds of cities growing in India, as well as with the socio-economic characteristics of populations that these locations will likely contain.

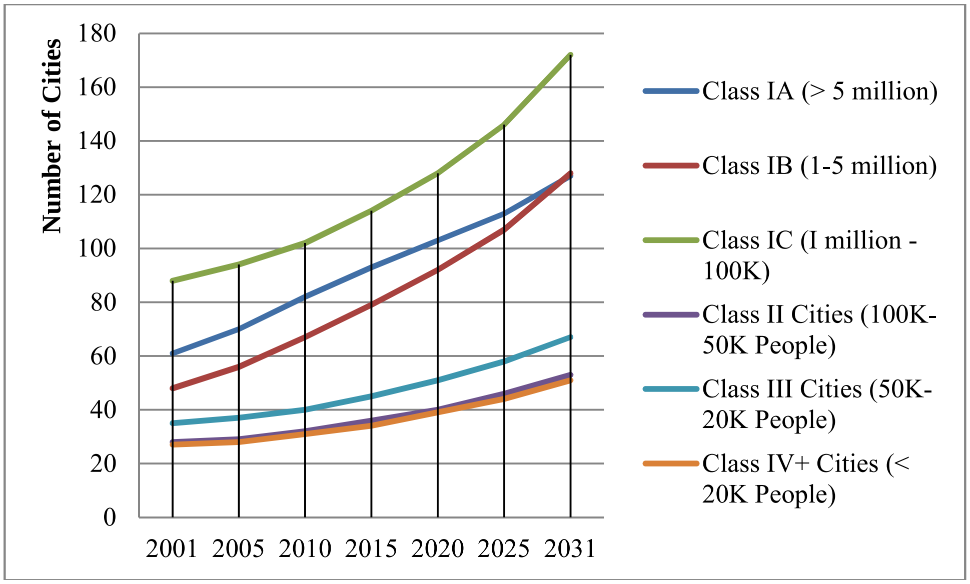

FIGURE 1.4 Projected urbanization in India.
Source: Govt. of India, Report on Indian Urban Infrastructure and Services, March 2011, table B2, pg. 220.

In India, literacy is defined as having "… the ability to read and write with understanding in any language" (http://lawmin.nic.in/ncrwc/finalreport/v2b1-5.htm, accessed November 30, 2012). This definition is quite similar in form to the standard used by UNESCO, yet there is often debate about what it means to be literate in India (see http://unstats.un.org/unsd/demographic/products/socind/illiteracy.htm, accessed November 30, 2012). Sridharan, E. (2008) shows how the literacy categories have shifted in the urban workforce since the mid-1970s (figure 1.5). While urban workforce illiteracy went down from 44% to 25%, this still implies one in four urban Indian workers is illiterate. Those with some schooling are the biggest segment of the bar-chart in each year shown. Workers with some college were only 7% in the 1970s, but this group had grown to 21% by the mid-2000s. This is a good indication of how education, at least in urban India, is a growing phenomenon. On average, men are better educated than women in urban India. However, when these data are split by gender for urban India, it shows that similar percentages of men and women workers get a college education. Hence, urban India is not only a place where income and education are increasing, but also gender equality.

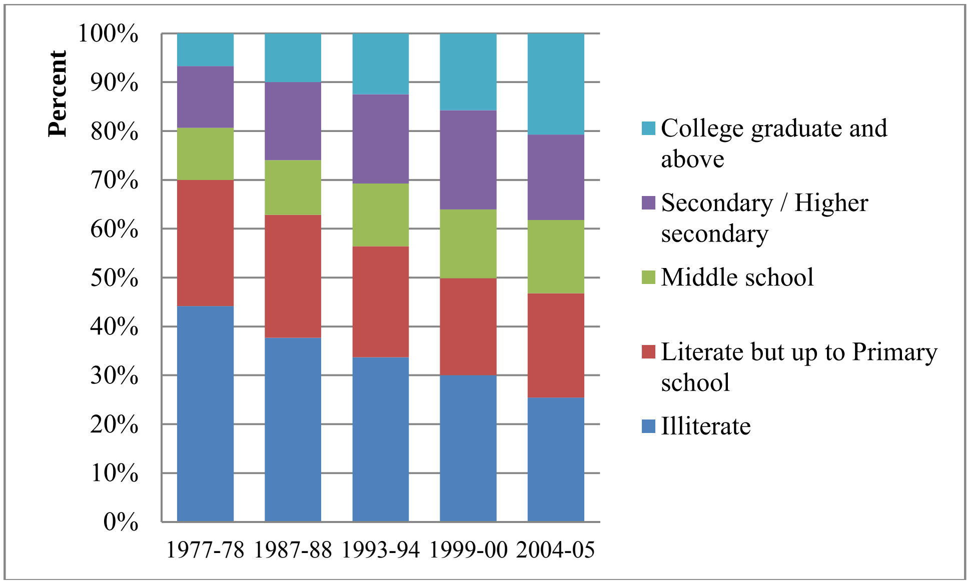

FIGURE 1.5 Educational composition of urban workforce (in %).
Source: Based on Sridharan, E., September 2008, table 11.

The growing GDP in India has resulted in (and comes from) a shift towards a service economy. The service sector is primary comprised of transportation, communication, finance and trade. In India, the largest growth is in services for wholesale and retail trades, transport, education, hotel and restaurant, and business services (Nayyar, 2012). Figure 1.6 shows how between 1977-78 and 2009-10, the segment of urban workers in each economic sector has grown (in millions). In particular, since the opening of the economy in the early 1990s, the growth in both "secondary" and "tertiary" sectors has been steadily upward. In percentage terms, while 15% of the urban economy was in the agriculture (primary) sector in 1977-78, it was only 8% in 2009-10. The service (tertiary) sector was 51% of the urban economy in 1977-78, and had grown to 58% by 2009-10; this translates to a growth from 25 million workers to 70 million workers in Indian cities.

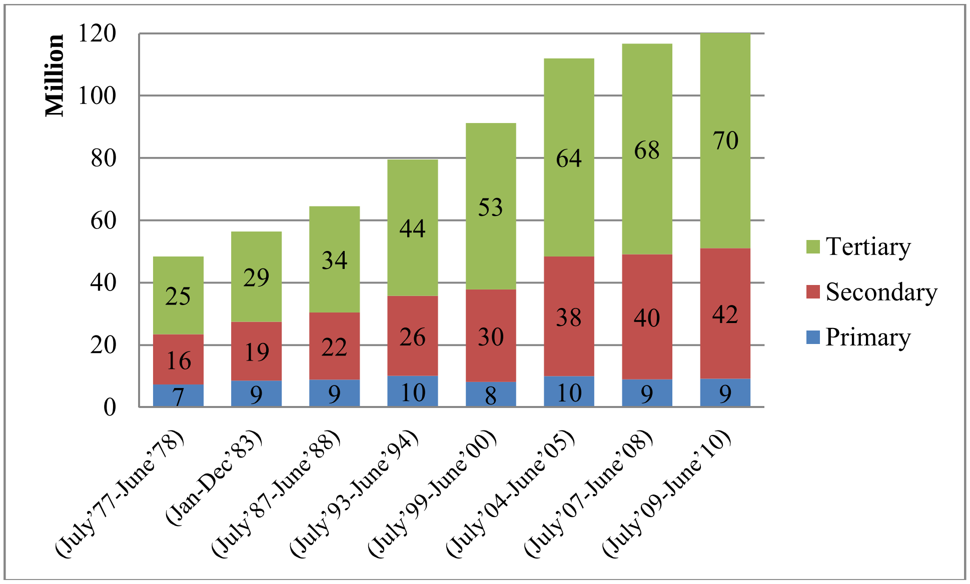

FIGURE 1.6 Number of urban workers by economic sector.
Source: Based on Himanshu, September 2011, 43-59, table 6a, pg 46.

The employment status of workers shows a different but important aspect of urban India (figure 1.7). From 1977-78 to 2009-10, the numbers of urban workers have grown significantly, and entrepreneurship is alive and well. In percentage terms, self-employed urban workers have barely changed at 41%, but in absolute numbers this group has grown from 21 million to 51 million workers. At the same time, regular workers, i.e., those employed full-time or part-time, have gone from 20 million to 51 million; this group has held at roughly 40% of the total urban work force in each year shown.

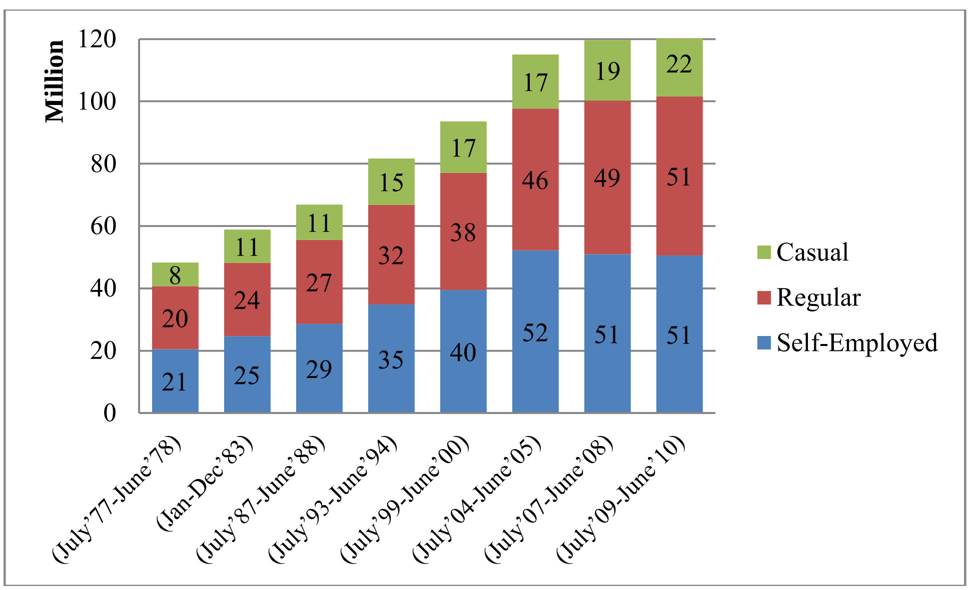

FIGURE 1.7 Number of urban workers by employment status.
Source: Based on Himanshu, September 2011, table 5a, pg 46.

In a recent collection of essays on the middle-class by Baviskar and Ray (Eds., 2011), there is an engaging narrative on what the middle-class is for India, with a particular focus on how this shifting category is not easy to capture into a formal group. The infamous caste system in India is often easily confused with class, but should be viewed as a different construct for analysis; many “lower-caste” households can be categorized as middle-class. Particularly in urban India, earning potential has made it possible to move beyond caste barriers, bringing with it all the trappings of middle-class consumption.

In a chapter by Sridharan, E. (Baviskar and Ray (Eds.), 2011) there is an attempt to quantify the middle-class (see figure 1.8). The figure shows how between 1989-90 and 1998-99 the numbers of urban Indians in various income categories changed. Though these are old data, the beginnings of the saga of middle-class change and growing affluence was evident by the late 1990s. The key years in India were the early 1990s when the economy was de-regulated, and the shifts towards higher incomes began. Clearly, those in the lowest income group (annual income up to ₹ 35,000 = $PPP 1,650 – see note below figure 1.8) were growing smaller, while those in the upper two groups were growing by the late 1990s. In percentage terms, the lowest income group was 37% of total urban India in 1989-90, and that almost halved to 19% in another ten years. The top two income groups (annual income above ₹ 105,000 = $PPP 4,950) were 10% of the distribution in 1989-90, and these groups constituted 25% of the income spectrum by 1998-99.

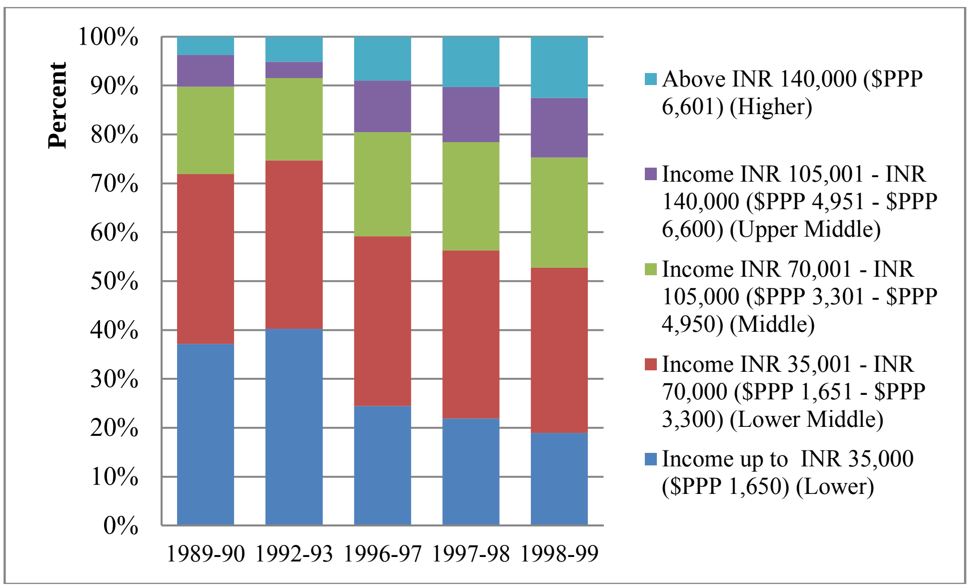

FIGURE 1.8 Changes in working and middle-class households in urban India.
Source: Based on E. Sridharan, Tables 2.1 and 2.2, pages.38 and 39 in Baviskar and Ray (Eds.), 2011.
Notes: ₹ is the symbol of the Indian National Rupee (often referred to as Rs. or INR). Equivalent purchasing power parity conversions in United States Dollar value ($PPP) are from http://unstats.un.org/unsd/mdg/SeriesDetail.aspx?srid=699, and $ 1 = ₹ 54, http://www.xe.com, both accessed November 30, 2012.

A projection of how middle-class households might have grown in the first decade of this century is presented in figure 1.9. Sridharan’s data shows households in various income categories. Notably, the “deprived” households are becoming a smaller portion of the stack each year of analysis, although they still constitute half the population, whereas “aspiring” and “seeker” households are growing steadily.

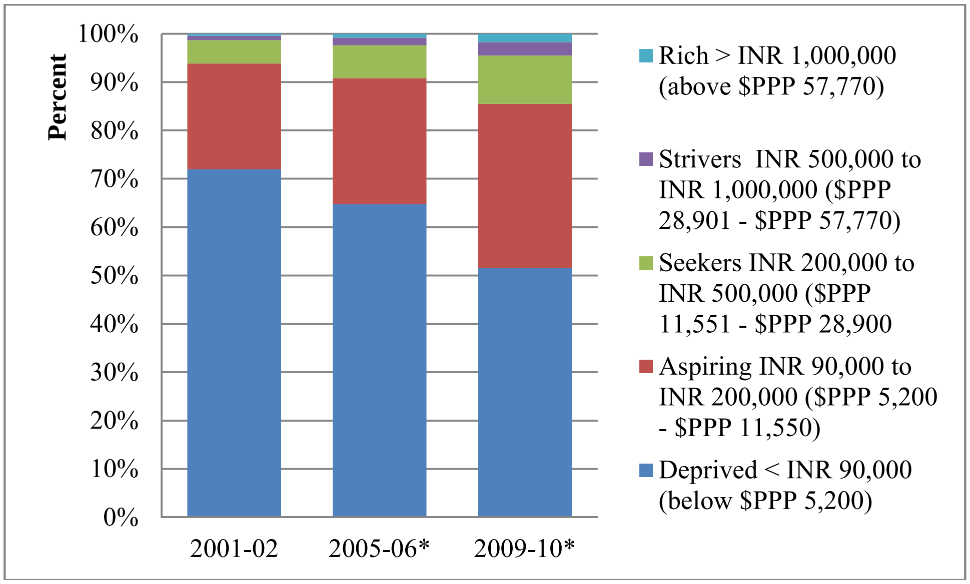

FIGURE 1.9 Projected growth in the Indian middle-class (* denotes projections).
Source: Sridharan, E., September 2008, table 2, pg. 19.
Note: $PPP conversions based on 2008 rates from http://unstats.un.org/unsd/mdg/SeriesDetail.aspx?srid=699, accessed November 30, 2012.

As incomes grow, so does the tendency of a population to own private vehicles, especially when other travel options such as transit are undersupplied. Figure 1.10 shows growth in registered vehicles in India since 1951 at 5-year intervals. Clearly, the numbers of two-wheelers have grown much more rapidly than that of cars, jeeps and taxis. Bus supply has barely increased. India is rapidly becoming a nation getting to places on two-wheelers. However, these numbers are in the millions, so even the relatively small number of cars take up a significant portion of urban road space.

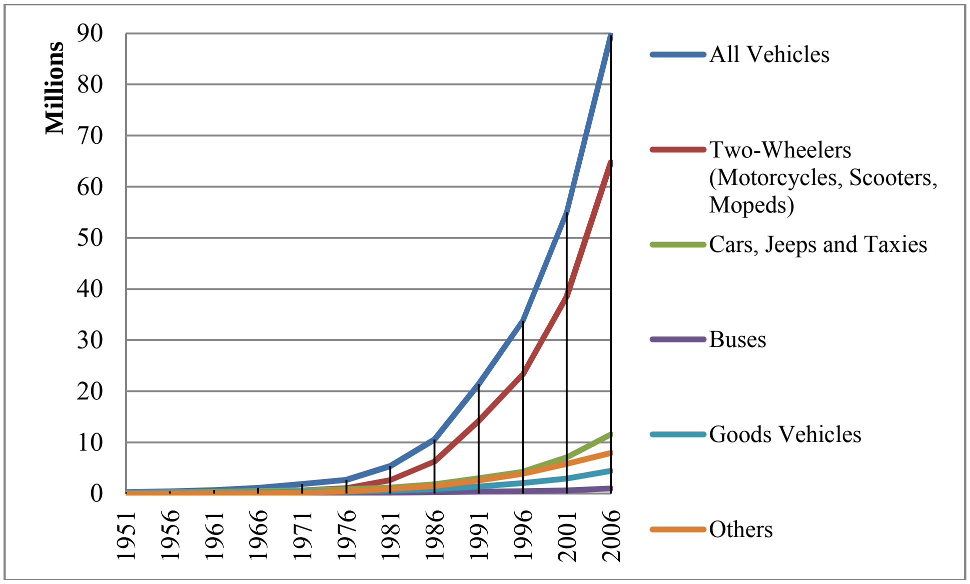

FIGURE 1.10 Motor vehicles registered in India.
Source: Transport Commissioner's Office, December 2009, table 6, pg. 24.

The 2011 census (http://www.censusindia.gov.in/2011census/hlo/hlo_highlights.html, accessed November 30, 2012) of India shows that bicycle availability in India moved marginally from 44% to 45%; for urban India it dropped from 46% to 42% for 2001-11. Motorized two-wheeler availability in India jumped from 12% to 21%; for urban Indian households it moved ten percent points from 25% to 35% for 2001-11. Car availability in India doubled from 2.5% to 5%; for urban Indian households it moved up four percent points from 6% to 10% for 2001-11. Of the total vehicle fleet, 71% are two-wheelers, 13% are cars, and the remaining are a mix of 3-wheelers (rickshaws of all kinds), tractors, trailers, etc. (Govt. of India, Planning Commission, 2007).

Thus, urban India is much more motorized than rural India (also figure 1.11). Car ownership was four times higher in urban India than in rural India, and motorized two-wheeler ownership was almost double than that in rural India in 2005. This is not surprising, since much of rural India can only afford a bicycle or a motorized two-wheeler. For example, there are more households owning bicycles in rural India than in urban India. This is an indicator of affordability of basic means of mobility in rural India.

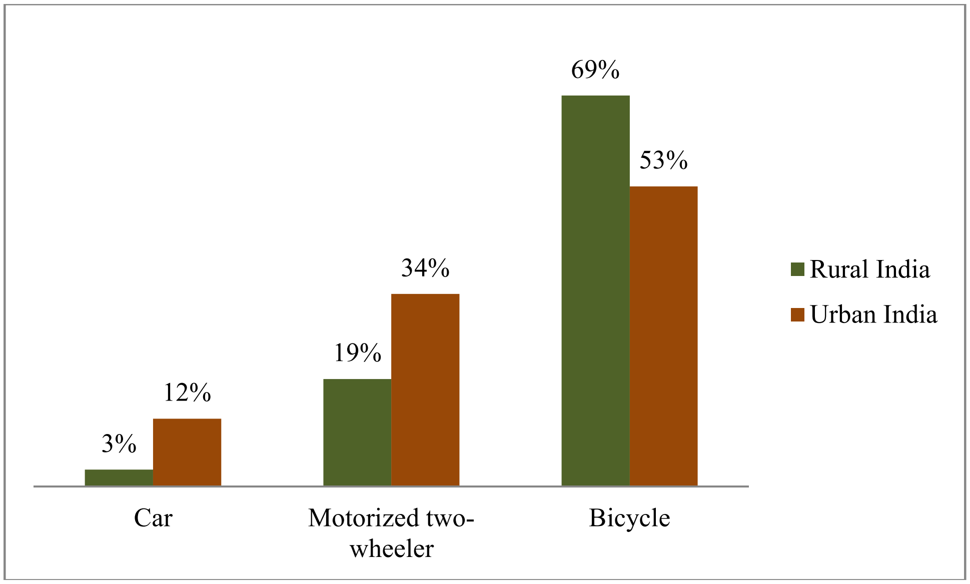

FIGURE 1.11 Vehicle ownership in Indian households in 2005 (in %).
Source: Sridharan, E., September 2008, table 16.

1.1.2 Transportation Infrastructure

It is not just socio-economic changes, but the type and quality of transportation infrastructure that has an effect on vehicle ownership and use decisions. The share of public transportation is decreasing rapidly in India, as private mobility options take hold and urbanization hastens. Currently only 22% of urban transportation is via public modes, and just 20 of India's 85 cities of over 0.5 million have a city bus service (Govt. of India, *Report on Indian Urban Infrastructure and Services,* 2011, pg. 57). Though some large cities have seen recent investments in rail-based transit systems as well as rubber based bus-rapid transit systems in the last decade, these represent a very small percentage of the spending in the transportation sector at this time.

To a large extent in India, as in other countries, infrastructure is shaped by government policy and investment. Currently in India most of the spending on transportation infrastructure is focused on roads and highways, with less focus on transit or travel demand management systems. Though the National Urban Transport Policy (NUTP) (http://urbanindia.nic.in/policies/TransportPolicy.pdf, accessed November 30, 2012), talks about provision of alternative modes of transportation such as high capacity transit, and about travel demand management, these are new ideas for most Indian cities.

In preparing for the 11th five year plan, the Planning Commission asked various ministries to prepare a review of assets and expenditure during the 10th Five Year Plan (2002-07), and set up estimates for needs for the 11th Five Year Plan (2007-12) (http://planningcommission.nic.in/plans/planrel/11thf.htm, accessed November 30, 2012). Roads grew by 5,600 miles (9,000 km) between 2002 and 2006, thus bringing the total road length in India to 41,400 miles (66,600 km). During this time, the total budget for roads was ₹ 595 billion ($ 13.52 billion), and the cost of improvements to the road network was a third of that, at ₹ 200 billion ($ 4.55 billion). Railway passenger volume grew 4.2% on average between 2001-02 and 2006-07, and passenger kilometers grew 7.4% – in the same time freight grew 8.1%. During this time, the total railway budget was ₹ 847 billion ($ 19.25 billion), of which 25%, amounting to ₹ 212 billion ($ 4.81 billion), was spent on system upgrades and additions.

The overall average annual growth rate in road-based transportation volume, including public and private mode travel, between 2000-01 and 2005-06 was 8.8%. Road-based transportation carried 82% of the total passenger load nationwide in 2000-01, and this share grew to 87% in 2004-05. Of the total ₹ 2.1 billion ($ 0.48 billion) in road-based transportation, the capital support for sustainable public transportation was merely ₹ 0.1 billion ($ 0.002 billion) (http://planningcommission.nic.in/aboutus/committee/wrkgrp11/wg11_roadtpt.pdf, accessed November 30, 2012, pg. 6). This snap shot of the transportation sector shows that the national focus is on intercity railways including freight, as well as road expansion, with very little attention given to passenger transportation on transit systems.

Throughout India, the road sector is controlled through local, state or national governments based on the hierarchy of the network. Most city roads are constructed and maintained by local (or state) taxes. Since local governments take charge of local streets, there is a wide range in terms of quality and quantity supplied. Urban transit systems, such as metros and bus rapid transit, are progressively financed through a mix of national funds, and joint venture or public private partnership models. However, such new networks are few and sparse. Largely, urban Indian transit networks are old systems at local (or state) levels which take charge of vehicle fleets, operations and logistics. In many Indian cities, bus transit can be improved substantially, but remains a lower priority. Older rail systems such as the Mumbai sub-urban railways are also overseen by the central Ministry of Railways, thus they have traditionally competed for attention with national railway passenger and freight needs.

On average, transit networks are very sparse for a country that is as dense as India, but the private market has come up with systems like license-based taxi services, but more common are licensed rickshaw services. Other jitney-like systems for key corridors are common in India, plying people and cargo between important destinations. These are made up of shared rickshaws, bigger rickshaw-like vehicles, or shared vans. Secondary systems such as private buses of various sizes are also progressively more visible in Indian cities. These markets are usually unregulated, and many scholars (e.g., Cervero and Golub, 2007 and Vasconcellos, 2001) have shown how unregulated paratransit supply is inefficient. Under these conditions, with growing incomes and the need for mobility, many emergent middle-class households choose to buy a motorized two-wheeler. Over time, as household's vehicle fleets grow, making the shift to transit could become difficult.

Having a private vehicle comes with its own issues, since most Indian cities have roads that are heavily congested, with peak times extending up to 3 hours in the morning and sometimes longer in the evening. Many two-wheeler and car owners have no option but to sit in peak hour traffic, breathing in the emissions and particulate matter, being exposed to accident risks, and spending hours in a day trying to get to places – things get worse in the monsoon. Households who can afford often choose to have a chauffeur to drive the car around. Some firms provide chauffeurs (or reimburse employees the costs) so that senior staff can work more effectively during the day. It is thus common to see cars that are driven by 'drivers' so that the car owner can sit back and finish office work or socialize. However, this is true for a smaller section of Indian society. Most private vehicle owners tend to be stuck in traffic and drive their own vehicles.

1.1.3 Private Transportation Modes

Motorization is taking a firm hold in India in the form of motorized two-wheelers (TWs) and cars. Though the car segment is fairly standard globally, with vehicles ranging from minis to sports utility vehicles (SUVs), the motorized two-wheeler market is quite varied. Banerjee (2011) discusses the car segment in India, showing how a system of government tariffs controlled vehicle production before the 1990s, limiting manufacture to a couple mid-size cars similar to sedans, and a very popular mini hatchback from the mid-1980s onward. Car sales took off from the 2000s, with many international brands entering India. Today, the car market in India has minis (up to 3,400 mm), compacts (3,401 mm – 4,000 mm), mid-size cars (4,001 mm – 4,500mm), executive cars (4,501 mm – 4,700mm), premium cars (4,701 mm – 5,000mm), and luxury cars (above 5,001). Further, Banerjee presents a snapshot of sale by car category in 2009 using compound annual growth rate (Banerjee, 2011, Table 1.2, pg. 10). Executive cars were the fasted growing segment at 112%, followed by luxury cars at 33% which are most commonly seen on Indian roads, but sales of minis shrunk by 11%. Thus, the much discussed 2000-dollar mini car, which began sales in 2009, does not seem to be the vehicle of choice for Indians. The base mini model for the Tata Nano (2 cylinder, 624cc, manual transmission) is priced at about ₹ 156,000 ($PPP 7,000) currently in Mumbai. Today, a basic mid-size sedan such as the Hyundai Accent (4 cylinders, 1495cc, manual transmission) can be bought in Mumbai for about ₹550,000 ($PPP 25,000).

In many South Asian cities the motorized two-wheeler (TW) has high market penetration, both in urban and rural locations. This vehicle segment in India is made up of motorcycles, scooters and mopeds, with e-bikes (Weinert, et al., 2007) largely unseen at this time. TWs have a long history in India, having first come on the scene in the 1960s, taking off in the 1990s, and growing exponentially since (Iyer and Badami, 2007). The first TWs had two-stroke engines, with low engine capacities (below 150cc), and many of these still exist in various parts of India, with their poor fuel burning properties and pollution issues. Scooters, with better designs (100-150cc), for carrying passengers and luggage, became somewhat popular from the 1980s through the 2000s. Mopeds, with very low engine capacities (50-75cc) became important as first vehicles for low-income households, or as a vehicle for young adults in middle-class households. Since the early 1990s, with the economic boom, motorcycles have become much more popular in the TW vehicle category. These are largely four-stroke engines (above 100cc), have better fuel economy and lower pollution output than their two-stroke TW counterparts. Today, motorcycles are commonly available in higher power ratings (above 150cc). Iyer and Badami (2007) show that motorcycle sales have overtaken scooter and moped sales since the late 1990s. A basic four-stoke 125cc motorcycle, or a well-designed four-stroke 110cc scooter in Mumbai costs around ₹47,500 ($PPP 2,200). Many TW manufacturers in India are designing vehicles specifically for young adults and women.

Field research shows that households in the established middle-class often make full payments for vehicles, while emergent middle-class households often use financing options. Many households in India have savings or can borrow from family, thus making it possible to buy expensive, but often necessary, possessions such as cars or TWs. These are available through most public and private sector banks as well as other financers, who offer low-interest loans and reasonable payback terms. Table 1.1 presets some financing options for the mid-size sedan and basic motorcycle discussed above.

Table 1.1 Financing Options for Cars and TWs

Vehicle	Price (₹)	% Rate of Interest	Payback period	Monthly payment (₹)	Monthly Payment ($PPP)
Hyundai Accent (Car)	550,000	10%	12 months	47,954	2,180
Hyundai Accent (Car)	550,000	10%	36 months	17,600	800
Hyundai Accent (Car)	550,000	5%	12 months	46,889	2,131
Hyundai Accent (Car)	550,000	5%	36 months	16,416	746
Motorcycle / Scooter	47,500	10%	12 months	4,141	188
Motorcycle / Scooter	47,500	10%	36 months	1,520	69
Motorcycle / Scooter	47,500	5%	12 months	4,049	184
Motorcycle / Scooter	47,500	5%	36 months	1,418	64

Notes: Calculations based on http://www.carwale.com/finance/calculateemi.aspx, equivalent purchasing power parity conversions based on http://unstats.un.org/unsd/mdg/SeriesDetail.aspx?srid=699, and $PPP 1 = ₹ 22, both accessed November 30, 2012.

1.1.4 Growing City Size and Private Travel

As Indian cities get larger in size, non-motorized transportation modes (NMT) (walking/biking) decrease within the mode split, but there is growth in public transportation travel (figure 1.12). Walking declines somewhat with NMT, and bicycle use drop significantly. Two-wheeler travel remains roughly at similar levels, and sees a sharp drop for the largest cities (>800K persons). In spite of the meager transit networks for dense Indian cities, a large portion (44%) of the travel demand, at least for very large cities, is by public transportation. Car travel does not change across city categories, while intermediate public transportation modes are a small percentage of the mode split.

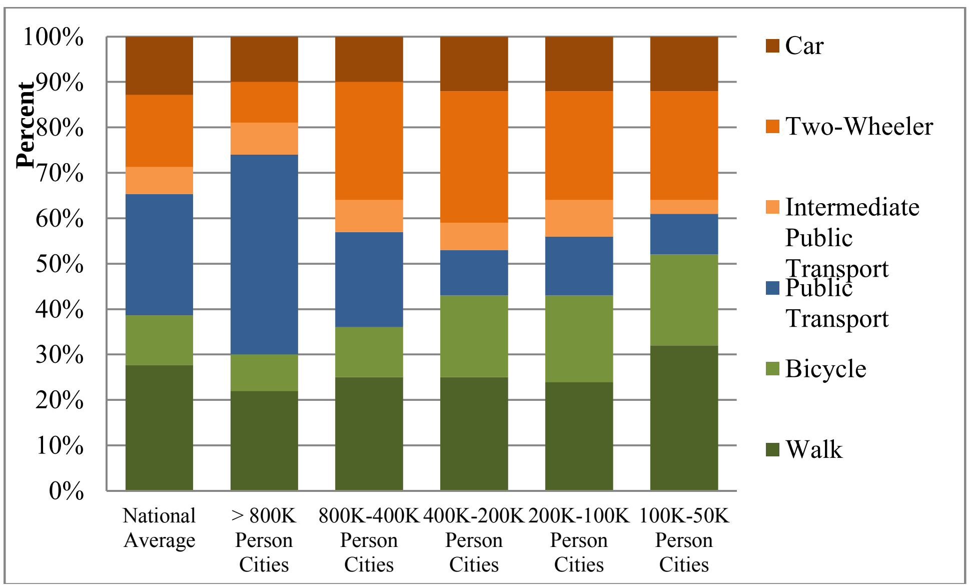

FIGURE 1.12 Mode split by city categories.

Source: Wilbur Smith (India), and Ministry of Urban Development (Govt. of India), 2008, table 2.20, pg. 36.

Projections up to 2031 across the city categories and across travel modes are shown in figure 1.13. These outcomes are based on a standard four-step gravity modeling framework, and include effects of street congestion, travel costs, availability of public transportation, and growth in city size (Wilbur Smith, et al., 2008). These projections suggest that public transport use (PT - blue lines) will gradually decrease. Also, the decreases in public transportation will be greater in larger cities than in smaller cities. Travel by personal vehicles and intermediate public transport modes (PV+IPT - orange lines) will increase across all city sizes, particularly at the two ends of the city size spectrum. Non-motorized modes (NMT - green lines) will barely change in the large and middle size cities, but these modes will progressively become a smaller portion of the mode split for small cities.

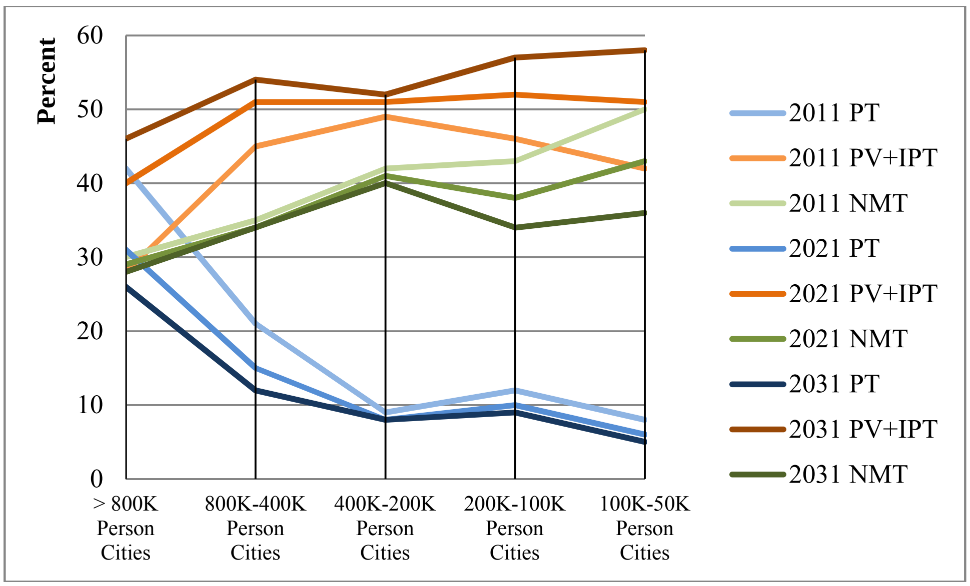

FIGURE 1.13 Projected changes in mode splits.

PT -Public Transport (Bus, Metro), PV-Personal Vehicles (Motorized Two-Wheelers, Cars), IPT-Intermediate Public Transport (Rickshaws, Shared vans, etc.), NMT-Non-motorized Transport (Walk, Bike)
Source: Wilbur Smith (India), and Ministry of Urban Development, Govt. of India, 2008, table 3.11, pg. 66.

Overall, based on these projections, larger cities would see a decrease in public transportation travel, and a large increase in private / IPT modes, whereas small cities would see a shift from NMT modes to private / IPT modes. All else being equal, the major travel modes will likely be personal transportation and intermediate public transportation. The negative impacts of these mode shifts on transportation infrastructure would become substantial as Indian cities grow, especially in the bigger size categories (see figure 1.4), resulting in worsening network congestion and air pollution, along with higher emissions of greenhouse gases and rising road safety concerns.

Shifts in modal shares away from walking and biking may be due to increasing incomes, but are also linked to longer commutes resulting from limited housing options near job centers, and with issues of safety for those biking and walking in Indian cities. As engine efficiencies improve with technology, the use of private vehicles might go up, all else being equal. Therefore, a multi-dimensional approach is necessary to understand the relationship between urban form, vehicle ownership and vehicle use.

1.1.5 Ongoing Policy Initiatives

Studies (e.g., Govt. of India (various years), Wilbur Smith, et al., 2008) on cities in India have made it clear that something needs to be done to reform Indian cities towards goals of social, economic and environmental sustainability. To this end, India has embarked upon a major effort to modernize cities with the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) (http://jnnurm.nic.in/wp-content/uploads/2011/01/PMSpeechOverviewE.pdf, accessed November 30, 2012). Begun in late 2005 and designed to last for seven years in the first cycle, JNNURM aims to encourage reforms and incentivize planned development of key cities. The diverse aims include improved governance through accountability, community participation, enhanced delivery of services, social housing, slum rehabilitation, and increased infrastructure production. In the first phase, 63 cities have been identified where investments are being made; 7 cities have over 4 million people, 28 have between 1-4 million people, and 28 have less than 1 million people. There are other sections within the JNNURM that will focus on small and medium sized cities and towns.

Of the total capital spending by infrastructure sector within the identified 63 cities, most of the outlays have been for much needed water supply, sewerage, and drainage improvements (figure 1.14). 17% of the spending is for roads including overpasses. Only 12% is in other transport infrastructure including mass rapid transport systems, bus transit terminals, and traffic / transit management centers. One consequence of the relatively small level of expenditure for mass transportation is that the networks are thin, especially at the peripheries of major cities and in the smaller cities, and the level of service is often poor.

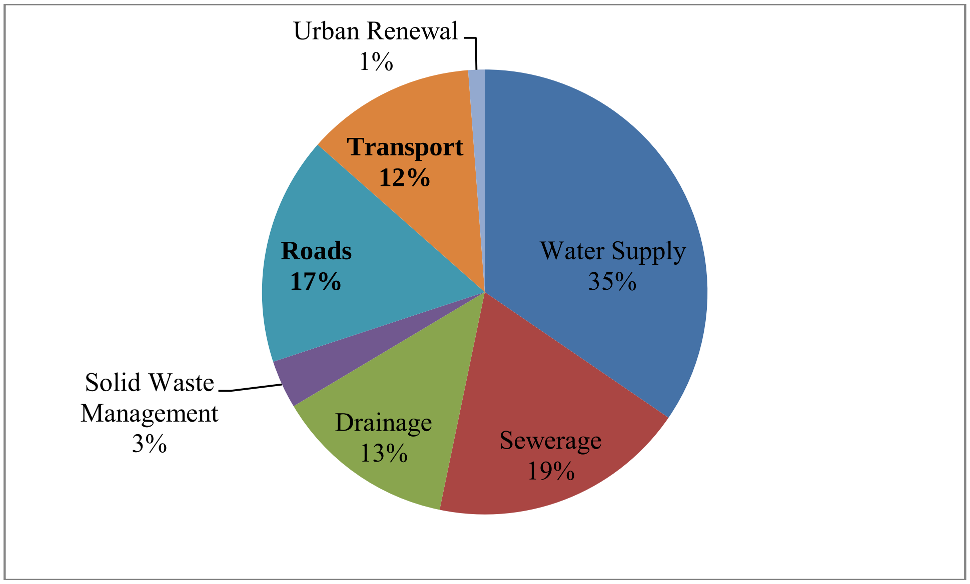

FIGURE 1.14 JNNURM spending by infrastructure sector.
Source: Govt. of India, Report on Indian Urban Infrastructure and Services, March 2011, table A22, pg. 194.

As discussed earlier, within the transportation sector, the supply of roads is going up at a rapid rate in India. The Ministry of Road Transportation and Highways' statistics on roads (figure 1.15) highlights the addition of road space in various categories. Much needed rural roads have increased significantly since the early 1990s, but often the quality of the road construction remains problematic, e.g., many of the rural roads are unpaved (see source for figure 1.15, pg. vii). However, in the urban geographies and in choice inter-city corridors there has been a significant supply of national highways, state highways and urban roads. On the one hand, these new capacities are much needed in a growing economy, yet on the other hand this additional road space is inducing demand for private automobility.

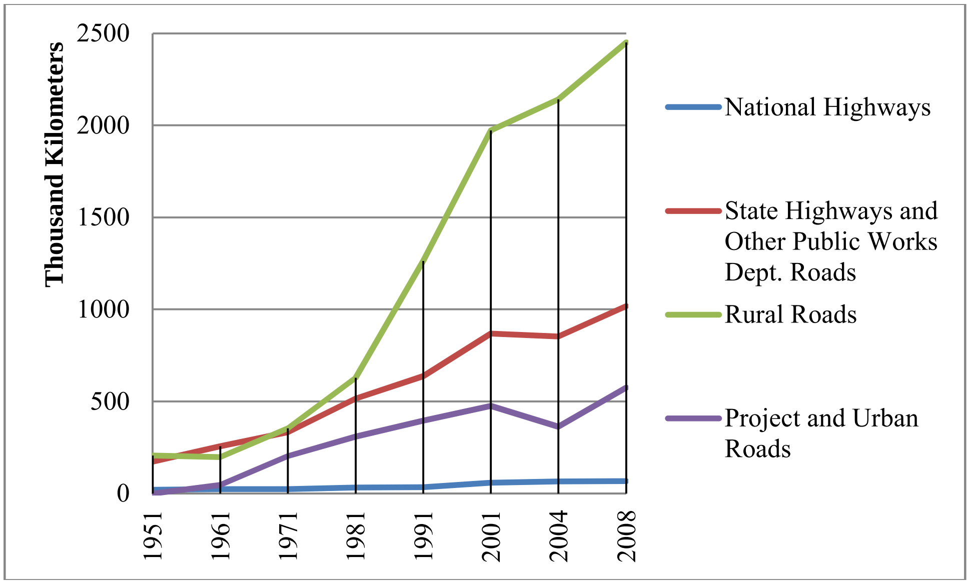

FIGURE 1.15 Growth of roads by category in India.
Source: Ministry of Road Transportation and Highways, Govt. of India, Basic Road Statistics of India, July 2010, pg.vii, table 3. (http://morth.nic.in/showfile.asp?lid=417, accessed November 30, 2012).

Infrastructure supply is closely linked with issues of equity in India. Fernandes (2004) argues that due to the demands of the middle-income and high-income groups in India, national discourse on infrastructure production proceeds with negative impacts on the poor. For example, in the case of the Delhi Metro system, much of the burden for land acquisition was on marginalized migrant worker households, whose informal settlements were removed (Siemiatycki, 2006). Therefore, though the demand for new infrastructure can come from multiple sections of society, the production of the infrastructure is usually in line with the political economy of the middle-class.

1.1.6 New Directions: Sustainable Transportation and Low Carbon Growth in India

A national policy on urban transport can provide the required guidance for a holistic sustainable vision for urban areas, which are under the purview of the state governments. Whereas it could be problematic to have national policy straightjacket practice at local level, there is value to having a set of minimum standards for all urban areas nationwide. State and local governments would ideally have the freedom for implementation based on case specificity. The National

Urban Transport Policy (NUTP) (http://urbanindia.nic.in/policies/TransportPolicy.pdf accessed November 30, 2012) lays out overarching ideas towards sustainable urban transport for Indian cities. Though this is an admirable first step, the document reads as an initial collection of best practices, rather than a set of carefully researched argument for reforms towards building better transportation in urban India.

For example, under objectives, the NUTP holds that "(i)ncorporating urban transportation as an important parameter at the urban planning stage rather than being a consequential requirement…" is important. However, there is limited systematic thinking in urban India, even in technically sophisticated metropolitan regions such as the Greater Mumbai Region, towards recommending new infrastructure based on where demand will grow. Commendably, the NUTP offers to take tentative steps towards technical capacity building, by offering up to 50% of the funds for systematic analysis of transportation and land use under JNNURM. The NUTP relies on private sector investments, and proposes tiered fares for new transit systems, or the wholesale inclusion of private sector paratransit. However, mechanics of implementation are not discussed, nor are regulatory frameworks in place to take care of issues such as predatory behaviors in paratransit markets (Cervero and Golub, 2007, Vasconcellos 2001). Therefore, at this time the NUTP must be viewed as a promising new effort that is guiding infrastructure development for transportation in India. However, it requires many additional layers of analysis and deliberation to act as a national policy capable of transforming urban transportation in India.

The twelfth five year plan for India has "low carbon inclusive growth" as one of its key strategies (Govt. of India, Planning Commission, May 2011). Within the transportation sector, the planning focus is on developing mass transportation systems, better infrastructure for non-motorized transportation, and better fuel efficiency for vehicles. In the urban transportation sector, the recommendations are based on projected rapid rise of private mobility, coupled with increases in energy consumption and GHG emissions. From a social equity perspective, the report points out how reliability on private travel modes and fewer investments in mass transit negatively impacts low-income groups. From a land use perspective, the report recommends interventions "… to ensure that cities remain dense and of mixed land-use with adequate provisions for housing for the poor…" (Interim Report, pg. 53). On pricing, the report says "…, rationalize parking policies and charges…" and "… enable schemes such as congestion charging..." (Interim Report, pg. 53). Using scenario testing, it predicts that GHG emissions from the transportation sector in India can go down between 2-4% through vehicle efficiency improvements, and 4-5% though a modal shift to mass transportation systems (Interim Report, pg. 59). Though these gains seem small, the additional benefits in the form of added mobility options are important for Indian cities.

In 2007, the total GHG emissions including removal by sinks for India came to 1,728 MT CO_2-eq (Govt. of India, Planning Commission, May 2011). Of these, 142 MT CO_2-eq. (7%) were from the transportation sector. Road transportation was responsible for 124 MT CO_2-eq. (88%) of the emissions within the transportation sector. Between 1994 and 2007, CO_2-eq grew by 62%, which computes to a compound annual growth rate of 4.5% in that time period. Various other reports (e.g., Wilbur Smith, et al., 2008, pg. 73) further point out that between 60-90% of CO_2 emissions in Indian cities are from cars and motorized two-wheelers.

Thus, India is rapidly urbanizing, much of the population growth is in large cities, and the workforce is getting better educated and progressively finding employment in the service sector of the economy. With increasing incomes, the middle-class is growing, motorization is increasing rapidly, public infrastructure investments are focused on pressing water and sewer issues than on transport, and transport investments are heavily oriented toward providing basic roads in rural areas, with little focus on improving transit options in cities.

Policies recently put forward promoting sustainable development and sustainable transport aim to moderate emissions, however, consumer trends and public investments are going in different directions. Factors driving these trends include improved access to jobs and education in the cities, private travel induced by additional road space, and the lack of non-private travel options in Indian cities. However, the government's primary transportation focus on the supply of road infrastructure for development is worsening mobility issues faced in Indian cities, and the answers are not limited just to the provision of more road space.

1.2 HYPOTHESES ABOUT VEHICLE OWNERHIP AND USE IN INDIA

Figure 1.16 shows a conceptual framework hypothesizing the path dependence towards vehicle ownership in India. As incomes grow, coupled with the lack of efficient public travel and IPT options, users are driven to vehicle ownership. Most households first buy a motorized TW, which provides access to opportunities for education and work, thus bettering their station in society. With growing household incomes, wage earners start to have a higher money value for time and value creature comforts of private vehicle travel. With growth in household size and income, families might invest in multiple TWs or a car, all else being equal. Over a few years, households could invest in a small vehicle fleet comprised of TWs and cars.

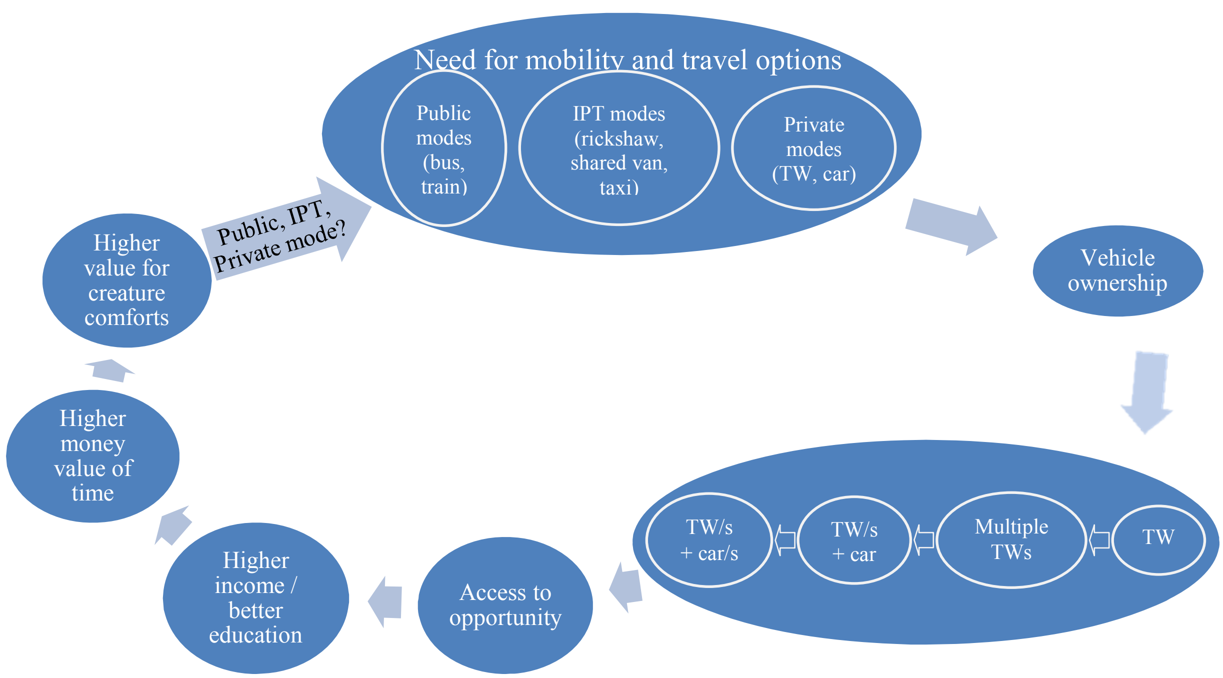

FIGURE 1.16 Travel needs, mode choices, and vehicle ownership.
(IPT – Intermediate Public Transportation, TW – Two Wheeler)

Increasing household incomes resulting in higher vehicle ownership and trip generation may provide a substantial challenge for transit infrastructure provision (Gakenheimer, 2002, Ingram, 1998). Pricing vehicle ownership using sales taxes and import duties on parts may not work, especially if travel choices remain constrained. From a political economy perspective, it may be difficult to add a layer of taxes on elements of middle-class consumption in India.

As household's vehicle fleets grow, making the mode shift back to transit gets more difficult. Currently, major transportation investments in Indian cities focus on trunk-line infrastructures such as bus rapid transit, rail and roadways. These are important strategies, but may not be enough to abate the onslaught of vehicle ownership.

1.3 GAPS IN THE LITERATURE

Many cities in emerging economies such as India and China face largely similar issues such as rapid urbanization, modernization, overall economic growth, motorization, and a booming service economy; yet the specifics are different between locations. For example, China's institutional structures allow for rapid policy making and change, whereas in India policy moves gradually through a system of checks and balances. However, there are similarities between cities in India and cities in countries such as Indonesia and Thailand, where institutions have evolved similarly, with similar forces of informality at work, and cities faced with rapid change.

Growth in mega city-regions is led by cities in the developing world (e.g., Gwilliam, 2002), with influxes of immigrants, having limited skills and incomes, seeking better lives. Many of these city-regions are seen not only as locations for opportunity and growth, but also failures in governance and infrastructure planning (Glaeser, 2011, Dimitriou, 2006, Gakenheimer, 2002, Ingram, 1998). Vibrant city-regions are products of decades of land-use and transportation policies guiding agglomerative forces (e.g., Cervero, 2001). Economic theory tells us that efficient city-regions, aiming for higher labor productivity, are manifestations of a fine balance between large diverse labor pools and efficient means of access to work destinations. Hence, all else being equal, it follows that if travel options for work commutes are weak, the city-region might suffer from ill effects such as over-crowding on available transportation networks, sub-standard housing locations, and a general low standard of living.

Ingram (1998) discusses city-regions in market-based economies redefining themselves through sub-center creation, with centralized service sector employment and decentralized manufacturing. This decentralization is reliant on transportation networks. Concurrently, as the economy moves towards the service sector, labor seeks specialized employment. This in turn results in higher incomes, and encourages vehicle ownership as the money-value of time goes up.

Though the increase in vehicle ownership in India is related to income and in particular, the rise of the middle-class, detailed analysis of middle-class transportation consumption is rare, and disaggregate household level analyses looking at transportation behaviors are few. A substantial body of literature on growth in cities in emerging economies focuses on this vehicle ownership agenda (e.g., Zegras and Gakenheimer, 2006). However, the analyses for Indian cases have generally been at a high level of aggregation – the micro-geographies within city-regions have not been explored in any substantial detail. Important exceptions are the research by Banerjee, I. (2011) who looked at vehicle ownership by households in Surat with a focus on car classes; Srinivasan, K., et al. (2007) who looked at mobility, changing travel patterns, commute mode choice, and travel expenditure for households in Chennai; and Banerjee, A., et al. (2007) who looked at activity engagement and time use patterns for commuters in Thane. Other relevant work by Badami and Iyer (2007, 2006) focused on how user preference, vehicle technology, fuel standards, and the regulatory environment have evolved and have affected the motorized two-wheeler segment. Some recent essays on urban transportation in the developing world

(Dimitriou, Gakenheimer, Eds., 2011) have the potential for framing questions of urban transport in India. Yet, they are either in other geographies or are based on broad conceptual ideas with less focus on critical empirical analysis.

Hence, there is no systematic research in the Indian context looking at how jobs and housing location in an urban geography influence travel time by private modes, or how variables such as density of development and proximity to transit influence utility derived from vehicle ownership and use. There is some discussion on cars in the popular and scholarly literature; however, there is no rigorous research on motorized two-wheeler ownership and use in India. It is increasingly apparent that there is a need for more detailed analyses of how urban form, socio-economics, and ownership / use of cars and motorized two-wheelers interact. Such investigations will not only provide better insights into the processes of motorization but can help inform policy. As the next section describes, this is the objective of this dissertation.

1.4 DISSERTATION OUTLINE

With this background, the dissertation turns to the case of Mumbai, where a detailed dataset on travel allows the analysis of vehicle ownership and use among households. The Greater Mumbai Region (GMR) is an interesting case to explore questions of vehicle ownership and use, against the backdrop of growing affluence in the Indian context. This research unpacks the question of why the middle-class in India is driven to buying and using cars and two-wheelers in a major Indian metropolitan area by asking the following:

(1) How does work location influence travel by public and private modes?
(2) What factors encourage vehicle ownership in middle-class households?
(3) What factors drive up vehicle use in middle-class households?

The following chapters provide a detailed analysis of these questions.

Chapter 2 provides detailed information on the case study city and metropolitan region of Mumbai. The chapter also provides an overview of the travel survey used in the analyses and discusses its limitations. The dynamics of growth in the GMR coupled with the availability of a household travel survey dataset are good reasons to undertake this as a case to explore ownership and use of cars and motorized two-wheelers in middle-class Indian households.

Chapter 3 explores the question, how do destinations for home-based work trips undertaken by middle-class individuals in the GMR influence travel? The unit of analysis here is the home-based work trip (N=40,301). This chapter looks at the nature of job-centers in the GMR, and discusses the effect of employment sub-centers on mode specific travel time, travel distance and speed. Appendix 1 shows detailed results of T-tests for key indicator means compared across various city geographies in this chapter.

Chapter 4 explores the question, what factors are driving vehicle ownership in middle-class households in the GMR for motorized two-wheelers and cars? The unit of analysis here is the household and the analysis is conducted using a multinomial logit vehicle ownership model (N=20,513), where the choice set is (i) no vehicle owned in household, (ii) only two-wheeler/s owned in household, or (iii) at least one car with possible two-wheeler/s owned in household.

Appendices 2 and 3 are linked to this chapter, and show results of a choice modeling approach for vehicle ownership using a nested structure, and details of the MNL model.

Chapter 5 explores the question, how do home / work location, land use and socio-demographic factors drive motorized two-wheeler and car use in middle-class households in the GMR? The unit of analysis is trip undertaken using a car or two-wheeler (N=13,826), and the dependent variable is the network distance traveled by car or two-wheeler in a household. The analysis is presented as VKT and PKT models – one each for two-wheeler use and car use. Appendix 4 shows detailed outputs of the regressions.

Chapter 6 presents an overview of lessons learned from the research, and offers concluding remarks.

Chapter 2

Case Study: Greater Mumbai Region (GMR) – Growth Dynamics and Household Travel Survey Dataset

2.1 INTRODUCTION TO THE GMR

This chapter is an introduction to the Greater Mumbai Region (GMR), which is the case for exploring the larger research question: what drives middle-class households in India to own and use cars or motorized two-wheelers? This first section presents a brief history of the GMR, and discusses its current spatial characteristics and organization. Growth and change in population, employment, transportation services, vehicle ownership, and current investments / plans are presented for Greater Mumbai (municipality) and the Region. The second section introduces the household travel survey dataset used in this research. The third section delves deeper into the travel diary dataset and discusses some key attributes. The fourth section discusses limitations of the dataset, and the last section presents a summary.

The area towards the south of the Mumbai peninsula, the traditional central business district, was originally a group of seven independent fishing villages. After being coveted by various European colonizers for its location as a potential port on the western seaboard of the Indian sub-continent, control came to rest with the British East India Company in the late 17th century. In the late 18th century, the British took up engineering projects that linked the islands with landfills and causeways, and helped establish this location as a trading post. These projects continued with the first railway line on the Indian sub-continent in 1853, connecting Mumbai to Thane. The economic engine kicked off with the city becoming a major cotton trading post in the latter half of the 19th century. After progressive economic development, through the years of India's fight for independence from the British and after, Mumbai gained preeminence as a major economic center (see Gandy, 2006 for history on Mumbai through the lens of water provision).

Most people today understand Mumbai as the colored sections in figure 2.1. Island Mumbai (in red), the traditional CBD, is also known as Town or South Mumbai, and is located at the southern end of the peninsula. This area is commonly understood as the financial capital of India. However, over time the Western and Eastern suburbs have been brought into the fold as employment and housing have grown in these areas. These three colored areas in figure 2.1 comprise Greater Mumbai, which falls under the Brihanmumbai Municipal Corporation (BMC).

The Mumbai Metropolitan Regional Development Agency (MMRDA), which is the Metropolitan Planning Organization for the region, refers to metropolitan area as the Greater Mumbai Region (GMR). From MMRDA's point of view, the GMR is divided into Greater Mumbai and Rest of the Region (RoR). Greater Mumbai, having most of the employment, is governed by a strong municipal entity. The RoR is a wider area with somewhat diffused urban agglomerations that are governed by various local bodies, and is composed of bedroom communities along with some nodes of industry and employment. Overall, the GMR is comprised of about 1,625 square miles (4,200 km^2), has about 22.7 million people (Govt. of

India, *Report on Indian Urban Infrastructure and Services,* 2011, pg. 15, table 1.3), and is made up of various contiguous municipal corporations and municipal councils with high and moderate population densities.

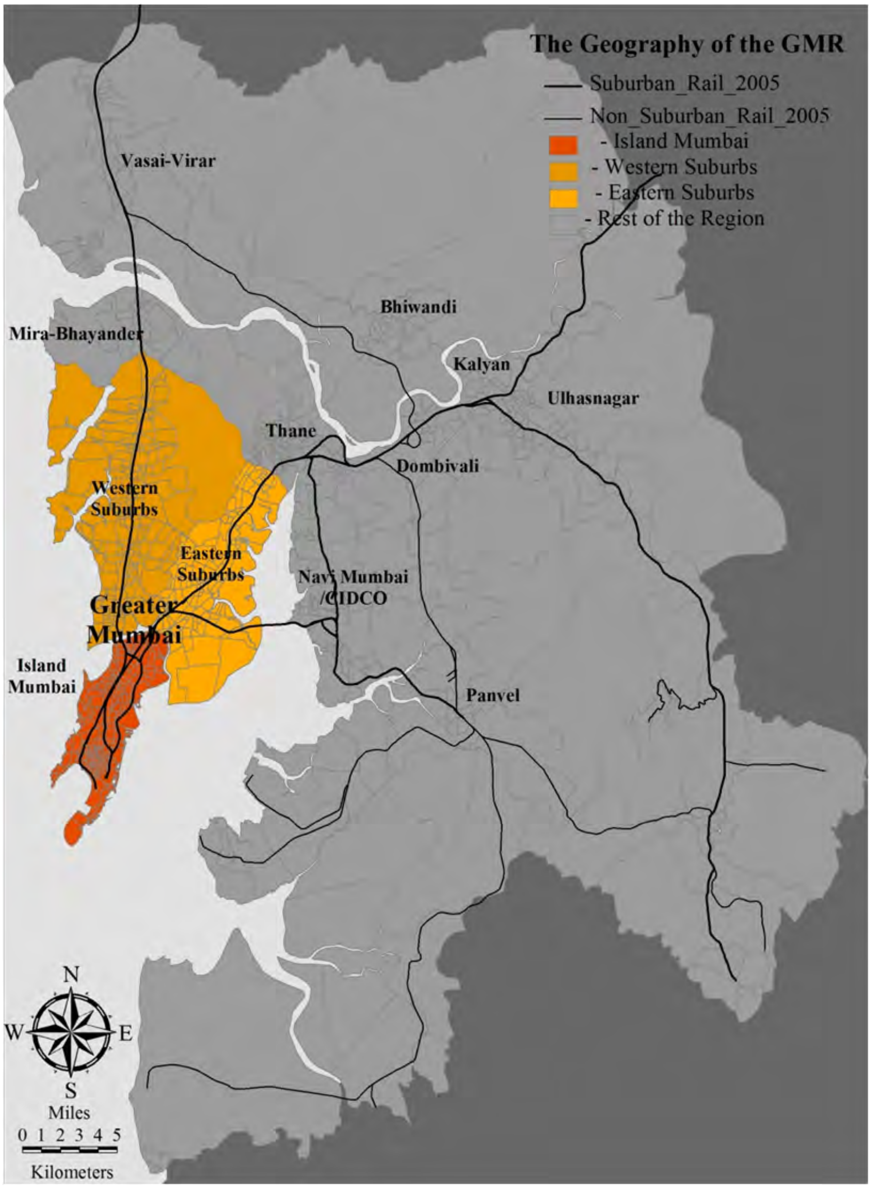

FIGURE 2.1 Geography of the GMR.

The GMR as a metropolitan region has developed in a distinct manner. Firstly, Thane, an economic sub-center and a secondary city in the region, has an equally long parallel history, and long-standing strong links to Greater Mumbai. Secondly, the evolution of rail-based transit, which is considered the backbone of Mumbai, helped create development corridors. These contiguous corridors parallel the rail lines and have evolved into housing and employment nodes in a manner similar to streetcar suburbs (see figures 3.1 and 3.4). Thirdly, the government's policy to decongest Mumbai in 1972 resulted in Navi Mumbai, a planned development corridor, which today has housing plus many manufacturing and knowledge economy jobs. In 1977, another government planned node within Greater Mumbai, the Bandra Kurla Complex was developed to supply office space. Fourthly, the rail network has helped stimulate new market-driven nodes such as Vasai-Virar and Ulhasnagar 25-35 miles (40-55 kilometers) out from the CBD over the last 20 years. Finally, higher road supply in the last decade, both arterial and local, coupled with increasing vehicle ownership and use has resulted in ever expanding edgeless development at the fringe of peripheral nodes.

2.1.1 Population Growth and Change in the GMR

Most statistical information on Mumbai is available for the region known as Greater Mumbai (see colored areas in figure 2.1). The large growth in outlying nodes is a relatively recent phenomenon. Figure 2.2 shows growth in population over the last 110 years for Island Mumbai, Suburban Mumbai and the totals for Greater Mumbai. The population of Island Mumbai is steady and starting to decline as more employment moves into this area relative to housing. For the western and eastern suburbs, however, the opposite is true as evidenced from the steady growth in population since the 1950s. Further, as housing gets expensive, individuals with higher incomes and education tend to live in Island Mumbai, and they tend to have smaller households.

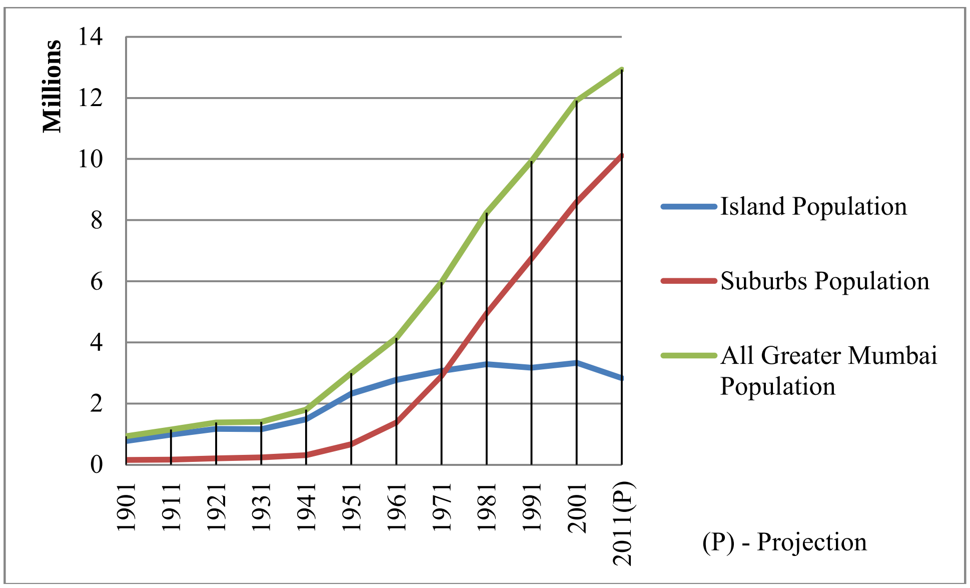

FIGURE 2.2 Population growth in Greater Mumbai (1901-2011).
Sources: Population and Employment Profile of Mumbai Metropolitan Region, table 6 (http://202.54.119.40/docs/Population%20and%20Employment%20profile%20of%20MMR.pdf, accessed November 30, 2012). Maharashtra Government, *Regional Plan for Mumbai Metropolitan Region*, September 1999, chapter 3, table 3.8, pg. 46 (http://www.regionalplan-mmrda.org/, accessed November 30, 2012).

Information in the census since 1970 has been collected at a level of micro-geography where it is becoming possible to understand change not only for Greater Mumbai, but also in the outlying regions. Figure 2.3 shows that population is steadily going up for the GMR, with the current population estimated at 22.7 million. Of this, 13 million, almost 60%, is within Greater Mumbai. The fastest growing regions in the outlying areas are the north-east region comprised of Thane, Kalyan, Ulhasnagar, Ambernath, Badlapur, and Bhiwandi, with an estimated population of 5.3 million. There is steady growth in the Navi Mumbai region which has about 1.8 million people. The western region comprised of Mira-Bhayander, Vasai-Navghar, Nallasopara, and Virar has similarly grown, and currently has an estimated population of about 1.6 million. The Navi Mumbai region is a planned region whereas the growth in the western region is primarily market driven. The similarity of their growth brings into focus the legitimacy of planned cities and market driven agglomerations, and the need for appropriate policy mechanisms to guide development.

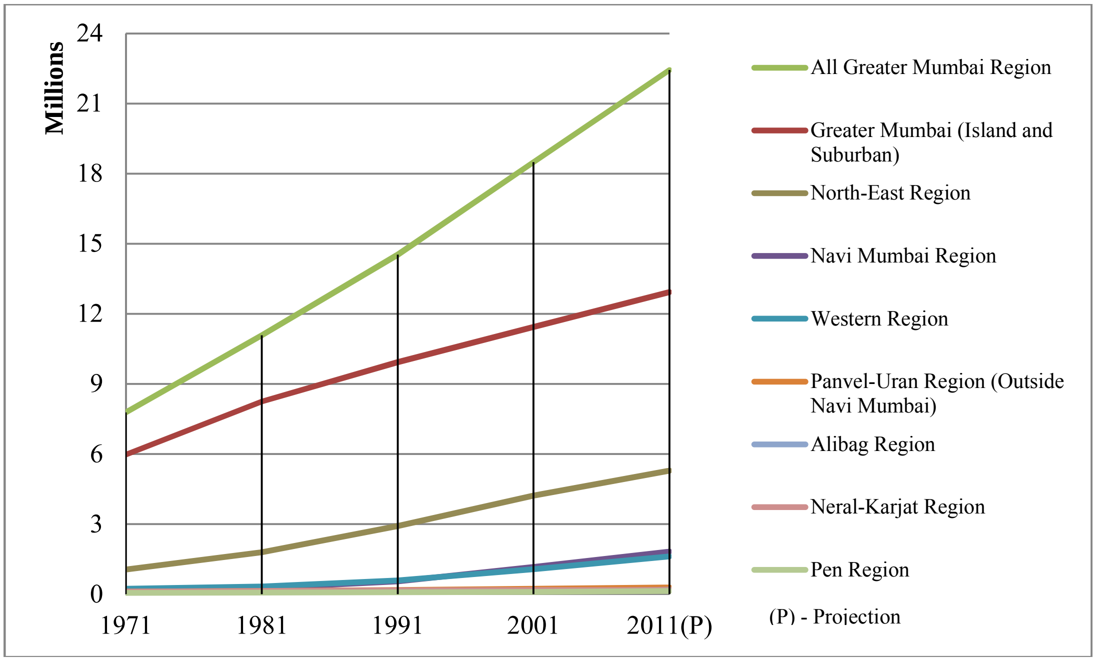

FIGURE 2.3 Population growth in the GMR (1971-2011).
Source: Regional Plan for Mumbai Metropolitan Region, Maharashtra Government, September 1999, chapter 3, table 3.8, pg. 46 (http://www.regionalplan-mmrda.org/, accessed November 30, 2012).

Table 2.1 shows details for the growth patterns evident in figure 2.3. The compounded annual population growth rate for the GMR is slowing down gradually, but the numbers are still staggering. In terms of the rate of growth, the Navi Mumbai region grew the fastest, with a compounded annual growth of 7.8% during the twenty years between 1981 and 2001. The western region followed with a 6% growth rate in the same 20-year time period. However, these two regions saw a slowing down in growth in the time period 2001-11. Further, the north-east region saw steady growth in the 1970s and 1980s, but growth seems to be slowing down gradually. These numbers and percentages indicate that a detailed analysis of the nature of growth, in terms of land uses and demographics, is needed not only in Greater Mumbai, but also in the north-eastern, western and Navi Mumbai sub-regions.

TABLE 2.1 Change in Population in the GMR

	Census year showing population in millions (2011 – projected)					Compounded Annual Growth Rate			
	1971	1981	1991	2001	2011(P)	1971-81	1981-91	1991-01	2001-11
All Greater Mumbai Region	7.78	11.08	14.53	18.49	22.44	3.6%	2.8%	2.4%	2.0%
Greater Mumbai (Island and Suburban)	5.97	8.24	9.93	11.43	12.93	3.3%	1.9%	1.4%	1.2%
North-East Region	1.05	1.80	2.92	4.22	5.28	5.5%	5.0%	3.7%	2.3%
Navi Mumbai Region	0.16	0.26	0.55	1.17	1.82	4.9%	7.8%	7.8%	4.5%
Western Region	0.23	0.33	0.60	1.06	1.62	3.6%	6.0%	6.0%	4.3%
Panvel-Uran Region (Outside Navi Mumbai)	0.11	0.14	0.18	0.23	0.29	2.5%	2.6%	2.3%	2.4%
Alibag Region	0.08	0.10	0.11	0.11	0.19	2.0%	0.9%	0.2%	5.5%
Neral-Karjat Region	0.11	0.13	0.17	0.18	0.18	1.6%	2.3%	0.8%	-0.2%
Pen Region	0.06	0.07	0.09	0.09	0.14	2.7%	1.8%	0.5%	4.1%

NOTE:

- Greater Mumbai is comprised of Island City, Western Suburbs, and Eastern Suburbs.
- Western Region is comprised of Mira-Bhayander, Vasai-Navghar, Nallasopara, Virar, Vasai-Virar Notified Area (VAVINA) coastal part, Vasai-Virar Notified Area rural part, and the remaining area of Vasai tehsil.
- North-East Region is comprised of Thane Municipal Corporation (TMC), Kalyan Municipal Corporation (KMC), Ulhasnagar, Ambernath, Badlapur, Bhiwandi, Bhiwandi Rural, South Kalyan, and North Kalyan.
- Navi Mumbai Region is comprised of Navi Mumbai Municipal Corporation (excluding 15 villages), NMMC (15 villages), Panvel, and Uran.
- Neral-Karjat Region is comprised of Neral and Khalapur.
- Panvel-Uran Region is comprised of Uran (outside Navi Mumbai), Rasayani, Panvel, rest of Panvel, Khopta, rest of Uran, and Karnala.
- Pen Region is comprised of Pen.
- Alibag Region is comprised of Alibag.

Source: Regional Plan for Mumbai Metropolitan Region, Maharashtra Government, September 1999, chapter 3, table 3.8, pg. 46 and 43 (http://www.regionalplan-mmrda.org/, accessed November 30, 2012).

The population density, since the 1970s, shows that the concentration of people living in Island Mumbai is gradually declining, whereas in suburban Mumbai the population density is steadily growing (figure 2.4). Within the suburbs, the density of population in the western suburbs is growing more so than for the eastern suburbs. However, with the constrained supply in housing within Island Mumbai and the western suburbs, coupled with growth in housing in the eastern suburbs, this trend might change in the near future i.e., we might see higher density in the eastern suburbs.

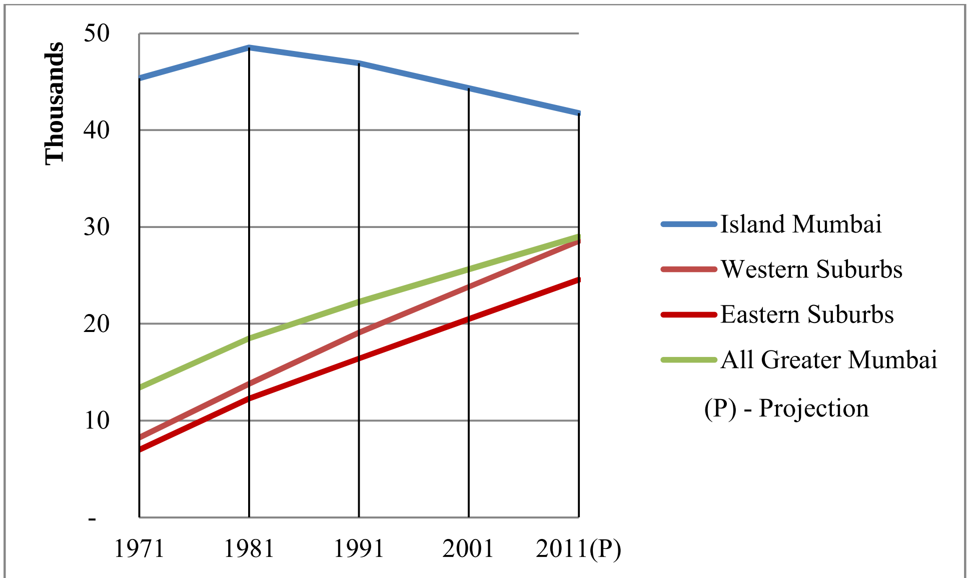

FIGURE 2.4 Population density (persons / km^2) in Greater Mumbai.
Sources: Population and Employment Profile of Mumbai Metropolitan Region, table 2 (http://202.54.119.40/docs/Population%20and%20Employment%20profile%20of%20MMR.pdf, accessed November 30, 2012). Regional Plan for Mumbai Metropolitan Region, Maharashtra Government, September 1999, chapter 3, table 3.8, pg. 46 (http://www.regionalplan-mmrda.org/, accessed November 30, 2012).

Figure 2.5 shows growth in population and employment from the 1970 census onward; also reporting future year projections. On average, 22% of the population in the GMR was employed based on enumerated data from the previous census years. The dataset used in this dissertation shows that 26% of the GMR is under 15 years, whereas 23% is between 16 and 25 years old. Therefore, almost half of the population of the city is under 25 years. The GMR is a relatively young city in terms of its demographics, with a mean age of 29 and a standard-deviation of 16. This might be the reason for the low level of employment. However, the prevalence and underreporting of informal jobs might also bring down the employment numbers significantly (see section 2.4).

Holding the 22% constant, the number of employed people in the GMR will go up to about 6.6 million in 2016, and if 30% of the projected population in 2026 were employed, there would be about 9.5 million working individuals in the GMR. However, the elbow in employment between 2001 and 2011 might be an indicator of optimism bias; the real formal employment numbers may be slightly below. Though these are projections, the general trend in growth in population and employment is valid. An important caveat is that the census data might be underreporting informal employment, whereas the projections might be internalizing this informal component. Accepting this as a possibility, if 13.8 million people are employed in both the organized and informal sectors given these projections for 2026, then 44% of the people in the GMR would be employed.

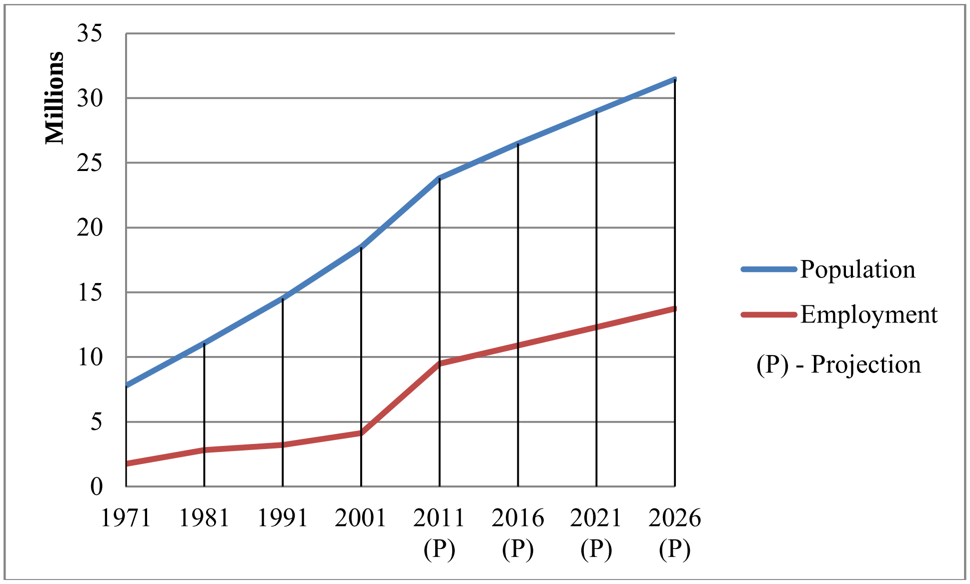

FIGURE 2.5 Growth in population and employment in the GMR.
Sources: Regional Plan for Mumbai Metropolitan Region, Maharashtra Government, September 1999, chapter 4, table 4.36, pg. 86 (http://www.regionalplan-mmrda.org/, accessed November 30, 2012). LEA International Limited, LEA Associates South Asia Private Limited, and MMRDA. *Comprehensive Transportation Study for Mumbai Metropolitan Region (Final Report and Annexures)* (Unpublished report). MMRDA (Mumbai Metropolitan Region Development Authority), LEA Canada and India, July 2008, table 7-1, pg. 7-1.

The sex-ratio in Greater Mumbai has been recorded since 1901 (figure 2.6), and has become more balanced since then. Much of the disparity in the sexes for Greater Mumbai can be attributed to men moving to Mumbai for work from other locations; over time they bring their families into Mumbai. As a percentage of the total population of Greater Mumbai, male migrants are a smaller number today, but still an appreciably large group in terms of absolute numbers. If the sex-ratio for the country has been in the +900 females / 1000 males zone, indicating a serious social problem, and is gradually improving with better education of women, it is unlikely that Greater Mumbai naturally has a radically different and lower sex-ratio. However, it is likely that the large segment of the male population in the Greater Mumbai are immigrants to the city, visiting their families elsewhere periodically, but engaging in seeking a better life for their remote households by working alone in Mumbai. Anecdotal evidence and field visits to Greater Mumbai lend support to this inference.

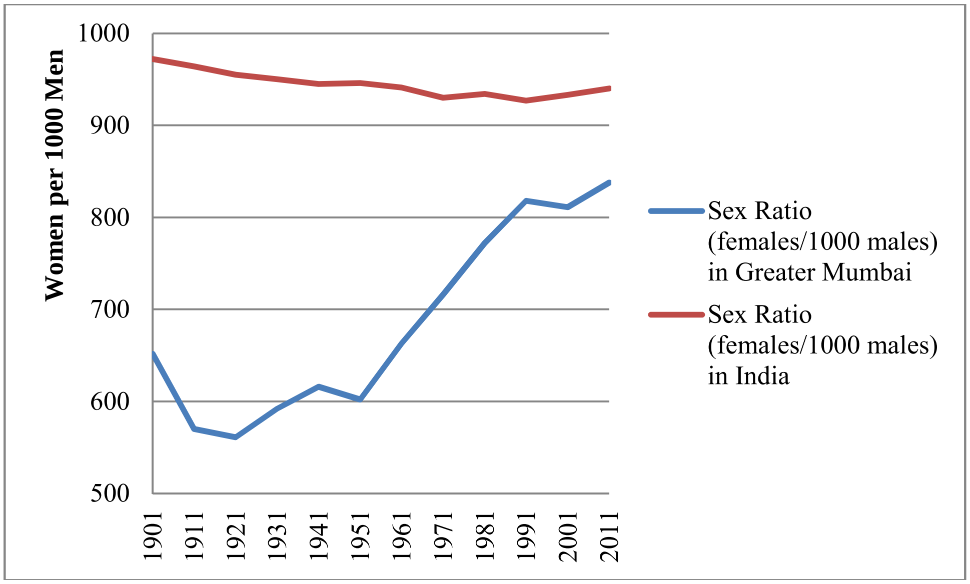

FIGURE 2.6 Sex ratio in Greater Mumbai.

Sources: Population and Employment Profile of Mumbai Metropolitan Region, table 7 (http://202.54.119.40/docs/Population%20and%20Employment%20profile%20of%20MMR.pdf, accessed November 30, 2012). "Mumbai's sex ratio worst in Maharashtra", The Times of India, April 2nd, 2011 (http://articles.timesofindia.indiatimes.com/2011-04-02/mumbai/29373897_1_girl-child-capita-income-males, accessed November 30, 2012). "Sons and daughters", The Economist Online, 4th April, 2011 (http://www.economist.com/blogs/dailychart/2011/04/indias_sex_ratio, accessed November 30, 2012).

2.1.2 Employment and Economic Change in the GMR

Work participation rates (figure 2.7) are gradually improving in Greater Mumbai for women, as women are getting better education and access to opportunities. However, the female work participation rate is only around 10% as compared to much higher rates for males. It is important to note here that the workforce participation rates for both genders are improving since the 1990s, but the traditional male earner household is still the norm in Greater Mumbai, as in much of the rest of India. As more women enter the workforce, the number of trip makers using the transportation infrastructure has increased. The surge in two-wheeler use by women in the established middle-class is often linked to households who might have a car, but will likely also own two-wheeler/s.

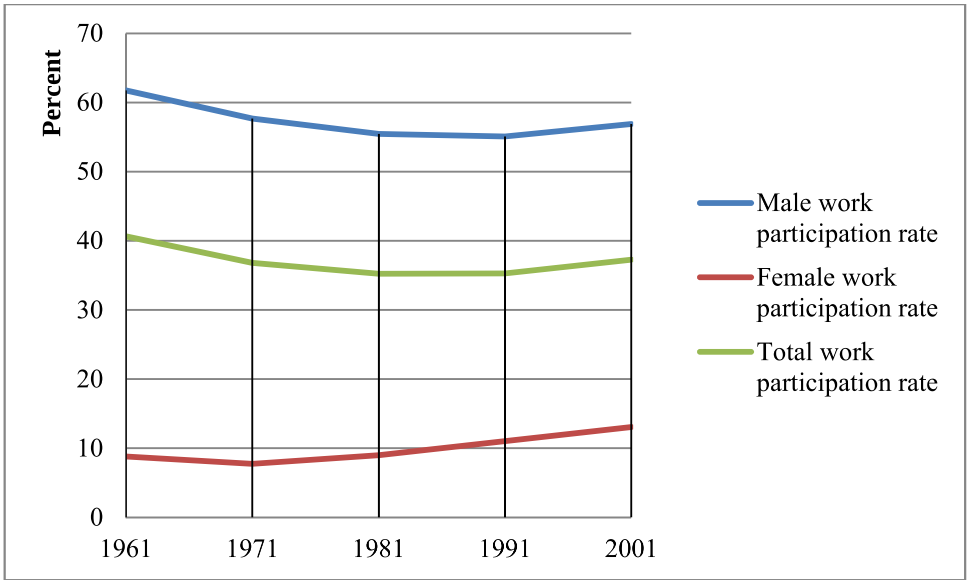

FIGURE 2.7 Work participation rates in Greater Mumbai.
Source: Singh, D. P. "Employment Situation in Mumbai: An analysis." Berlin, Germany, 2010, table 3, pg. 5.

Figure 2.8 shows how different segments of the economy have changed in Greater Mumbai. The participation of workers in manufacturing has fallen from 40% in the 1980s down to 29% in 2001. However, those in trade and commerce (service economy), comprising of wholesale-retail, hotel-restaurant, and finance-real estate sectors has grown from 18% of the employed workforce in 1961 to 33% in 2001. The construction sector has seen a gentle increase from 3% in 1961 to 6% in 2001.

Based on field visits to the GMR and my general knowledge of the area, I assume that employment in the manufacturing sector has further declined within Greater Mumbai, whereas employment in trade and commerce has increased in the 2011 census. Much of the manufacturing within the GMR is outside Greater Mumbai, and it is likely that the share of manufacturing-based employment may have grown or remained steady in the outlying areas. This shift from a manufacturing to a knowledge economy has repercussions for the question of household vehicle ownership and use that this dissertation analyzes, since incomes tend to grow as an economy moves from manufacturing-based jobs to knowledge-based jobs.

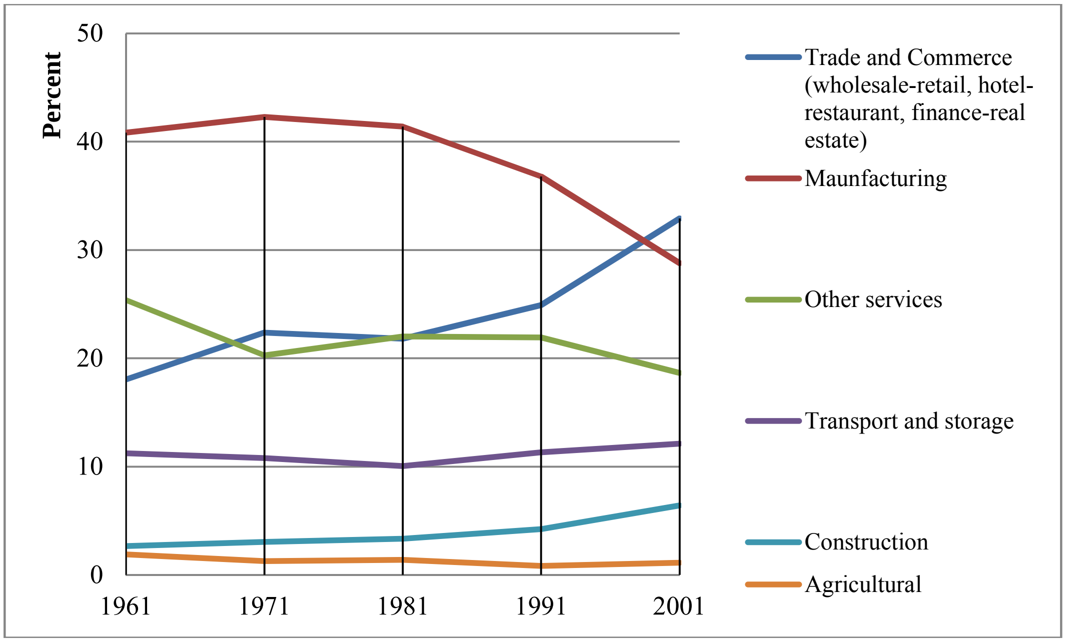

FIGURE 2.8 Changes in the distribution of workers by industry in Greater Mumbai.
Source: Singh, D. P. "Employment Situation in Mumbai: An analysis." Berlin, Germany, 2010, table 7, pg. 8-9.

There is a significant difference between the genders with respect to employment (figure 2.9). For well-paying jobs such as senior managers and professionals, the employment for men and women is similar in terms of percentages. However, there was a higher percentage of the total female workforce in 2007-08 that was employed as associate professionals, technicians, clerks, and other elementary occupations. In comparison, a higher percentage of the total male workforce was employed in crafts and machinery operations. Almost similar percentages of men and women are employed in well-paying jobs, and though the numbers of women will be much lower, this dynamic indicates that, in comparison to women in previous decades, women are getting better educated and moving up faster in the employment hierarchy. Not only will the growth in two-income households change vehicle ownership rates in Mumbai, but also the nature of female employment will likely result in a shift in the kind of vehicles owned and used within Mumbai, all else being equal.

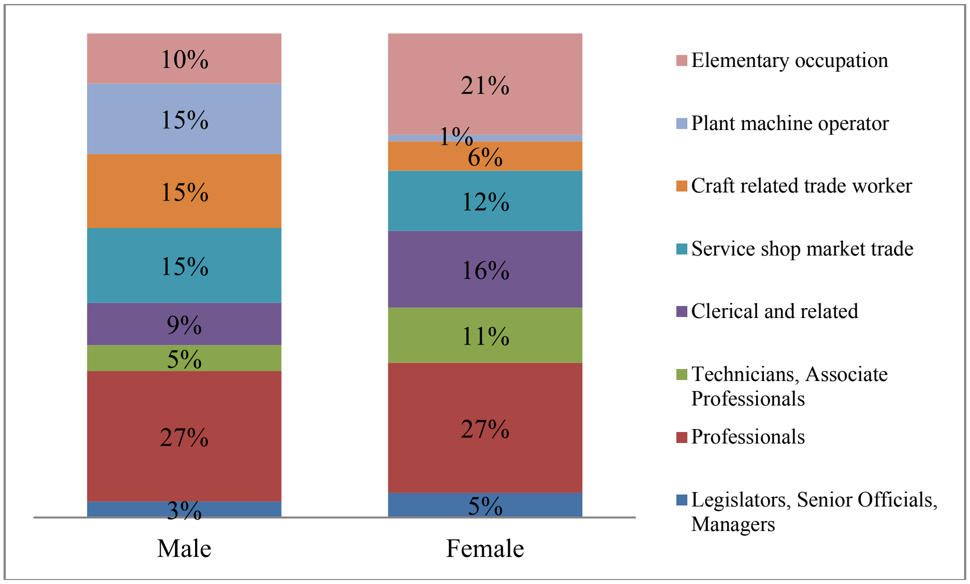

FIGURE 2.9 Occupation distribution by gender in Greater Mumbai (2007-08).
Source: Singh, D. P. "Employment Situation in Mumbai: An analysis." Berlin, Germany, 2010, table 14, pg. 14.

Another important consideration is how much value is being added to the region's domestic product from the economic sectors within Greater Mumbai. As the service sector gains a larger share of the domestic product, the likelihood of increase in spending power within the GMR is higher. Such spending power can be directed to many consumables including the transport budget for households. Figure 2.10 shows that the "secondary" sector is becoming a smaller portion of the domestic product for Greater Mumbai, whereas the "tertiary" sector is gradually growing.

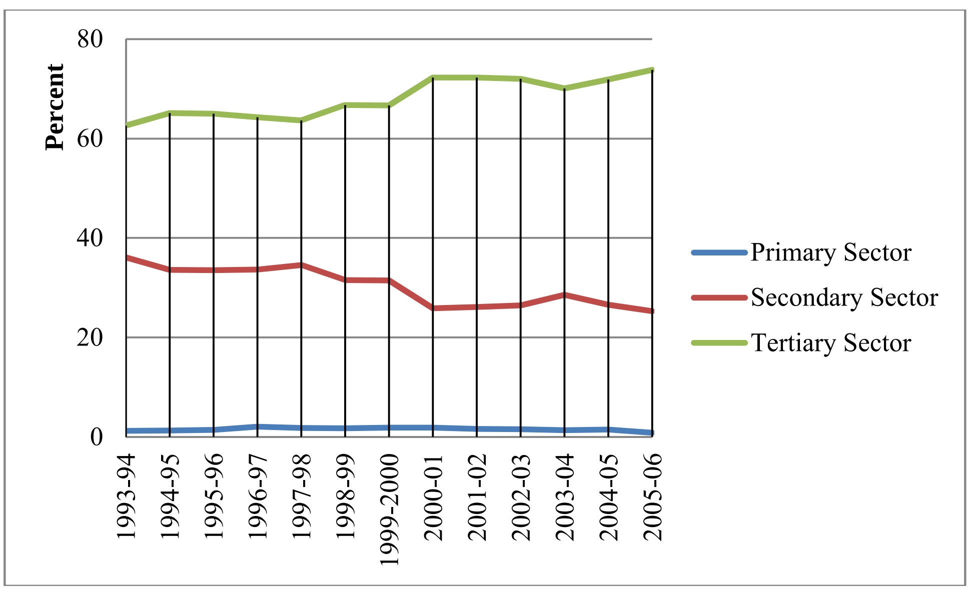

FIGURE 2.10 Contribution of economic sectors to net district domestic product for Greater Mumbai.
Source: Singh, D. P. "Employment Situation in Mumbai: An analysis." Berlin, Germany, 2010, table 17, pg. 17.

The size of business establishments can be interpreted as an indicator of how the added domestic product may spread in the emergent and established middle-classes. Figure 2.11 shows three economic snapshots for Greater Mumbai's business establishment size; very small firms have grown, whereas larger firms are becoming a smaller percentage of the total establishments.

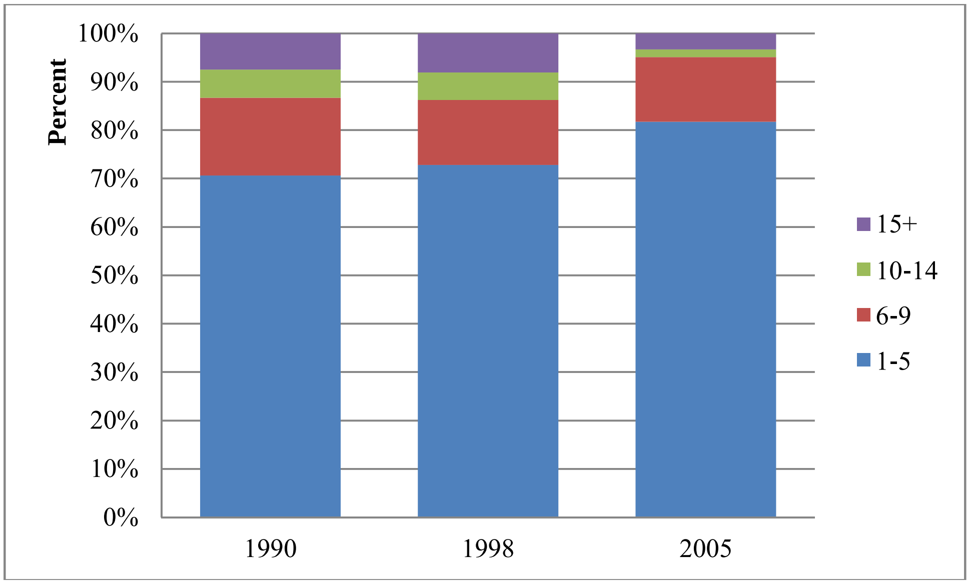

FIGURE 2.11 Percentage distribution of establishments in Greater Mumbai having hired workers by employment size.
Source: Singh, D. P. "Employment Situation in Mumbai: An analysis." Berlin, Germany, 2010, table 20, pg. 19.

In a similar vein, per capita net district domestic product could indicate higher spending power; though this gross metric will hide income disparities. In general, the per-capita net district domestic product for Greater Mumbai has increased rapidly over the last 15 years (figure 2.12).

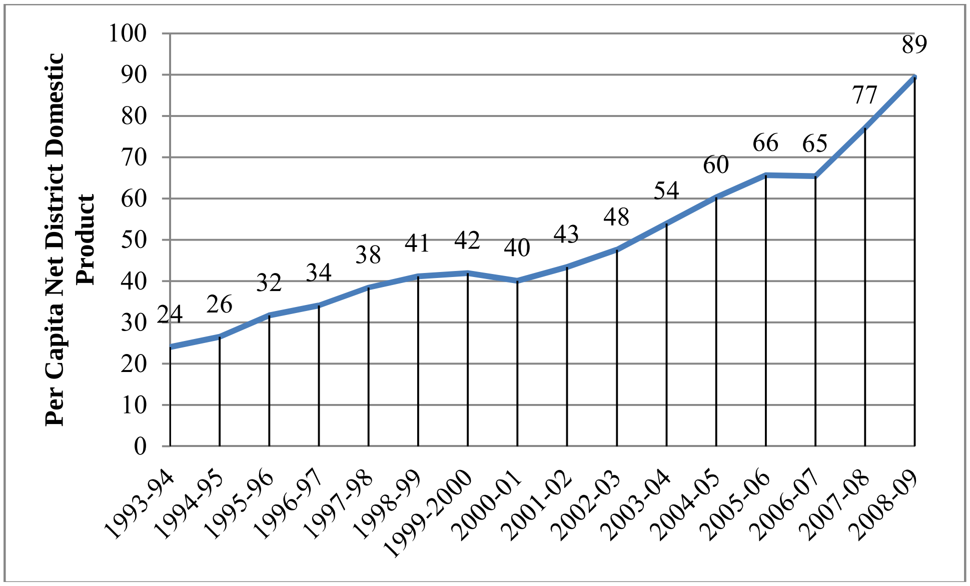

FIGURE 2.12 Per capita net district domestic product for Greater Mumbai (in real 2010 1,000 ₹).

Source: Singh, D. P. “Employment Situation in Mumbai: An analysis.” Berlin, Germany, 2010, table 16, pg. 16.
Note: ₹ is the symbol of the Indian National Rupee (often referred to as Rs. or INR).

2.1.3 Transportation Change in the GMR

Growth in population and employment, increasing development in outlying sub-centers and at the urban fringe, higher incomes and a larger share of professional / technical / administrative employment are all trends that are likely to lead to demands for greater mobility, with more trips being made and greater private vehicle ownership and use. This section discusses available data on transportation trends for Greater Mumbai.

The Transport Commissioner’s Office for the state of Maharashtra, within which the GMR is located, puts out a publication listing important transport-related metrics. However, the reporting geographies are based on state designated districts, whereas the MMRDA identifies the GMR based on a definition of the metropolitan region that does not align with the state districts. This jurisdictional mismatch creates some problems in reporting transport sector data from this source. Overall, a trend towards higher vehicle ownership is evident for Greater Mumbai and the Thane region. Yet, it is interesting to see how motor vehicles on the road since 2003 for Greater Mumbai have not grown as rapidly as for the Thane region, which is an outlying area to the north-east (figure 2.13).

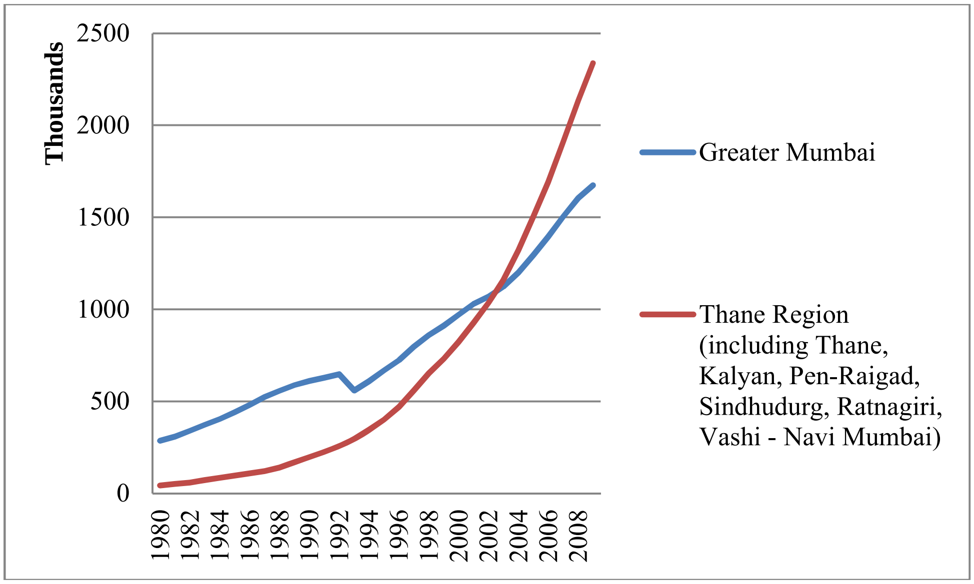

FIGURE 2.13 Motor vehicles on the road.
Source: Transport Commissioner's Office, Maharashtra State, December 2009, table 11, pg. 40-49.

Similarly, new registered vehicles have grown more rapidly for the Thane region than for Greater Mumbai since 1995-96 (figure 2.14). The global economic recession may have some bearing on lowering numbers of new registered vehicles after 2006-07. Households, in a recession, will allocate more resources to necessities such as food and education, rather than on purchases such as new vehicles. The Bandra-Worli Sea Link (an 8-lane road bridge) was opened in 2009; this should drive up vehicle ownership marginally. Future data might show the upward vehicle ownership impacts of this new added infrastructure, and other overpasses and arterials, through vehicle registration data. Further, the Tata Nano was launched in 2009, and other sub-compacts were introduced in the market in the last few years, and field research shows this car class growing on streets in Indian cities. Unfortunately, getting data on their sales is beyond the resources of this dissertation.

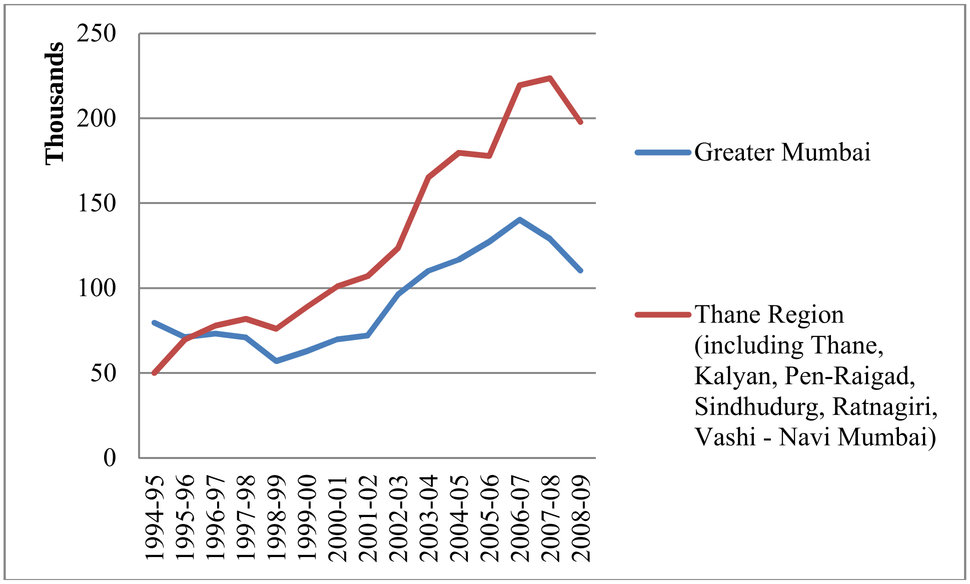

FIGURE 2.14 Number of newly registered vehicles.

Source: Transport Commissioner's Office, Maharashtra State, December 2009, table 17, pg. 133-34.

Similar to the rest of India, the GMR has experienced growth in private vehicle ownership. Figure 2.15 shows the growth of cars and two-wheelers between 1996 and 2005 for all GMR, Greater Mumbai, and Rest of the Region (RoR). The growth rates for two-wheelers per thousand (in greens) are higher than those for cars (in reds) in all three geographic categories, but the growth rate in the RoR is higher for both cars and two-wheelers than in Greater Mumbai. This indicates that households in the outer areas of the GMR are buying private vehicles at a higher rate than those within Greater Mumbai.

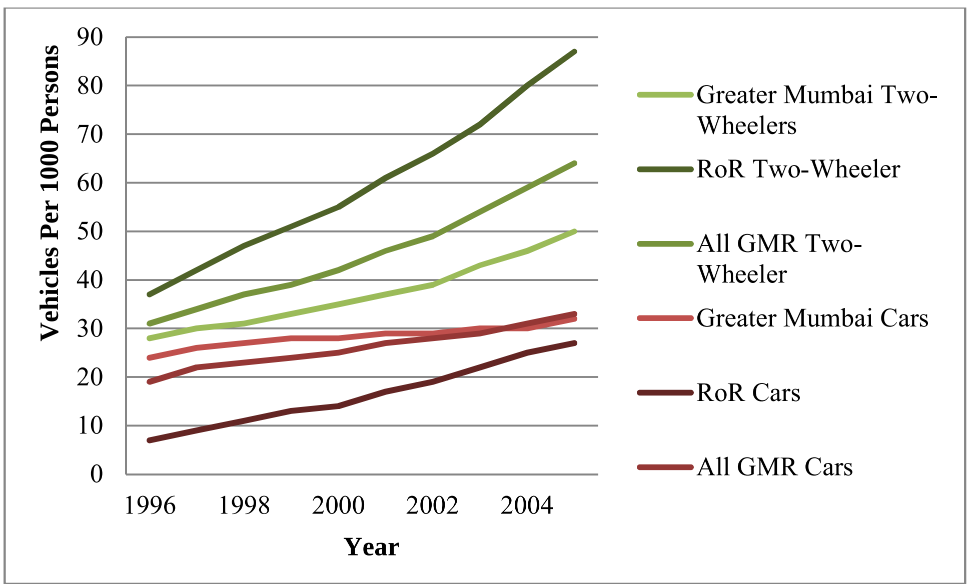

FIGURE 2.15 Cars and two-wheelers per 1000 persons in the GMR (shown for Greater Mumbai, RoR, and all GMR).

Source: LEA International Limited, et al., 2008, pg. 4-111.

2.1.4 Consequences of Vehicle Fleet Growth in the GMR

The growth of the vehicle fleet means more personal mobility, but this also comes with costs; one such cost is safety. The World Health Organization reports that India had 105,725 reported road traffic fatalities and 452,922 reported non-fatal road traffic injuries in 2006 (http://apps.who.int/iris/bitstream/10665/44122/1/9789241563840_eng.pdf, accessed November 30, 2012). China had 89,455 reported road traffic fatalities and 431,139 reported non-fatal road traffic injuries in 2006. In comparison, the United States, which is a highly motorized society, had 42,642 reported road traffic fatalities and 3,305,237 reported non-fatal road traffic injuries in 2006. This high number is likely a reflection of accurate reporting in the United States. Sweden had a total of 471 reported road traffic fatalities and 26,636 reported non-fatal road traffic injuries in 2006. Though the countries reported here are handpicked, the data suggest that road safety is a much larger concern in rapidly motorizing countries such as India and China.

Figure 2.16 shows the number of reported road accidents and persons injured in accidents involving vehicles since 2004 in Mumbai. There is an upward trend since 2004. It is important to acknowledge that these numbers may be quite far from the true statistics, since many road accidents go unreported because of lax regulatory oversight, limited insurance coverage, and private settlements between parties involved in accidents.

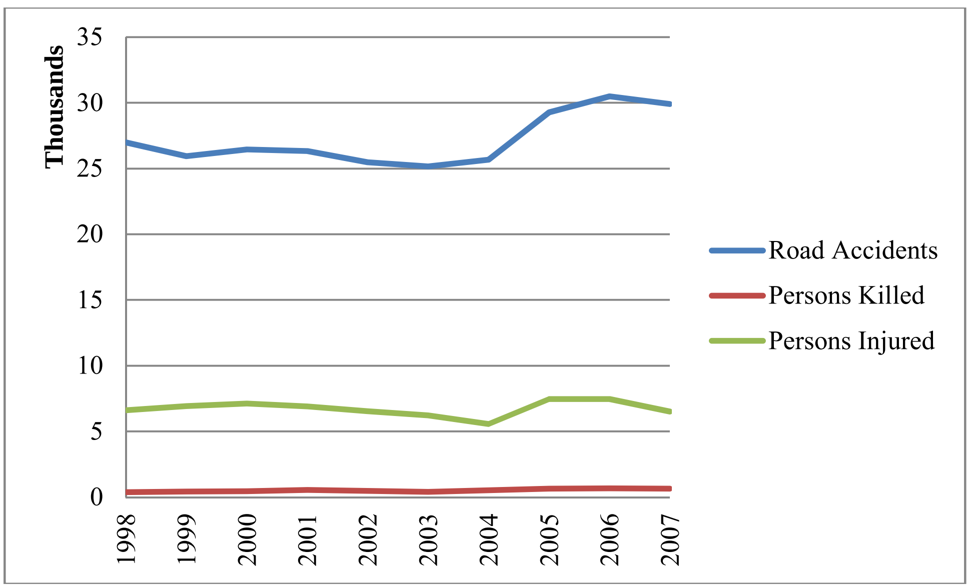

FIGURE 2.16 Reported accidents in Mumbai.
Source: Transport Commissioner's Office, Maharashtra State, December 2009, table 39, pg. 267-69.

Other negative impacts from vehicle fleet growth are from emissions, which have significant health and quality of life effects. Sub-regional differences are apparent in the data available from government sources. Not only was the total vehicle fleet bigger in the Thane region (2.3 million compared to 1.7 million in Greater Mumbai) in 2009, but there were also differences between the fuels used by vehicles in different categories in the two regions (table 2.2). Almost all the motorized two-wheelers in both geographies used petrol. In the motorcars, jeeps and station wagons category, in Greater Mumbai 55% used petrol, 36% used diesel, 5% used Liquid Petroleum Gas (LPG), and 4% used Compressed Natural Gas (CNG); in the Thane region, 69% used petrol, 27% used diesel and 3% used LPG. In the taxis and rickshaws category, in Greater Mumbai 89% used CNG, 5% used petrol, 3% used diesel, and 2% used LPG; in the Thane region 53% used petrol, 35% used diesel, 12% used CNG and 1% used LPG. In the bus category, in Greater Mumbai 88% used diesel and 12% used CNG; in the Thane region all buses used diesel.

These differences in the numbers and percentages of taxis, rickshaws and buses in the two areas using CNG and diesel must have impacts on (i) street level air quality, and (ii) methane leakages from CNG use, resulting in overall worse air quality in the Thane region in 2009. Overall, in Greater Mumbai 73% of the vehicles used petrol, 15% used diesel, 10% used CNG and 2% used LPG; whereas in the Thane region 76% of the vehicles used petrol, 22% used diesel and the remaining 2% used either LPG or CNG. Though this dissertation does not delve deeper into specific emissions impacts of vehicle use in the GMR, this is an important area of future research for Indian cities.

TABLE 2.2 Fuel Use by Vehicle Category for Greater Mumbai and the Thane Region (in '000)

	Diesel		Petrol		LPG		CNG		Other Fuels	
	N ('000)	%	N ('000)	%	N ('000)	%	N ('000)	%	N ('000)	%
Greater Mumbai (Total Vehicles = 1,674,366)										
Motorcycles, Scooters, Mopeds	0	0%	910	100%	-	0%	-	0%	-	0%
Motorcars, Jeeps, Station Wagons	185	36%	282	55%	24	5%	22	4%	0	0%
Taxis, Rickshaws	5	3%	8	5%	4	2%	144	89%	-	0%
Buses	10	88%	-	0%	-	0%	1	12%	-	0%
Others	56	71%	17	22%	4	5%	1	1%	1	1%
Total	256	15%	1,217	73%	32	2%	169	10%	1	0%
Thane Region (including Thane, Kalyan, Pen-Raigad, Sindhudurg, Ratnagiri, Vashi - Navi Mumbai) (Total Vehicles =2,337,614)										
Motorcycles, Scooters, Mopeds	-	0%	1,306	100%	-	0%	-	0%	0	0%
Motorcars, Jeeps, Station Wagons	135	27%	341	69%	17	3%	0	0%	-	0%
Taxis, Rickshaws	74	35%	112	53%	2	1%	25	12%	-	0%
Buses	16	100%	-	0%	-	0%	0	0%	-	0%
Others	278	90%	25	8%	0	0%	1	0%	6	2%
Total	503	22%	1,784	76%	19	1%	26	1%	6	0%

Source: Transport Commissioner's Office, Maharashtra State, December 2009, table 13(A), pg. 62 and pg. 69.

2.1.5 Non-private Travel and New Investments in the GMR

Mumbai's public transport modal share is78%, accounting for 11 million daily trips (http://www.mmrdamumbai.org/, accessed November 30, 2012). The GMR has a high density heavy rail network for an Indian city, comprising 250 miles (400 km) and almost 90 stations, serving commuters traveling within the GMR, and connecting Mumbai to the rest of the country

(LEA International Limited, et al., 2008). Trains are a popular means of mobility in the GMR, accounting for almost 52% of the total trips. New investments under the Mumbai Urban Transport Project (MUTP) have resulted in extra capacity in the form of additional trains, and light rail metro and monorail links. A little over a fourth (26%) of the non-walk trips are on buses, and under MUTP, additional capacity in the form of 700 eco-friendly buses, and five bus terminals have been added. However, most of these transit investments for rail and bus systems are within Greater Mumbai, leaving the periphery currently with little added supply (refer figure 2.1).

Other modes of travel within the GMR include auto-rickshaws, shared vans, private buses, company buses, and a small number of people travel by ferries. Intermediate public transportation (IPT) modes like rickshaws make up about 9% of total non-walk trips in the GMR (LEA International Limited, et al., 2008, pg. 4-12). There is little publicly available data showing if transit and IPT trips are increasing or decreasing in the overall mode share, especially for the middle-class in the GMR.

2.1.6 Regional Planning for the GMR

The main officially adopted policy document that guides urban planning in the GMR is the "Regional Plan for the Mumbai Metropolitan Region 1996-2011," available at http://www.regionalplan-mmrda.org/ (accessed November 30, 2012). Analogous to many master planning documents, it highlights the changes in the region in terms of population and economy, and lays out a foundation for proposed planning. The Master Plan sets out policies for industrial growth, office locations, shelter needs, urban land, water resources, transportation, and environmental management. It proposes regulations for land use, development control guidelines, governance changes, investment scenarios, and highlights investment needs.

Within the transportation sector, it forecasts growth in vehicle ownership will be more than two fold the 1991 levels, specifically, private vehicle growth is expected to go from 44 to 61 per 1000 persons. The plan projects that in 2011, 85% of the non-walk passenger trips will be on public transportation. In recognizing the extreme congestion on rail networks, the Master Plan talks about 4,000 passengers / train loads at peak hours when the design was for 1,750 passengers / train. Most of the investments have been in roads, but the Plan recognizes the need to expand investments to public transportation, recommending system improvements and additions to the railway network. Though there is a discussion on parking pricing and cordon pricing in Island Mumbai, there has been little evidence of change on the ground. Many recommendations such as public sector bus agencies with private sector fleets have, in part, resulted in improvements in the Region.

Though there are sector specific plans, e.g., for infrastructure, no comprehensive Master Plan document update is evident.

2.1.7 The GMR as an Exemplar

To sum up, the GMR is experiencing rapid growth in the urban population, polycentric growth at the edge, growing employment, higher participation of women in the work force, the economy gradually moving into the knowledge sector, higher spending power in households, growing vehicle fleets, and higher numbers of road accidents and emissions impacts from the transport sector. Though the local government is trying hard to keep up with the rapid growth and change, much of the planning and implementation of projects remains reactionary.

Though the city has had a supply of rail and rubber based transit options for long, and a lively culture of transit use, yet similar to many other Indian cities, Mumbai has a growing number of private vehicles. In reference to transit provision, Mumbai can be thought of as a counterfactual to other Indian cities, since most other Indian cities do not have as many transit options. Indeed, given such a diverse supply of transit options, why would households in Mumbai choose to own and use a private vehicle? Mumbai thus can serve as an example of what may be the future for other Indian cities. Though there is a move to supply transit in many other cities in India, absent a forceful change of policies also looking at land use, the future might be unsustainable for the Indian city.

Luckily, the GMR has good data on growth patterns and transportation which can support research into the motorization phenomenon, allowing for the development of improved understandings of the factors involved, and laying the groundwork for future policy studies.

2.2 INTRODUCTION TO THE HOUSEHOLD TRAVEL SURVEY DATASET

The primary data for this dissertation comes from a household travel survey that was conducted in the GMR by the MMRDA. Additionally, many of the insights into this work come from my having lived and worked in India for many years. Having visited and stayed in Mumbai multiple times, I am familiar with the metropolitan region. Further, while negotiating the release of the dataset from MMRDA, I went on field visits in Mumbai where I became a participant observer. During this time, between May and September 2010, I performed open-ended interviews with a few middle-class households in Mumbai to understand their views on the need for vehicles in the household.

Most of the MMRDA data, used for analysis in this dissertation, were collected between April 2005 and January 2006, which covered about 62,000 households all across the GMR. An additional 4,000 households were surveyed between February 2006 and April 2006. The surveys were not conducted in the two months during the academic summer break. It is likely that this was done to not miss capturing households' school and college trips, which form a large portion of travel within the GMR. The final total dataset contains information on 65,992 households. The survey was designed to cover various sub-regions in the GMR, which is made up of 35 urban areas of various sizes plus 1,200 villages. Overall, the dataset comprises a random 1.5% sample of the total population within the GMR (from LEA International Limited, et al., 2008, Annexure 2-1).

Figure 2.17 shows the distribution of the data collection effort across the months in a year. Most households were surveyed in two phases; during the 1st try, all information on housing, vehicle ownership, parking, demographic information (age, gender, education, income, etc.), employment, usual travel patterns (days of travel, times of outbound and return trips, time taken, modes taken, travel costs), etc. was collected. In the 2nd try, information from the one-day travel diary was collected from the household members. Household members who were not capable of reporting their daily trips, e.g., young children, very old, or those members who were illiterate, were asked about their travel by the surveyor during this second household visit. Some households necessitated a third visit to clarify issues with reported information; however, such households were very few.

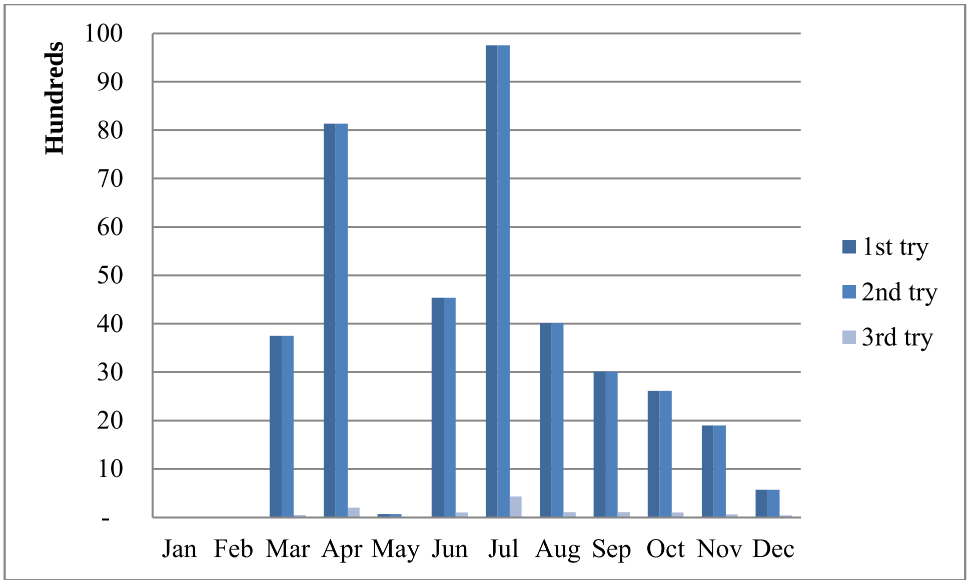

FIGURE 2.17 Month of survey.

A significant portion of the surveys were conducted during the monsoon months in Mumbai (June through September). During monsoon in India, issues of water logging, delays on existing transit systems, accidents, etc. are relatively higher than in other months. Hence, it is likely that travel behaviors are slightly modified during these months. However, this is also the time-period in the year when the pressure on the transportation networks is much more pronounced. On the one hand, conducting the surveys during the monsoon may result in abnormal reporting due to respondent's adjustments to the limitations that the rains impose on daily travel. On the other hand, this time period exhibits a yearly worse-case scenario which is important to study.

Table 2.3 shows how the surveyed households in the dataset are distributed across pre-defined income groups. During the survey, rather than asking individuals and households for a specific income, the survey was designed with nine income categories (A through I), where A was the most marginalized group in terms of income, and I was the most well-off group. The survey asked households and individuals to report what income group they were in, for both household income and individual income. Of the total 65,293 households in the cleaned up dataset, 34% were in group D, 28% were in group C, and 21% were in group E. The very poor groups (A and B) and the well-off groups (F, G, H, and I) had relatively fewer households.

Based on an understanding of earning and consumption patterns in Indian cities, this dissertation chooses to further classify these groups into "classes", wherein groups A through C are the "working poor", groups D and E comprise the "emergent middle-class", and groups F through I comprise the "established middle-class" (also see Baviskar and Ray (Eds.), 2011, Mckinsey Global Institute, 2007, Varma, 1998). These classes are a heuristic tool to help make sense of pre-defined number based income categories. There is no consensus in the literature about where a certain class begins or ends.

The classification for this research stops with the established middle-class because the very well-off in group I are a very small segment of the total households surveyed (113 households or 0.2%). Further, even the very well-off will generally only own so many vehicles per household. Hence, for the purpose of this analysis, this group is included in the established middle-class. Future research on pricing policies might look at vehicle make and buying patterns of car owning households in a longitudinal study. Then it might become meaningful to probe deeper into segments within the middle-class; unfortunately, this dataset does not report information on vehicle classes.

TABLE 2.3 Income Categories in the Dataset

Category	Monthly Income (Lower bound) in ₹	Monthly Income (Upper bound) in ₹	Monthly Income Midpoint in ₹	Monthly Income Midpoint in $PPP	Annual Income Midpoint in ₹	Annual Income Midpoint in $PPP	Households in group	% of Households in each category	"Class"	% of Households in categories D through I
A	-	1,500	1,000	63	12,000	750	1606	2%	"Working poor" (41%)	
B	1,501	3,000	2,250	141	27,000	1,688	7001	11%		
C	3,001	5,000	4,000	250	48,000	3,000	18291	28%		
D	5,001	10,000	7,500	469	90,000	5,625	21932	34%	"Emergent middle-class" (55%)	57.1%
E	10,001	20,000	15,000	938	180,000	11,250	13388	21%		34.9%
F	20,001	30,000	25,000	1,563	300,000	18,750	2355	4%	"Established middle-class" (4%)	6.1%
G	30,001	40,000	35,000	2,188	420,000	26,250	457	1%		1.2%
H	40,001	50,000	45,000	2,813	540,000	33,750	150	0%		0.4%
I	50,001	-	55,000	3,438	660,000	41,250	113	0%		0.3%

Note: ₹ is the symbol of the Indian National Rupee (often referred to as Rs. or INR). Equivalent purchasing power parity conversions in United States Dollar value ($PPP) are based on 2006 (year of survey) $PPP 1 = ₹ 16. Source: http://unstats.un.org/unsd/mdg/SeriesDetail.aspx?srid=699, accessed November 30, 2012.

Since the question of interest for this research is vehicle ownership and vehicle use, the focus is on those income groups that are likely to own a vehicle, have one available through their workplace, or consider getting one. Therefore, for the purpose of this research, groups A through C were dropped i.e., 26,898 households or 41% of the total dataset comprising the working poor is not part of the analysis (also see figure 2.18 and discussion). By dropping the working poor from the analytical frame I do not mean to suggest that the concerns of this group are unimportant. Instead, it is a practical consideration to understand the broad effects of vehicle ownership. Thus, it is critical to study those households who might own and use vehicles.

Consequently, a dataset was extracted from the larger sample to include only emergent plus established middle-class households (median annual household income over ₹ 48,000 = $PPP 3,000). Of the total cleaned up sample, 59% households were middle-class by this definition. Of these, 92% of the households were emergent middle-class (median annual household income between ₹ 48,000 and ₹ 180,000 = $PPP 3,000 and $PPP 11,250), and 8% of the households were established middle-class (median annual household income over ₹ 180,000 = $PPP 11,250). After cleaning up the data, 38,352 households remained for this analysis.

It is likely that emergent middle-class households own a motorized two-wheeler, whereas the established middle-class households own a car plus other vehicles. This conjecture was supported by looking at car and motorized two-wheeler ownership rates across the income groups (figure 2.18). Further, confirmation for this inference came from informal discussions with middle-class individuals in Greater Mumbai who independently came to the same conclusion i.e., the working poor tend not to own vehicles, emergent middle-class households tend to own motorized two-wheelers, and established middle-class households tend to own cars plus other vehicles. Finally, this inference was based on income category definitions used in a pilot study done during 2003-04 to understand the travel behavior of the poor (Baker, et al., 2005, table 33).

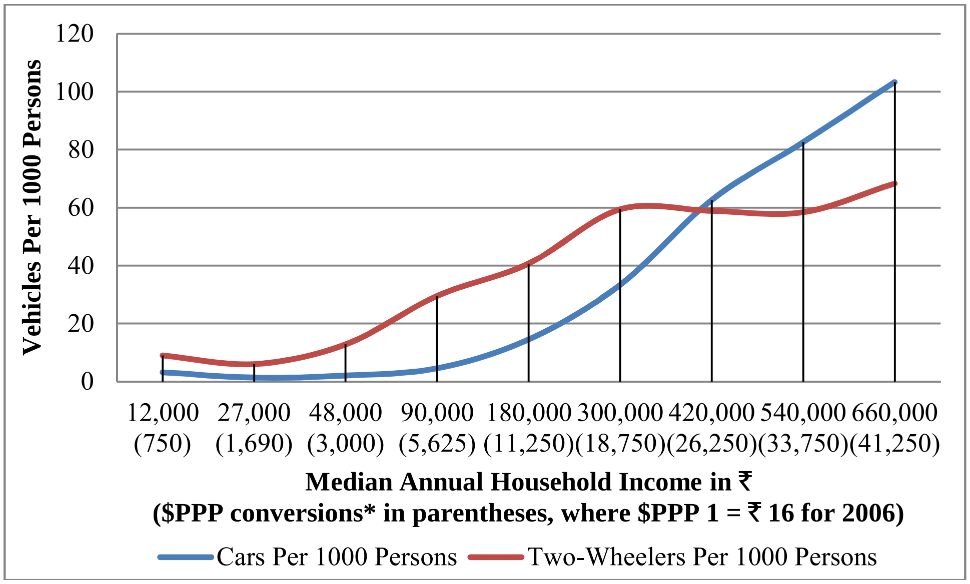

FIGURE 2.18 Cars and motorized two-wheelers per 1000 persons by income categories.
* http://unstats.un.org/unsd/mdg/SeriesDetail.aspx?srid=699, accessed November 30, 2012.

Table 2.4 shows how many of the 38,352 middle-class households in the dataset had vehicles available in each of the categories including motorized two-wheelers, cars, bicycles, and ‘other vehicles’. These numbers include both vehicles owned and available for use in a household. Households with multiple vehicles are rare in the GMR. There are 61 motorized two-wheelers per 1000 persons, 20 cars per 1000 persons, and 19 bicycles per 1000 persons in the GMR. All inclusive, 101 vehicles are owned or available for every 1000 persons.

TABLE 2.4 Vehicle Availability by Household

	Motorized Two-wheelers	Cars	Bicycles	'Other vehicles'	All vehicles categories
1 Vehicle Households	5,755	1,843	1,665	157	9,420
2 Vehicle Households	377	122	141	16	656
3+ Vehicle Households	31	29	24	9	93
Totals	6,163	1,994	1,830	182	10,169
Vehicles per 1000 persons	61	20	19	2	101

Overall, 31,028 (81%) of the middle-class households in the data did not own any motorized vehicle, 5,401 (14%) owned only motorized TW/s (but no car), and the remaining 1,917 (5%) owned at least one car (along with the possibility of motorized TW/s).

2.3 CHARACTERISTICS OF THE TRAVEL DIARY DATASET

The survey asked members of households to report their trips for a 24-hour weekday. Those who were illiterate, too young or too old had someone else fill out their travel diary; these trip diaries were flagged as proxy surveys. Data are reported as single trips, e.g., a trip from home to work is reported as one trip, whereas a tour from home to work to shop and back home are reported as three separate trips. Each trip is categorized under a unique household number, person number and trip number.

Table 2.5 reports origins and destinations by trip purpose for the sub-sample of middle-class households analyzed in this research. 56% of the home-based trips end at work, 35% end at school, and 9% end up in at other destinations. Work-based trips mostly end at home (98%), with very few (2%) going to other destinations. Similarly, most school-based and 'other' trips end at home, with a few exceptions. There are very few numbers of trips, (n =1,540) comprising 0.84% of all 182,586 trips in travel diary that begin at work, school or other locations and do not end up at home.

A low number of trips for errands such as shopping may also be due to (1) door-to-door vending for groceries in most middle-class households (though likely not in working poor households), (2) fine grain land uses implying very short (less than 10 minutes) walking trips to the corner grocery store or fresh produce vendor that are very likely underreported, (3) Domestic helpers undertaking many errands, and having most likely not reported their trips. However, domestic helpers for shopping errands are a feature of the established middle-class.

TABLE 2.5 Trip Origins and Trip Destinations by Trip Purpose for the Middle-Classes

	Destination is Home		Destination is Work		Destination is School		Destination is Other		Total	
	N	Percent	N	Percent	N	Percent	N	Percent	N	Percent
Origin is Home	5	0%	50,496	56%	31,900	35%	8,239	9%	90,640	100%
Origin is Work	49,774	98%	1	0%	102	0%	786	2%	50,663	100%
Origin is School	31,776	99%	72	0%	0	0%	102	0%	31,950	100%
Origin is Other	8,856	95%	132	1%	24	0%	321	3%	9,333	100%
Total	90,411		50,701		32,026		9,448		182,586	

Table 2.6 shows mode splits for home-based trips. Most work trips were either by walking biking (36%) or were train-based trips (38%). A fair number were also by bus (12%), motorized two-wheelers (8%), and a small percent were by intermediate public transportation modes or cars. More than two-third home-based school trips were by walking or biking, with another 16% by bus, 10% by train and the residue by IPT or private modes. Similarly, home-based 'other' trips were mostly by walking or biking (69%), and the rest by transit, IPT and private modes.

TABLE 2.6 Mode Split for the Home-Based Work, School and 'Other' Trips

	Home-based work trips		Home-based school trips		Home-based 'other' trips		Total home-based trips	
	N	Percent	N	Percent	N	Percent	N	Percent
NMT (Walk, Bike)	18,144	36%	21,300	67%	5,682	69%	45,126	50%
IPT Mode (Rickshaw, Taxi, etc.)	1,554	3%	1,849	6%	573	7%	3,976	4%
Bus	6,148	12%	5,104	16%	529	6%	11,781	13%
Train	19,018	38%	3,222	10%	668	8%	22,908	25%
Motorized Two-Wheeler (TWs)	4,183	8%	284	1%	614	7%	5,081	6%
Car	1,449	3%	141	0%	173	2%	1,763	2%
All modes (total)	50,496		31,900		8,239		90,635	

Of the total 182,586 trips that were reported in the travel diaries by middle-class individuals, 13,826 trips were by a car or a two-wheeler as a main travel mode – either as driver or passenger. Figure 2.19 shows how middle-class trips taken by car or two-wheeler as drivers or passengers were split between home-based work, school and 'other' trips (see chapter 5 for a detailed discussion).

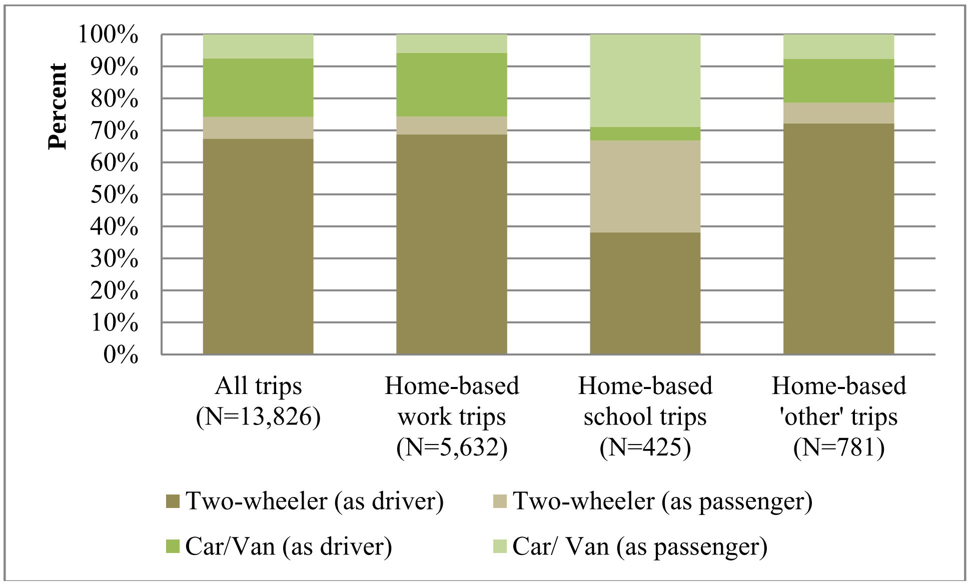

FIGURE 2.19 Total middle-class trips by car or two-wheeler.

The MMRDA considers 6 am-11 am the morning peak, and 5 pm-11 pm the evening peak (LEA International Limited, et al., 2008). When the middle-class trips were plotted against the 24-hour day (figure 2.20), this pattern held. The peak in home-based trips around noon, is most likely from home-based school trips i.e., children leaving for schools with afternoon sessions.

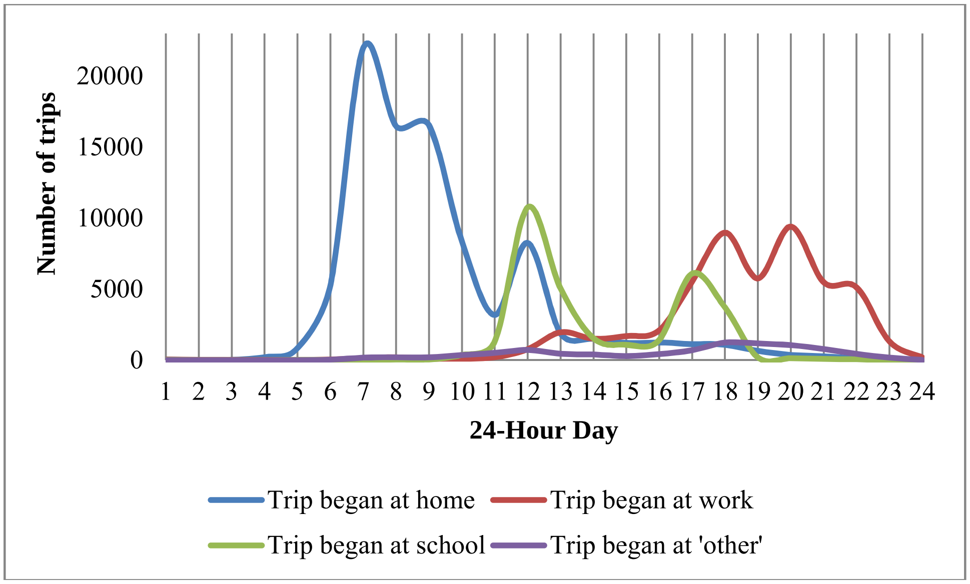

FIGURE 2.20 Time of travel by trip origin.

There is a strong link between travel modes and incomes in the GMR. Figure 2.21 shows median annual household incomes (along with $PPP equivalents for 2006 in parentheses) along the x-axis and mode splits in each income category along the y-axis. Non-motorized modes become a smaller portion of the primary mode choice as incomes grow. Cars as main modes increase quite steadily as incomes grow too, especially for those with median annual household incomes above ₹300,000 ($PPP 18,750). The transit mode split, comprised of train and bus trips, is significant for all middle-class income groups. It varies between 35% for those with median annual household incomes of ₹90,000 ($PPP 5,625) and 44% for those with median annual household incomes of ₹300,000 ($PPP 18,750). The choice of intermediate public transportation modes such as rickshaws varies between 4% and 8%, whereas motorized two-wheeler use varies between 4% and 11%.

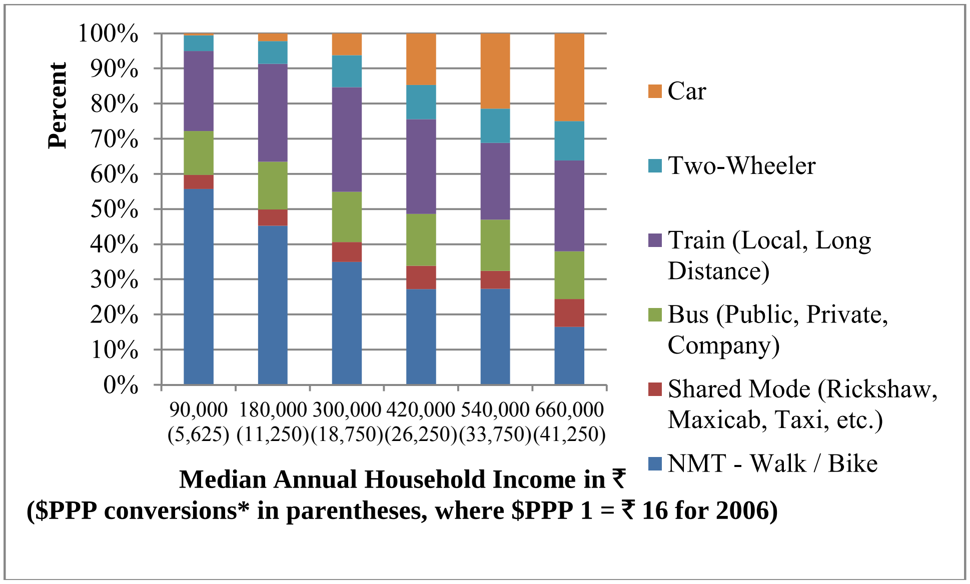

FIGURE 2.21 Main travel mode across income categories.
* http://unstats.un.org/unsd/mdg/SeriesDetail.aspx?srid=699, accessed November 30, 2012.

2.4 DATASET LIMITATIONS

There are some concerns with collecting such travel survey data in the Indian context that may raise questions about the quality of the dataset and any consequent analysis. Reported incomes and work trips for informal employment might be misreported. It is likely that income is over-reported by lower income groups, and under-reported by higher income groups. Thus, the per capita income indicators for various CBD definitions, along with per capita income coefficients in the vehicle ownership and use models are likely estimated on data that understates actual incomes.

Informal employment complicates trip reporting. There are two forms of informal employment to contend with in the Indian context – the working poor's version e.g., an unlicensed street vendor with a food cart, and the middle-class version e.g., an educated housewife tutoring school children. Trips for informal employment are likely under-reported across all income categories since many of the activities involved do not end in a formal work location. Thus, the vehicle use models are likely estimated on data that understates the actual amount of travel.

Another major limitation of the dataset is the gender split. Though there are 838 women per 1,000 men in the GMR (see figure 2.6), of the total 108,605 middle-class individuals surveyed, 74% were men and only 26% were women; this gender split should be close to 54% men and 46% women. It is unclear whether women were unwilling to participate, not approached to participate due to the presence of male householders, or did not travel on the survey days.

Further, as is evident from the discussion about sex-ratios in the GMR, it is likely that a fair number of trips are undertaken by men who have moved to the GMR without their families. It is unclear if these men are proportionally represented in the data, given that they do not necessarily live in a "household." Many single migrant men tend to live in informal housing to save on rent, enabling them to support families in the hinterlands – many share accommodations. Based on field observations, on average, this group tends to fall in either the working poor or emergent middle-class category. Vehicle ownership and use, and travel in general, for such individuals are likely constrained by housing and work location, and by education and income levels. Such groups of migrant populations are the norm in most Indian cities, but the dynamics are very likely different in the GMR, given the sheer numbers. The consumer and travel behaviors of male migrants in Indian cities are an area for future research.

The slums of Mumbai are infamous for their geographic and temporal prevalence, with multiple generations in a household living in sub-standard housing conditions. Many households are forced to live in informal housing even though they make a decent income by Indian standards. Given that the housing supply is severely constrained in Greater Mumbai, it is not surprising that not many housing options exist for those with limited incomes (Glaeser 2011, Bertaud and Brueckner 2005). Housing category is an important indicator of affluence and social mobility. Many households might report living in formal housing categories, because reporting otherwise could be problematic. Therefore, the housing category dummy coefficient estimated in vehicle ownership models is likely based on data that overstates formal housing.

The focus of the travel diary data collection was to understand trips that end in work or school destinations, so leisure (weekend / Sunday) trips are likely under-reported. This is important to acknowledge since leisure trips might encourage vehicle ownership to some extent in the Indian context. However, the dataset does report such trips; this is an element to explore in future research. The low-number of trips that do not begin or end in home, work or school is also problematic (table 2.5). There are usually a fair number of trips during the work day for running errands. Since shopping trips do not show up in any income category, it is likely that this is a weakness in the survey instrument and data collection.

Overall, there are limitations with the dataset used for this dissertation in terms of the reported income, informal employment trips, gender split, housing category, and under reported weekend / discretionary and shopping trips. While these limitations should be kept in mind when interpreting the results, the survey nevertheless offers important insights into travel and vehicle ownership / use among middle-class Indians in Mumbai, and given that a better dataset does not exist for a major Indian city at this time, this research moves forward, highlighting the limitations and drawbacks when interpreting results.

2.5 SUMMARY

This chapter presented an overview of the Greater Mumbai Region, and discussed the travel survey for the GMR on which the analyses presented in this dissertation are based. The dynamics of growth in the GMR and its role as a cutting-edge, leading city in India, coupled with the availability of a household travel survey dataset, are good reasons to undertake this as a case. The subsequent chapters explore travel by public and private modes to various sub-centers in the GMR, ownership and use of cars and motorized two-wheelers in middle-class Indian households in the GMR, looking at job plus housing location, land use characteristics, transit proximity, and socio-economic characteristics to help understand interrelated but distinct conceptual pieces of private vehicle holding in the Indian context.

CHAPTER 3

Employment Centers and Middle-Class Travel Behavior in Mumbai

3.1 POLYCENTRIC METROPOLITAN REGIONS

The Greater Mumbai Region (GMR) is among the most populated mega city-regions in the world, housing over 22 million people. Rail networks, which grew steadily after India's independence, turned into development corridors here. Over time additional employment centers developed as the rail network expanded out north and east from these established cores. State initiatives to decongest Mumbai resulted in new nodes in the 1970s. Market forces resulted in establishing employment centers farther north and east along these rail networks, 25-35 miles (40-55 kilometers) from the traditional central business district (CBD). The GMR's growth illustrates a transformation from a monocentric to a polycentric city. However, current transport investments focus on strengthening connections within the core, whereas the outlying nodes have received less attention.

This chapter empirically identifies employment sub-centers using work destination data taken from the household travel survey dataset of 38,352 middle-class households making 40,301 home-based work trips. Two alternative spatial definitions for the CBD – Island Mumbai as CBD and Greater Mumbai as CBD are conceptualized. The chapter then compares commuters going to various employment geographies, based on household size, earning members per household, income, education, transportation budget, trip-costs, vehicles owned, travel mode, travel time, and travel distance. Mode specific mean travel time, travel distance and speed for the various geographies are also compared.

The chapter is organized as follows. This first section is an overview, followed by a theoretical framework on suburban development experiences, discussing the literature showing links between urban structure and the journey-to-work. The second section makes the case for employment agglomeration in the GMR, presents two conceptualizations of the CBD for the region, and examines the socio-economics and transportation behaviors of commuters to these separate geographies. The concluding section presents a summary and policy discussion.

3.1.1 Evolution of City-Regions and the Transportation Connection

Around the world, cities have evolved in part because of changes in transportation technologies and policies, and the opportunities they present. While most scholarly studies have focused on cities and regions in developed economies, they offer insights for cities in emerging economies as well, in part because many cities in these countries adopt – or are pushed to adopt – the development strategies that have been used elsewhere. There are, however, some differences that deserve attention, including the effects of poverty and of a high degree of informality. Informality is not just limited to transportation options, but also in housing supply, employment options, and incomes generated (see section 2.4).

Muller (2004) presents an excellent overview of how the city-region has developed in the United States, focusing on the influence of evolving transportation technologies. The monocentric city held cohesion because of the lack of mobility options. However, the spread of rail transit, followed by steadily increasing auto ownership, increased the speeds and distances that could be traversed. These factors along with subsidized housing policies helped suburbanize the United States. Cervero (1986a, 1986b) discusses how the consequent suburbanization of jobs resulted in higher demand for private automobility, and increased congestion on the road transportation network. The Edge City phenomenon (Garreau, 1992) resulted in peri-urban nodes, a form of urbanization where developers responded to the need for housing and related amenities by building enclaves tweaked to specific demand dynamics. Lang (2003) discusses the emergence of yet another form of suburbanization, characterized by low-scale development, single-use structures, extreme high dependence on the automobile, rapid dispersion of growth, and the lack of a center. Most metropolitan areas in the United States contain many varieties of suburbs today, and while a few have established growth boundaries, notably in Oregon, the majority have no clear edge. Some suburbs lack a center as Lang suggests, others have centers – often designed centers for employment and retail.

City-regions in Europe with old centers, and slower growth rates, had a different development paradigm. Stockholm invested in rail infrastructure to create a “necklace of pearls” pattern of development. Paris renewed and expanded the existing urban core steadily while managing outward development around rail networks, resulting in a compact and high density city-region. In comparison, the London city-region, in spite of having similar historic precedents and growth of rail networks could not contain the diffusion of jobs and housing (Ingram, 1998). Overall, the outward growth of a city is a case-specific tale, and one that demands study and caution in relation to policy formulation.

In many cities in the emerging economies, due to lower levels of incomes, private vehicle ownership is not the norm. In India, for example, the transportation market provides options for intermediate public transportation via rickshaws, shared-rickshaws, jitneys, private-sector buses, etc. Since rail and bus transportation networks are inadequate in Indian cities, many emergent middle-class households rely on these IPT options, especially when they buy housing in urban peripheries. Therefore, over the last two decades, housing has bloomed in urban peripheries.

3.1.2 Polycentric Urban Structure and the Journey-to-Work

There is general consensus that cities have come to be because they offer economies of scale and other advantages from agglomeration. The simplest model sees the city as being set up along a bid-rent curve, with participants making trade-offs between the rent they can afford to pay while minimizing their journey-to-work travel time to a single center (e.g., Alonso, 1964). This conception of the transportation and land-use relationship has been challenged (e.g., Wheaton, 1979), and re-worked so that more nuanced understandings of the city structure have emerged (Muth, 1985 offers a good overview). There is overall agreement that when travel demand to a central location becomes so great that congestion results, it incentivizes decentralization of activities. However, the notion of the city as a place where travel time to work frames urban structure remains; this dissertation follows in that tradition.

Giuliano and Small (1991) empirically identify and discuss specialized employment sub-centering in Los Angeles, arguing that if agglomerative forces are strong, decentralization can result in the creation of sub-centers. Anas, et al. (1998) argue that though the process of decentralization and sub-center formation plays out in metropolises, unchecked edgeless suburbanization can lead to city-regions losing their hierarchical integrity and economic importance. Cervero and Wu (1997) show that commute times for suburban employment sub-centers are smaller than those for denser central city employment sub-centers. However, those commuting in outer regions rely more on private forms of travel, whereas those commuting to central city employment sub-centers have a higher transit mode share.

Cervero (1989) shows that for Chicago and San Francisco metropolitan areas, jobs-housing imbalances are associated with longer work commutes. However, Giuliano and Small (1993) argue, using the Los Angeles metropolitan area as a case, that such "excess" commuting cannot be explained simply by land-use policies that result in jobs-housing imbalances. Other reasons such as the cost of moving, access to multiple employment centers given high job turnovers, and households with two-workers – all provide reasons for long commutes.

Polycentric development is also fairly common in Indian cities, which have developed in two phases. The first phase was contained largely within municipal boundaries. Cities had a mix of formal housing, both individual housing and apartments, as well as informal housing in the form of slums within municipal jurisdictions, along with higher degrees of mixed use. However, in a second phase, over the last two-decades, the emerging economic development has pushed development demand upwards. This new demand, in combination with cheaper land and lower cost of building, is resulting in development moving into urban peripheries, thus resulting in suburbia. Much of the housing and employment in the surroundings of Indian cities is formal, and provides an ideal location for emergent middle-class households, who are seeking affordable housing. However, there are pockets of informality in land markets, resulting in illegal buildings. Also, much of this urban fringe development follows a leap-frogging pattern over agricultural lands. Over time employment has also followed this outwardly movement, thus creating journey-to-work patterns that are not just suburb-center, but also center-suburb and suburb-suburb.

In the GMR, housing shortfalls severely limit residential location choice (Baker, et al., 2005), and two-worker households are a smaller percentage of the population than in the United States. Therefore, journey-to-work travel time is likely linked to the jobs-housing imbalances. Bertaud and Brueckner (2005) show that in Bangalore building height restrictions in the central-city have resulted in lower density in the city center and expanded the city-region outward. This has implications for Mumbai (Glaeser, 2011), where land use density controls in the central-city, and more development permits in outer nodes have resulted in rapid growth in fringe nodes. Whereas most jobs are concentrated within Greater Mumbai, the lack of housing options might force the working poor and emergent middle-class families to move to outlying nodes over time; thus, increasing journey-to-work times.

Baker, et al. (2005) focus on the poor in Greater Mumbai (approximately corresponding to median annual household income over ₹ 48,000 = $PPP 3,000 from table 2.3), and find that they spend much larger portions of their incomes on transportation. The emergent middle-class, in particular, is likely to live in housing in the periphery, not necessarily in urban core informal housing. The findings suggest that though the well-off and working poor live in close proximity, areas with weaker public transit and low employment density tend to have higher percentages of working poor households. The analysis also finds that a large segment of travel in working poor households is for non-discretionary trips.

3.2 THE GREATER MUMBAI REGION (GMR): A POLYCENTRIC CITY-REGION

Working with the household travel survey dataset, and using trip destination information for home-based work trips by the primary wage earner in middle-class households, a spatial analysis of where trips ended was constructed. Figure 3.1 shows this analysis, highlighting contiguous employment densities along rail networks up to Mira-Bhayander and Thane, with densities getting more pronounced towards Nariman Point – the traditional CBD. Outlying sub-centers such as Vasai-Virar to the north, and Bhiwandi or Ulhasnagar to the east have also evolved into employment nodes (also see figure 3.4).

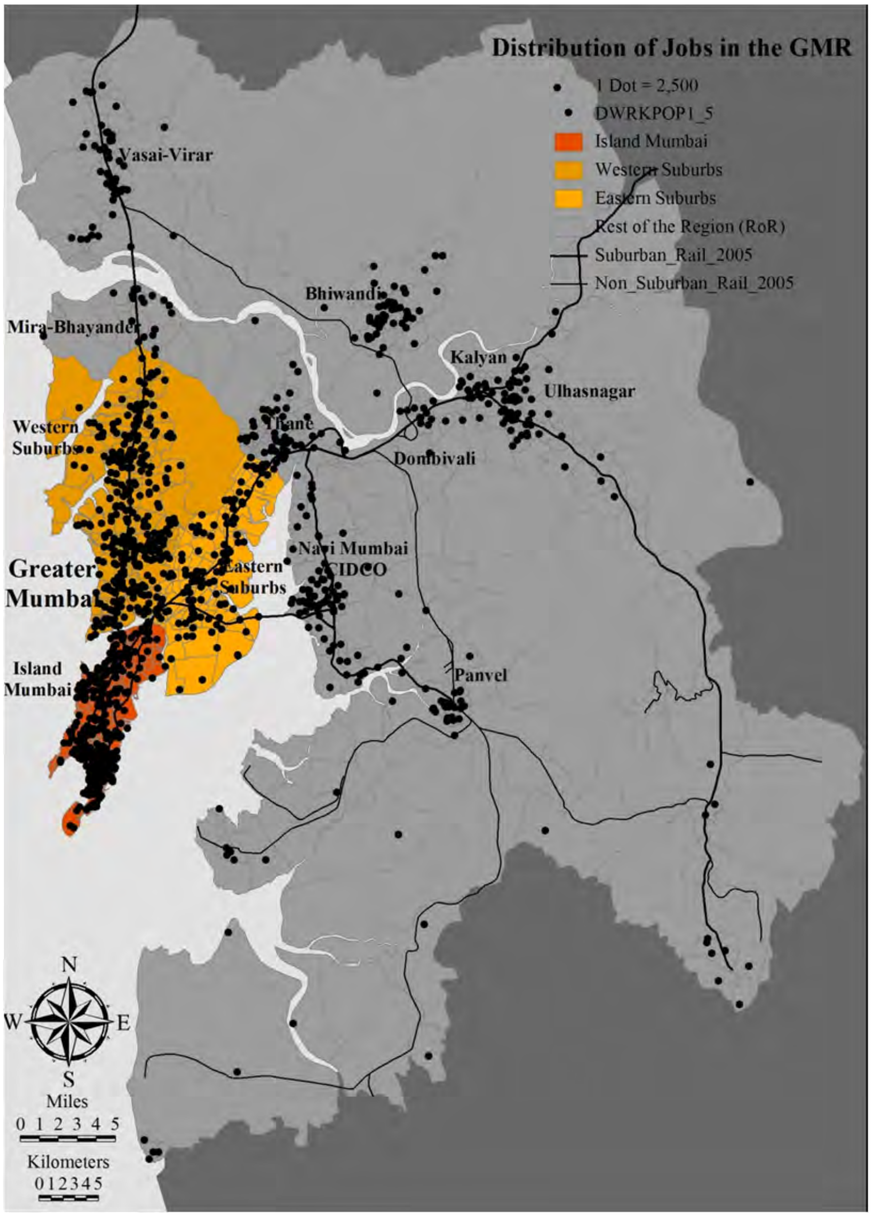

FIGURE 3.1 Distribution of jobs in the Greater Mumbai Region (GMR) (1 dot = 2,500 middle-class work destinations).
Source: Household Travel Survey dataset, MMRDA and LEA Associates South Asia Private Limited, Mumbai, India.

As the map shows, the GMR today can be thought of in two ways: (i) a region with two development corridors and outlying nodes along rail lines, or (ii) as a group of nodes, each of which exists in an agglomerative yet dispersive relationship with the others, each having a coherent center and evolving edgeless fringe growth.

3.2.1 A Subset of the Household Travel Survey Dataset

The data used for this chapter is from the household travel survey conducted between April 2005 and April 2006 in the GMR by the MMRDA. Key features of this dataset are described in detail in sections 2.2, 2.3 and 2.4 in chapter 2. For the purposes of this chapter, recall that the survey focused primarily on work and school trips, and most likely understated shopping and social-recreational trips. Further, most of the trips undertaken by the middle-class (median annual household income over ₹ 48,000 = $PPP 3,000), were by transit or private vehicles – walking and biking trips reduced with rising incomes.

Though it would be interesting to see if major centers for employment in the GMR are also centers for recreation and shopping, the data does not allow for this. Of the total 90,635 middle-class home-based trips reported in the survey, 50,496 (56%) ended in a work place (see table 2.5). Only these home-based work trips were used for the analysis because the research in this chapter aims to empirically establish employment destinations.

The trips that start and end in the same Traffic Analysis Zone (TAZ) had to be dropped since the trip distance was calculated from centroid-to-centroid along the street network resulting in zero travel distance for such within TAZ trips. The final sample had N=40,301 middle-class home-based work trips, of which 47% were by train, 23% were walk / bike trips, 15% were by bus, 9% were by motorized two-wheelers (TWs), 3% trips each were by intermediate public transportation modes and by car. The MMRDA analysis (LEA, et al., 2008) estimated that 7.8 million people in the GMR are employed. Based on the research in this chapter, the total one-way middle-class commutes are estimated at roughly 3.4 million.

3.2.2 The Nature of Agglomeration in the GMR

The literature reports on various metrics used to identify employment centers in an urban geography. For example, Giuliano and Small (1991) and Cervero and Wu (1997) use gross employment density peaks and calculate workers per acre to isolate specific sub-centers. In the absence of detailed metropolitan-wide zonal employment data, employment agglomerations for the GMR were identified, in the first step, by graphing the percent of work trips cumulatively (along y-axis) against the number of TAZs included in each fifth percentile (along x-axis) (figure 3.2). Up to the 80th percentile, the number of work trips included rises steadily but gradually. This is likely because most of the developed areas in the GMR have fine-grain mixed land-uses resulting in many of the TAZs attracting a fair share of work trips. However, at the 80th percentile, the remaining 206 TAZs attract 65% of the total work trips in the GMR, suggesting agglomeration. Of the estimated 3.4 million one-way middle-class commutes, 2.2 million ended in these remaining 206 TAZs.

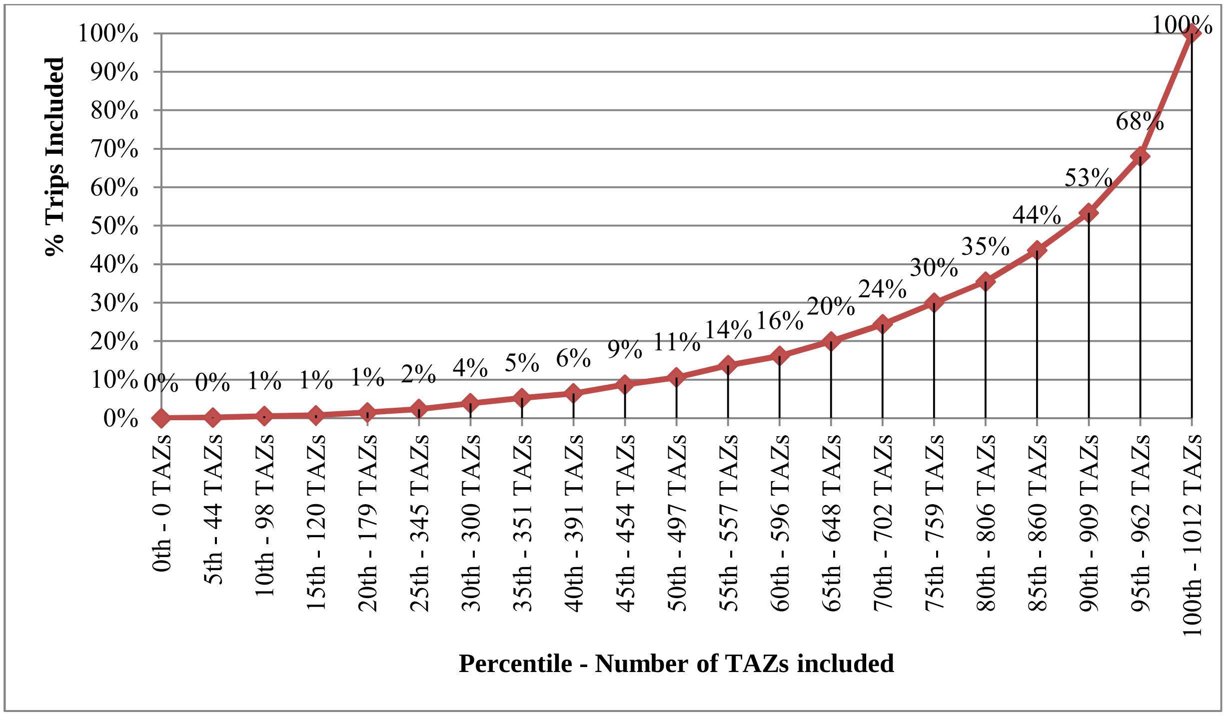

FIGURE 3.2 The nature of agglomeration in the GMR.

The second step was to spatially locate the TAZs included in the top 20th percentile to comprehend the nature of the agglomeration. Figure 3.3 shows the TAZs in the GMR that attract 65% of the work trips. Most of the employment is concentrated in Island Mumbai and along rail corridors in Greater Mumbai. However, there are smaller employment nodes north and east along the rail lines.

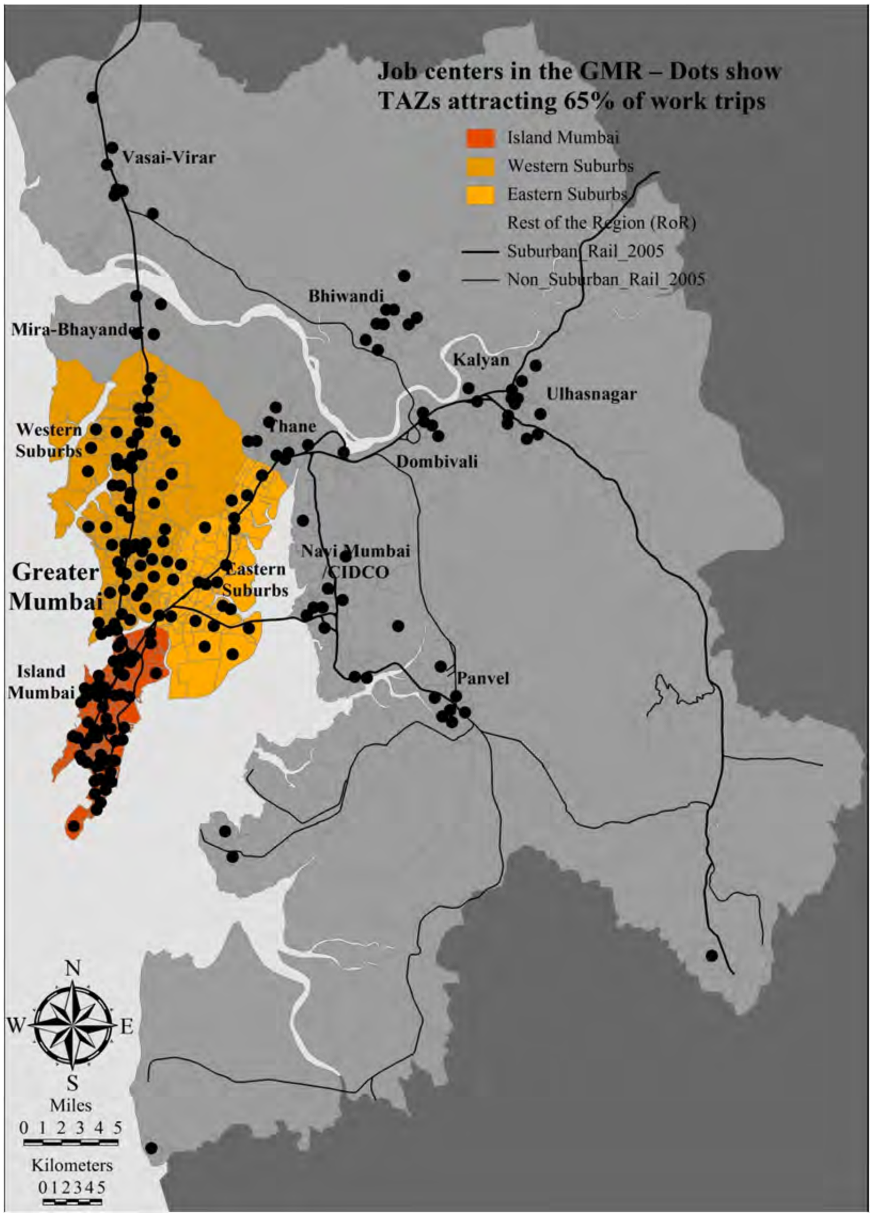

FIGURE 3.3 Job centers in the GMR – Dots show TAZs attracting 65% of work trips.

Figure 3.4 shows three dimensional views of employment (and housing) densities in the GMR, and reiterates the concentration of employment in Island Mumbai and along the rail corridors in Greater Mumbai. Jobs are also concentrated in secondary nodes such as Thane and Ulhasnagar. Household densities follow a similar pattern with concentrations in Island Mumbai, Greater Mumbai and outlying nodes along transportation corridors.

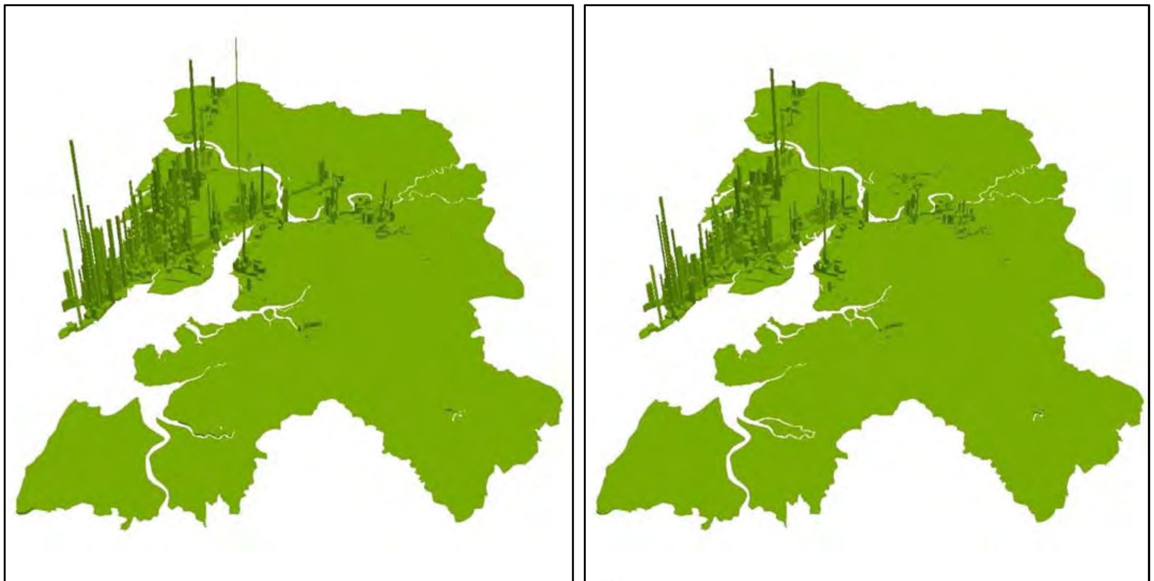

FIGURE 3.4 Employment density (jobs / km^2) and housing density (households / km^2) in the GMR (views from south-east).

The employment centers within the GMR have a mix of office, industry, retail and other kinds of work destinations for middle-class commuters. Of the total middle-class work commuters in the GMR, 46% go to an office, 21% work in an industrial location, 13% in the retail sector, and 20% are employed in other jobs involving restaurants, hotels, entertainment, construction, the education sector, the health sector, etc.

3.2.3 Conceptualizing the Central Business District for the GMR

Traditionally the central business district has been thought of as that geographic unit which has the highest concentration of employment. In many city-regions, it is possible to isolate multiple business districts (e.g., Giuliano and Small, 1991). However, in empirically identifying employment centers for a city-region, there are boundary issues that limit how any geographic entity is conceptualized. The definition of any sub-center is a function of how the original zones were set up and the researcher's judgment.

Like many other city-regions, in the GMR, employment densities are especially high at some points such as in Island Mumbai, but are generally spread out along transportation networks. Further, figures 3.3 and 3.4 show smaller concentrations of jobs in the outlying areas, many of which can be thought of as nodes. Some 0.6 million middle-class home-based work trips, or about one sixth of the total middle-class work trips, end up in these smaller employment districts.

MMRDA, the metropolitan planning organization for the GMR, has a specific method of segmenting the area into clusters. These definitions are tied to an understanding of sub-regional municipal entities rather than evolving sub-centers. This analysis used the MPO's definitions of geographic clusters, along with the employment densities, to construct two notions of the business district for the GMR. Figure 3.5 shows how Island Mumbai, with its high concentration of jobs, acts as a traditional CBD (left), as does the Greater Mumbai region, which includes Island Mumbai plus the western and eastern suburbs (right). As conceptualized, Island Mumbai as CBD has 31% (1 million) of the total jobs in the region, whereas Greater Mumbai as CBD has 67% (2.3 million) of the total jobs in the region.

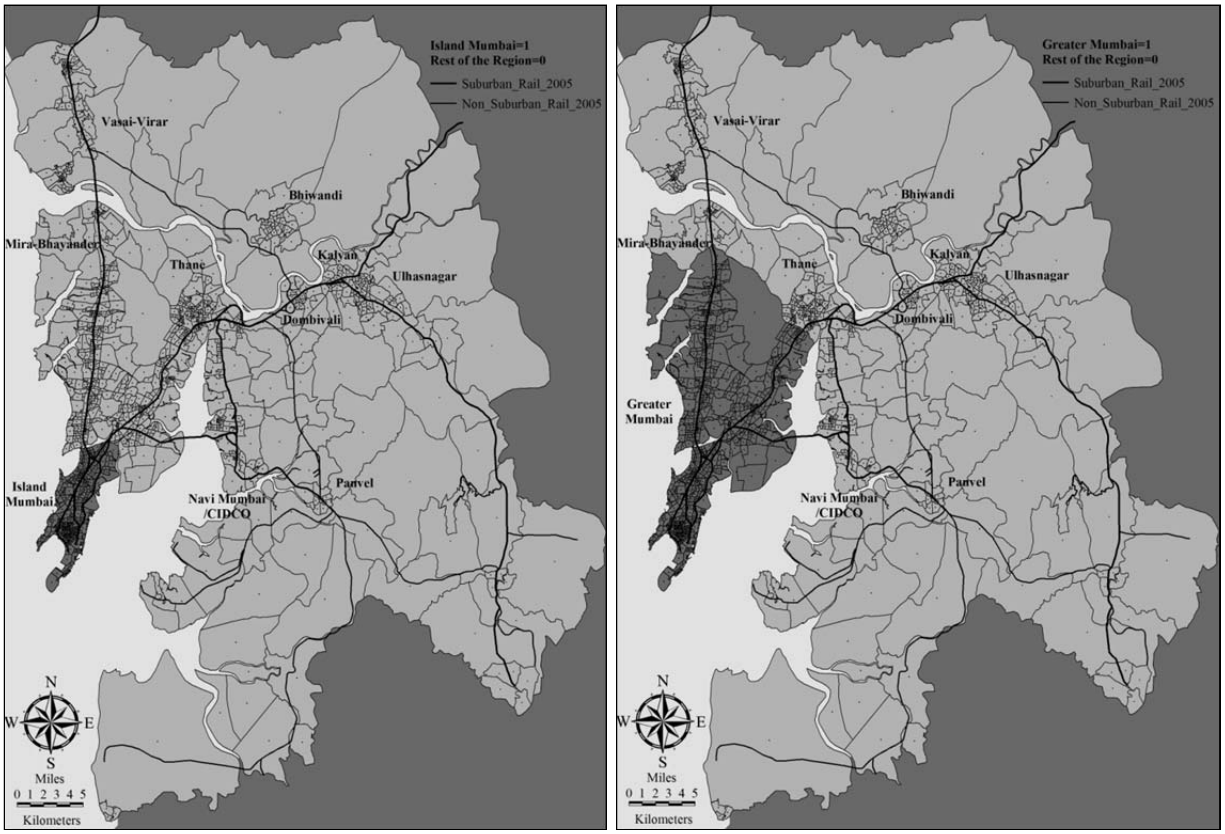

FIGURE 3.5 Island Mumbai as CBD (left) and Greater Mumbai as CBD (right).

3.2.4 Differences between the Two Conceptualizations of the CBD

Table 3.1 presents socio-economic indicators for all middle-class home-based work trips for the two conditions: Island Mumbai is CBD and Greater Mumbai is CBD. The unit of analysis is the home-based work trip, not the household. The indicators show that commuters to destinations outside Island Mumbai or Greater Mumbai tend to come from bigger households, with slightly more earning persons per household, tend to have lower mean annual household incomes, tend to have lower per capita incomes, have slightly lower percentages of people with technical diplomas or college degrees, have a much higher percentage of people working all 7 days per week, lower mean annual transportation budgets, higher out-of-pocket trip costs, fewer cars per thousand work trips, and significantly higher numbers of two-wheelers per thousand work trips.

Two tail T-tests conducted at α=0.01 show that the means for the socio-economic indicators are statistically different between Island Mumbai and the rest of the GMR, as well as Greater Mumbai and the RoR. This is true for all but mean persons per middle-class commuter's household between Island Mumbai and the rest of the GMR, indicating that these two means are statistically not different. Appendix 1 presents detailed output for the T-tests presented in this chapter.

TABLE 3.1 Socio-Economic Indicators for Middle-Class Home-Based Work Trips

	Island Mumbai as CBD			Greater Mumbai as CBD		
	Island Mumbai = 1	Rest of the GMR = 0	T-test (α=0.01) 2-tail	Greater Mumbai = 1	Rest of the Region = 0	T-test (α=0.01) 2-tail
Mean persons per middle-class commuter's household	4.66	4.67	$t(40{,}299) = 0.448$, $p = 0.654$	4.61	4.82	$t(19{,}250) = 10.772$, $p = 0.000$
Mean earning persons per middle-class commuter's household	2.08	2.14	$t(28{,}010) = 5.821$, $p = 0.000$	2.09	2.20	$t(20{,}111) = 9.431$, $p = 0.000$
Mean annual middle-class commuter's household income (1000 ₹s, 1000 $PPPs in *italics*)	161 *10.05*	155 *9.69*	$t(26{,}769) = 6.092$, $p = 0.000$	159 *9.96*	151 *9.43*	$t(40{,}299) = 8.554$, $p = 0.000$
Per capita annual income for mean middle-class commuter's household (in 1000 ₹s, 1000 $PPPs in *italics*)	38 *2.38*	37 *2.30*	$t(27{,}123) = 4.976$, $p = 0.000$	38 *2.39*	35 *2.16*	$t(22{,}946) = 14.688$, $p = 0.000$
% middle-class commuters with technical diploma or college education	35%	32%		35%	28%	
% middle-class commuters working all 7 days per week	9%	17%		11%	23%	
Mean annual middle-class commuter's transportation budget (in ₹s, $PPP in *italics*)	4,805 *300*	4,639 *290*	$t(29{,}084) = 3.812$, $p = 0.000$	4,830 *302*	4,349 *272*	$t(21{,}244) = 10.499$, $p = 0.000$
Middle-class commuter's mean out-of-pocket trip cost (in ₹s)	8.23	8.59	$t(13{,}114) = 2.473$, $p = 0.013$	8.21	9.50	$t(13{,}114) = 7.401$, $p = 0.000$
Mean cars (owned or available for use) per 1000 middle-class work trips	80	60	$t(24{,}368) = 5.441$, $p = 0.000$	70	60	$t(21{,}857) = 2.666$, $p = 0.008$
Mean two-wheelers (owned or available for use) per 1000 middle-class work trips	140	220	$t(33{,}934) = 19.832$, $p = 0.000$	160	290	$t(16{,}622) = 24.128$, $p = 0.000$

Notes:
- All reported statistics are only for one-way middle-class home-based work trips.
- ₹ is the symbol of the Indian National Rupee (often referred to as Rs. or INR).
- For 2006, the year of the survey, $PPP 1 = ₹16 (equivalent purchasing power parity conversion, Source: http://unstats.un.org/unsd/mdg/SeriesDetail.aspx?srid=699, accessed November 30, 2012), $ 1 = ₹ 44 (historic market conversion rate, Source: http://www.xe.com, accessed November 30, 2012).

Table 3.2 presents transportation indicators for all middle-class home-based work trips for the two CBD definitions: Island Mumbai is CBD and Greater Mumbai is CBD. The transportation indicators show that commuters to destinations outside CBD locations, on average, tend to make more work related trips per day, have shorter travel times, and shorter work-trip distances. These findings show that workers to non-CBD locations have different work commutes than their counterparts working in Greater Mumbai The mode splits show that commuters to non-CBD locations have much higher non-motorized transportation (NMT) mode shares, intermediate public transportation (IPT) mode use, and two-wheeler use for home-based work trips. Train use is very high for work trips to the CBD, whereas car use is roughly the same across all the region and definitions of the CBD. These findings are similar to those from many city-regions (Ingram, 1998, Cervero and Wu, 1997, and Giuliano and Small, 1991).

Two tail T-tests conducted at α=0.01 show that the means for the transportation indicators are indeed different between Island Mumbai and the rest of the GMR, as well as Greater Mumbai and the RoR. This is true for all three indicators, mean number of work trips, mean travel time and mean travel distance.

TABLE 3.2 Transportation Indicators for Middle-Class Home-Based Work Trips

	Island Mumbai as CBD			**Greater Mumbai as CBD**		
	Island Mumbai = 1	Rest of the GMR = 0	T-test (α=0.01) 2-tail	Greater Mumbai = 1	Rest of the Region = 0	T-test (α=0.01) 2-tail
Mean number of home-based work trips for middle-class commuters	2.1	2.2	$t(37{,}006) = 21.792$, $p = 0.000$	2.1	2.4	$t(13{,}969) = 32.428$, $p = 0.000$
Mean travel time, including transfer and wait time, for middle-class commutes (in minutes)	56	39	$t(25{,}123) = 49.090$, $p = 0.000$	50	33	$t(23{,}144) = 52.255$, $p = 0.000$
Mean distance traveled for middle-class commutes (in kilometers)	21	12	$t(20{,}540) = 49.293$, $p = 0.000$	17	10	$t(29{,}269) = 49.590$, $p = 0.000$
Mode split for middle-class home-based work trips						
NMT (walking, biking) is main travel mode	15%	28%		17%	38%	
Intermediate public transportation mode (rickshaw, shared van, taxi) is main travel mode	1%	5%		2%	7%	
Bus is main travel mode	12%	16%		15%	13%	
Train is main travel mode	65%	37%		56%	24%	
Two-wheeler is main travel mode	4%	11%		6%	15%	
Car is main travel mode	4%	3%		3%	3%	

Notes:
- All reported statistics are only for one-way middle-class home-based work trips.
- Distances traveled are calculated along shortest network paths using ArcMap 9.1, and provide a better approximation than centroid to centroid straight-line distance.

If Island Mumbai is considered the central business district or 'CBD', the Western and Eastern Suburbs as the first ring 'suburbs', and the Rest of the Region (RoR) as the 'periphery', then tabulating how many trips by travel mode started and ended in which of the three zones offers some insight into travel behavior. Table 3.3 presents this split for home-based work trips for the middle-class in the GMR, with each travel mode segment showing an association value using a Cramer's V statistic. A high Cramer's V indicates a high degree of trips within the zone, whereas a low value of the same indicates that trips by that mode were spread across other zones.

Home-based work trips using NMT and IPT (e.g., rickshaw) modes were largely CBD-CBD, suburb-suburb or periphery-periphery – the Cramer's V indicates very strong association.

Trips on buses or two-wheelers, or in cars were also largely within the same geography, with Cramer's V indicating strong association, but not as strong as that for NMT and IPT modes. Train trips, however, were more distributed across the GMR, with the highest (22%) being suburb-CBD, followed by 18% being RoR-CBD, 17% being RoR-Suburb, and 15% being Suburb-Suburb. Across all modes, there is relatively strong association for middle-class home-based work trips within the same geography, with a Cramer's V value of 0.493, indicating that localized travel is the norm in the GMR, but differences exist across travel modes.

TABLE 3.3 Home-Based Work Trips by Travel Mode between CBD, Suburbs and Periphery

Destinations →	**'CBD' / Urban Core**		**First Ring 'Suburb'**		**Urban 'Periphery'**		
	Island Mumbai		West / East Suburbs		RoR		
	N	Percent	N	Percent	N	Percent	Total
NMT (Walk, Bicycle) (Cramer's V=0.984*)**							
Island Mumbai	1,992	21%	14	0%	-	0%	2,006
West / East Suburbs	21	0%	2,955	32%	10	0%	2,986
RoR	5	0%	47	1%	4,274	46%	4,326
IPT (Taxi, Rickshaw, Shared van) (Cramer's V=0.881*)**							
Island Mumbai	81	6%	4	0%	-	0%	85
West / East Suburbs	17	1%	409	31%	7	1%	433
RoR	12	1%	21	2%	769	58%	802
Bus (Public, Company, Private) (Cramer's V=0.750*)**							
Island Mumbai	1,345	23%	199	3%	17	0%	1,561
West / East Suburbs	242	4%	2,312	39%	156	3%	2,710
RoR	61	1%	326	5%	1,271	21%	1,658
Train (Local, Long Distance) (Cramer's V=0.134*)**							
Island Mumbai	1,560	8%	1,094	6%	219	1%	2,873
West / East Suburbs	4,115	22%	2,916	15%	674	4%	7,705
RoR	3,389	18%	3,190	17%	1,733	9%	8,312
Two-Wheeler (Cramer's V=0.791*)**							
Island Mumbai	434	12%	72	2%	6	0%	512
West / East Suburbs	93	3%	982	28%	36	1%	1,111
RoR	32	1%	194	6%	1,671	47%	1,897
Car (Cramer's V=0.673*)**							
Island Mumbai	348	26%	46	3%	13	1%	407
West / East Suburbs	120	9%	391	30%	49	4%	560
RoR	19	1%	57	4%	281	21%	357
Overall (Cramer's V=0.493*)**							
Island Mumbai	5,760	14%	1,429	4%	255	1%	7,444
West / East Suburbs	4,608	11%	9,965	25%	932	2%	15,505
RoR	3,518	9%	3,835	10%	9,999	25%	17,352
Totals	13,886	34%	15,229	38%	11,186	28%	40,301

Further unpacking the finding that travel times are shorter to work locations in non-CBD zones across all modes (table 3.2), this section highlights how travel times vary by different modes in the various geographies. Table 3.4 reports mean travel times (in minutes), comprised of travel time and waiting time, by main mode of travel for home-based work trips to either of the CBD defined geographies – Island Mumbai or Greater Mumbai. Except for mean travel time by bus, which is significantly shorter in the CBDs, all other mean travel times are either almost equal between CBD and non-CBD locations or significantly shorter in the non-CBD locations.

Two tail T-tests conducted at α=0.01 show that the mean travel times for most modes between Island Mumbai and the rest of the GMR, as well as Greater Mumbai and the RoR are statistically different. This is true in all cases but for intermediate public transportation trips between Greater Mumbai and the RoR, and for car travel across the GMR.

TABLE 3.4 Mean Travel Time (In Minutes) by Main Mode of Travel for Home-Based Work Trips

	Island Mumbai as CBD			**Greater Mumbai as CBD**		
	Island Mumbai = 1	Rest of the GMR = 0	T-test (α=0.01) 2-tail	Greater Mumbai = 1	Rest of the Region = 0	T-test (α=0.01) 2-tail
NMT (walking, biking) is main travel mode	16	18	$t(3,813) = 9.154$, $p = 0.000$	17	18	$t(8,288) = 4.174$, $p = 0.000$
Intermediate public transportation mode (rickshaw, shared van, taxi) is main travel mode	32	25	$t(116) = 3.436$, $p = 0.001$	26	25	$t(1,318) = 1.268$, $p = 0.205$
Bus is main travel mode	38	43	$t(3,710) = 9.171$, $p = 0.000$	40	48	$t(1,881) = 10.202$, $p = 0.000$
Train is main travel mode	71	61	$t(18,829) = 24.569$, $p = 0.000$	66	60	$t(18,888) = 10.746$, $p = 0.000$
Two-wheeler is main travel mode	28	23	$t(732) = 4.935$, $p = 0.000$	28	19	$t(3,429) = 15.915$, $p = 0.000$
Car is main travel mode	34	33	$t(1,188) = 0.634$, $p = 0.526$	34	33	$t(479) = 0.810$, $p = 0.418$

Similarly, further exploring the finding in table 3.2 that travel distance across all modes is shorter to work locations in non-CBD locations than CBD locations, this section highlights how travel distance, calculated along street networks between TAZ centroids, varies by various modes for the different geographies. Since the network distances are not calculated between street addresses, there might be a slight overestimation of distance. Table 3.5 presents mean travel distance (in km) by main mode of travel for home-based work trips to the two CBD conceptualizations – Island Mumbai as CBD and Greater Mumbai as CBD. People walk / bike longer distances in non-CBD locations and ride farther on buses. On average, middle-class home-based work trips by car are longer to non-CBD locations.

Two tail T-tests conducted at α=0.01 show that the mean travel distances for most modes between Island Mumbai and the rest of the GMR, as well as Greater Mumbai and the RoR are statistically different. This is true in all cases but for intermediate public transportation trips between Greater Mumbai and the RoR, and for car travel across the GMR.

TABLE 3.5 Mean Travel Distance (in Kilometers) Along Networks by Main Mode of Travel for Home-Based Work Trips

	Island Mumbai as CBD			Greater Mumbai as CBD		
	Island Mumbai = 1	Rest of the GMR = 0	T-test (α=0.01) 2-tail	Greater Mumbai = 1	Rest of the Region = 0	T-test (α=0.01) 2-tail
NMT (walking, biking) is main travel mode	2.0	3.2	$t(3,711) = 13.966$, $p = 0.000$	2.6	3.3	$t(6,998) = 9.168$, $p = 0.000$
Intermediate public transportation mode (rickshaw, shared van, taxi) is main travel mode	11.4	5.3	$t(112) = 3.819$, $p = 0.000$	6.5	5.3	$t(799) = 2.365$, $p = 0.018$
Bus is main travel mode	7.0	9.9	$t(3,393) = 12.227$, $p = 0.000$	7.7	13.2	$t(1,828) = 17.298$, $p = 0.000$
Train is main travel mode	29.4	22.1	$t(16,918) = 29.878$, $p = 0.000$	26.2	22.2	$t(4,216) = 13.419$, $p = 0.000$
Two-wheeler is main travel mode	7.7	6.5	$t(703) = 2.988$, $p = 0.003$	7.8	5.6	$t(3,514) = 9.043$, $p = 0.000$
Car is main travel mode	9.2	9.6	$t(1,322) = 0.776$, $p = 0.438$	9.1	10.6	$t(451) = 2.345$, $p = 0.019$

Mean speeds were calculated by main travel mode using the formula speed equals network distance traveled along streets between TAZ centroids divided by travel time (not including waiting time). Table 3.6 shows comparisons for mean speed in (km / hr) across travel modes for the various CBD and non-CBD conceptions. Overall, train travel is speedier in the GMR both within and outside the urban core. Bus travel is slower by comparison, with the impact of urban core congestion evident in the lower mean bus speed in CBD. Travel speeds by IPT modes are higher in Island Mumbai as CBD, in comparison to Greater Mumbai as CBD. IPT travel consists of car-based taxis, which are the only IPT model allowed in Island Mumbai – rickshaws and taxis are both allowed in the Western and Eastern Suburbs. Therefore, higher speeds by IPT modes in Island Mumbai are a reasonable finding. Speeds for two-wheelers and cars are higher by private modes in the Rest of the Region.

Two tail T-tests conducted at α=0.01 show that the mean travel speeds for most modes between Island Mumbai and the rest of the GMR are statistically different, but for two-wheelers. The T-tests also confirm that mean travel speeds for NMT, bus, train, and car are significantly different between Greater Mumbai as CBD and the RoR. However, speeds are not different for travel by IPT and two-wheeler modes between these two geographies.

TABLE 3.6 Mean Speed (Network Distance / Travel Time in km / hr) by Main Mode of Travel for Home-Based Work Trips

	Island Mumbai as CBD			Greater Mumbai as CBD		
	Island Mumbai = 1	Rest of the GMR = 0	T-test (α=0.01) 2-tail	Greater Mumbai = 1	Rest of the Region = 0	T-test (α=0.01) 2-tail
NMT (walking, biking) is main travel mode	9.4	13.2	$t(2{,}604) = 5.714$, $p = 0.000$	11.1	13.9	$t(8{,}548) = 6.195$, $p = 0.000$
Intermediate public transportation mode (rickshaw, shared van, taxi) is main travel mode	20.9	14.4	$t(117) = 2.814$, $p = 0.006$	15.4	14.6	$t(1{,}318) = 0.871$, $p = 0.384$
Bus is main travel mode	12.2	16.1	$t(4{,}141) = 10.379$, $p = 0.000$	13.5	19.5	$t(1{,}844) = 10.885$, $p = 0.000$
Train is main travel mode	26.2	25.1	$t(18{,}847) = 5.128$, $p = 0.000$	25.4	26.7	$t(3{,}313) = 3.810$, $p = 0.000$
Two-wheeler is main travel mode	17.3	18.5	$t(3{,}518) = 1.019$, $p = 0.308$	17.7	19.0	$t(3{,}097) = 1.562$, $p = 0.118$
Car is main travel mode	16.0	19.2	$t(1{,}291) = 3.394$, $p = 0.001$	17.1	20.5	$t(510) = 2.758$, $p = 0.006$

3.3 SUMMARY AND POLICY DISCUSSION

This chapter showed that the GMR has middle-class employment concentrations in the traditional CBD of Island Mumbai, but also in the first ring Western and Eastern Suburbs. Employment tends to be concentrated along transportation corridors, both within Greater Mumbai, and in outlying nodes such as Thane, Navi Mumbai-CIDCO, Kalyan-Ulhasnagar and Bhiwandi. The chapter compared various metrics for socio-economics and transportation between Island Mumbai as CBD and the rest of the GMR, as well as between Greater Mumbai as CBD and the RoR. The socio-economic and travel indicators showed that commuters to work destinations in the urban periphery were at a disadvantage relative to their CBD going colleagues. Policies that create subsidies for transit-based trips to and within peripheral nodes should be considered.

The origin-destination trip percentages across zones suggested that train travel in the GMR enabled farther travel across zones. Adding capacity to key demand corridors would be an important strategy as demand grows for train-based trips from the periphery. Improvements to IPT modes, which constituted a large percentage (58%) of periphery-periphery trips, would be important. This could be achieved by making IPT modes efficient by setting and enforcing better service standards, per kilometer pricing and cross-zone licensing requirements. Since bus trips were focused within zones, it would be beneficial if there were improvements such as flexible service designs for bus travel within local geographies. Since 22% car-based work trips were interzonal, policy makers should consider cordon pricing strategies after further critical analysis.

Mean travel time, travel distance and speed by the various modes between the two defined sub-centers and peripheral geographies showed that train-based trips to CBD locations though longer in duration and distance were the fastest. Bus trips were longer for work destinations in peripheries, but travel by bus was faster in the urban peripheries. This suggests that system upgrades to the rail network and new investments in bus transit could improve transit travel time, thus containing some of the mode shift to private travel.

CHAPTER 4

Vehicle Ownership in Middle-Class Indian Households: Mobility in Mumbai

4.1 THE NEED FOR A PRIVATE VEHICLE

As median household incomes rise in India, discretionary spending in the consumption basket is going up, along with increases in transportation budgets. In particular, middle-class households are investing in private vehicles such as motorized two-wheelers (TWs) and cars. While these investments increase personal mobility, they also add negative externalities such as congestion, emissions, higher accident rates, and noise pollution.

This chapter explores the drivers of TW and car ownership in middle-class Indian households. The analysis is conducted using a household travel survey from the Greater Mumbai Region (GMR), where the unit of analysis is the household, using a discrete choice modeling framework. The choice set is households having (i) no vehicles, (ii) only TW/s, or (iii) at least one car. This chapter is organized as follows: In the following section, the need for private vehicles is discussed. In the second section previous work on mode choice and auto ownership in the urban Indian context is referenced. The third section then discusses the data used in the analysis of vehicle ownership, and presents a spatial analysis of vehicle ownership in the GMR. The fourth section presents the modeling framework (MNL), discusses the model structure, variables used in the model, and finishes with a detailed discussion of a choice model for vehicle ownership. The fifth section shows applications of the model using sample enumeration. The final section closes with a policy discussion.

4.1.1 Accessibility, Mobility and Travel Modes

The conceptual differences between accessibility and mobility are widely discussed in the literature (e.g., Lucas, Blumenberg, Weinberger (Eds.), 2011). Accessibility is a function of physical infrastructure plus affordable means of transportation to move people and their goods; thus, accessibility depends on physical nearness and mobility. Mobility is a “measure of the agency” that users have to move themselves or their goods (Bryceson, et al., 2003). This is dependent on a) how good the transportation system is plus the time and direction of the users’ travel needs, and b) the means available to the person e.g., public transportation modes (buses, trains, etc.), intermediate public transportation (IPT) modes (rickshaws, shared vans, taxis, etc.) or private transportation modes (TWs or cars, etc.), plus the knowledge of and affordability for travel options. The first component of mobility is about the effectiveness of the system in space, whereas the second is about the capacity of a person to use the system. Accessibility is about opportunity provided by transportation and land-use to engage in activities – it is not about behavior. Mobility is about behavior and consumer choice.

Costs and benefits of comparative modes in terms of travel times, monetary outlays, etc., for routine travel, relative to the incomes and other attributes of consumers, have a higher impact on the utility of vehicle ownership. However, the dataset used for analysis did not have information on comparative modes and monetary outlays. Thus, a reduced form conceptualization (Boarnet, 2011) is used in this dissertation, with life cycle variables such as marital status, age of wage earners in a household, number of children; socio-demographic variables such as education, occupation, income, type and size of housing unit; location variables such as where wage earners live and work; and other variables such as density of development, supply of transportation options, etc. All of these factors influence the choices individuals make for travel modes. Variables such as location and density are indirect proxies for the costs travelers face by different modes, and it is these capitalized costs that weigh in on vehicle ownership.

In many urban areas, access to opportunities for education and work is enhanced by the availability of public transportation options. Social and economic capital is generated with better networks. In metropolitan regions that lack public transportation options, private vehicle ownership allows for this improved mobility. However, the need for mobility is only one component in getting a household to own a motorized vehicle; many other factors drive households towards vehicle ownership. Most urban locations in the developing world do not have adequate biking and pedestrian infrastructure, or the mores that might keep non-motorized transportation users safe. Many urban dwellers in these regions also need to cover large distances to get to work, making non-motorized travel unlikely. In many city-regions in the developing world transit systems exist but are overcrowded, accident prone, noisy, unsafe (especially for children, women or older individuals), given to frequent break-downs, and infrequent. In the peripheral urban areas of metropolitan regions and small cities in the developing world, the public supply of transit is very limited. This need is filled up by IPT providers with rickshaws, shared rickshaw-like vehicles, shared vans, animal drawn carts, and a slew of other options. However, these IPT markets tend to be predatory and rarely provide well for the needs of low-income groups in the manner that well-designed transit markets might (Cervero and Golub, 2007, Vasconcellos, 2001). These low levels of service characteristics of the transit and IPT markets encourage individuals with growing incomes to segue into private vehicle ownership.

Vehicle ownership in a household has to do with the convenience of having a point-to-point means of mobility. In many emerging economies, national governments tacitly modulate policies to make vehicle ownership and use easy since motorization is a symbol of progress (Dimitriou, 2006). At a household level, there is some evidence of families choosing to own vehicles as status symbols (Banerjee, 2011, Gatersleben, 2011, Vasconcellos, 1997). In India’s case, the emerging vehicle market has low barriers to entry i.e., regulatory burdens such as licensing, emissions controls or insurance are fairly easy to circumvent, and financial markets provide low-interest loans making vehicle ownership even more affordable (see section 1.1.3).

There has been some recent analysis looking at vehicle ownership in the Indian household (next section). However, a framework that looks at the land use drivers for vehicle ownership along with socio-demographic factors has not been undertaken. Since rail transit has been the backbone of work commuting in Mumbai for decades, the GMR provides a special case for analyzing vehicle ownership. Compared to other Indian cities Mumbai easily has the best transit systems. Therefore, in theory, the need for vehicle ownership should be less for a Mumbai household. This chapter explores why given this reality on the ground, there is rapidly growing vehicle ownership in the GMR. It specifically asks the research question, what factors are driving vehicle ownership in middle-class households in the GMR for two-wheelers and cars?

4.2 VEHICLE OWNERSHIP AND TRAVEL BEHAVIOR RESEARCH ON INDIA

Banerjee, I. (2011) looked at Surat and considered how households might shift between TWs and cars, between various cars categories, and between new and used vehicles. She found that increasing per capita income and larger household size positively impact household vehicle holdings. Her research shows that larger households tend to prefer smaller vehicles, which are efficient in terms of use costs, allow for multiple passengers to ride, are easier to navigate in the congested network and park, and that vehicle price and use costs are significant variables explaining vehicle preference. Households in Surat that prefer cars and TWs are bigger, but households owning just cars tend to be smaller. Higher density negatively impacts ownership of mixed fleets (cars and TWs) in a households, but positively impacts car ownership in a household. A higher number of children in a household positively impact both mixed fleet and just car ownership.

Srinivasan, et al., (2007) analyzed household travel survey data from Chennai. In a longitudinal analysis, they found that cars ownership went up with peer pressure among friends (> 5 of 10 friends owning cars), peer pressure from neighbors (> 5 households of 10 owning cars), availability of a cell phone and credit card, home ownership, available car parking at home or nearby, and more women drivers in the household. But car ownership went down with peer pressure from TW ownership in the neighborhood (> 7 out of 10 persons owning TWs) and proximity to activity centers. TW ownership went up with more male and female drivers in the household, peer pressure amongst friends (> 7 of 10 friends owning a TW), and availability of a cell phone; but it went down with more peer pressure for car ownership amongst friends (> 5 of 10 friends owning a car), age, and presence of other motorized vehicles in the household.

In a comparative analysis, Banerjee, A. (2007) analyzed datasets from Thane in India, the National Household Travel Survey from the United States, and the Microcensus Travel Survey from Switzerland. He modeled travel time frontiers for mobile commuters and mobile non-commuters, defining travel time budget as an unobservable frontier that influences real travel time. His work has repercussions for travel behavior and mode choice. The model for Thane shows that travel time budgets for mobile commuters i.e., those who made at least one work related trip on the travel day and were over 18 years, went up with transit use, higher participation in activities per day, higher incomes, employment in the service sector, having a driver license, college education, household vehicle ownership, and number of children in the household. In Thane, commuters have a travel budget of about 2.5 hours, thus suggesting that as travel time worsens, commuters might engage in behaviors such as using private modes, working remotely, or finding work closer to home location to cut back on travel time.

Tiwari and Kawakami (2001) worked on a 1990 travel dataset for the Greater Mumbai Region (GMR), and estimated nested multinomial logit models that looked at household mode choices between bus, train, owned vehicle, and hired vehicle. Their work showed a very elastic private mode demand, indicating that increasing the pricing on private modes reduced their market share. The public travel mode share was inelastic, and higher pricing marginally reduced market shares. Generally, a substitution effect was observed between modes with higher pricing i.e., if one mode was priced higher, demand shifted to other modes. With higher incomes, the probability of commuting by private modes increased and public modes decreased. However, with increasing travel distances, mode choices shifted to private modes.

4.3 VEHICLE OWNERSHIP DATA AND SPATIAL DISTRIBUTION

4.3.1 Household Travel Survey Data

The data used for this chapter is from a household travel survey conducted between April 2005 and April 2006 in the GMR by the MMRDA. Along with various socio-economic and travel questions, the respondents were asked to complete a one-day travel diary. The complete dataset contains information on about 66,000 households, and represents a random 1.5% sample of the total population within the GMR (LEA International Limited, et al., 2008, unpublished report). Key features of this dataset are described in detail in sections 2.2, 2.3 and 2.4 in chapter 2.

4.3.2 The Spatial Distribution of Vehicle Ownership

Before developing an understanding of the various factors that might influence vehicle ownership in middle-class households in the GMR, it was important to figure out where households with cars and TWs were located. Figure 4.1 shows vehicles ownership rates (vehicles / 1000 persons) by Traffic Analysis Zone (TAZ) using proportional dots. The left graphic (with blue dots) shows car ownership rate, and the right graphic (with green dots) shows TW ownership rate.

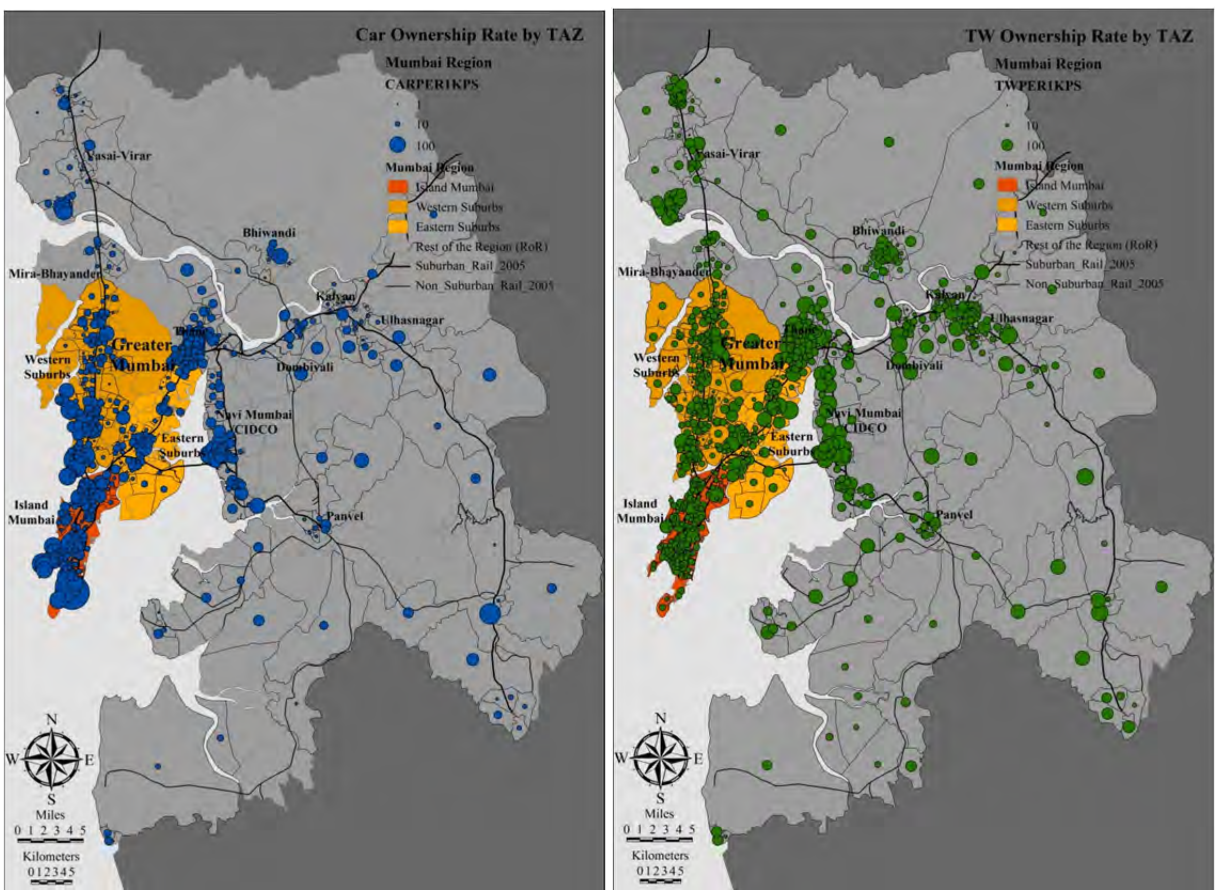

FIGURE 4.1 Cars (in blue) and motorized two-wheelers (in green) per 1000 persons in the Greater Mumbai Region (GMR).

Car owners are concentrated in the traditional CBD i.e. Island Mumbai, particularly towards the south and north-west of the sub-region. More affluent western suburbs, west of the railway line, tend to have higher concentrations of car owners, with a fair number of households in the north part of the western suburbs and in the eastern suburbs owning cars. Secondary cities such as Thane and Navi Mumbai have a high concentration of car ownership too, whereas outlying nodes such as Bhiwandi, Kalyan, Ulhasnagar and Panvel have a smaller car ownership pattern.

TW owning households are not only more plentiful, but also more spatially spread out. The green dots indicate households with TWs inhabiting most of the urbanized nodes in Greater Mumbai and RoR. In comparision to the car owning households, TW owning households are more spread out in Western and Eastern suburbs, and in major and minor nodes in the RoR. Intestingly, some rural locations in the GMR also tend to have a smattering of TW owning households.

4.4 MULTINOMIAL LOGIT MODEL (MNL) FOR VEHICLE OWNERSHIP

The modeling of discrete choices such as number and type of vehicle holdings in a household is best done through econometric techniques based on the theory of utility maximization. The idea is that households will maximize utility by choosing a certain alternative within a set of available alternatives, given socio-demographics, land use and other characteristics. Following Ben-Akiva and Lerman (1985) and Train (2003), this chapter presents a multinomial logit (MNL) model of type of vehicles owned in a household in Mumbai. The MNL is shown by,

$$P_n(i) = \frac{e^{\mu V_{in}}}{\sum_{j \in C_n} e^{\mu V_{jn}}} \quad \text{where,}$$

P_n = probability of a choice being made
n = indicator for decision maker
i = choice i
μ = the utility derived from a choice
V_{in} = systematic utility expressed as a function of observable variables
j = all available alternatives
C_n = choice set for decision maker n

The utility derived from any alternative is comprised of a systematic component V_{in} and a random component ε_{in}, and is generally shown by the expression $U_{in} = V_{in} + \varepsilon_{in}$ for all $i \in C_n$. The V_{in} is comprised of observable attributes such as socio-demographic characteristics of the decision maker as well as characteristics of the choice, such as price, land use, etc. The unexplained error term ε_{in} is assumed to be independently and identically distributed EV (extreme value) across alternatives and individuals; thus, leading to the MNL expression above.

In the modeling software used in this research, BIOGEME 2.0 (Bierlaire, M., 2010) robust statistics are reported and are shown in the model results (table 4.2).

4.4.1 Model Structure

In the cleaned up estimation dataset of 38,346 households, 81% (N=31,028) did not own any motorized vehicle, 14% (5,401) owned only motorized TW/s (but no car), and the remaining 5% (N=1,917) owned at least one car; some of the latter owned multiple cars and/or a car and one or more TW. Multiple model structures were tried including nesting by type and number of vehicles held by household. Particularly, in a more fine grain model, households were grouped by type and number of vehicles owned (see appendix 2 for a discussion of this model structure and lessons learnt). After running logsum checks on the nests, it became evident that the households in the lowest nests were not distinctly different, given the V_{in} used in the models. Consequently, the choice set C_n where households (i) owned no vehicles, (ii) owned only motorized TW/s, or (iii) owned at least one car (along with the possibility of motorized TW/s)) was used in the modeling (see figure 4.2). The results of this model are presented in this chapter, while appendix 3 presents further details from the model output.

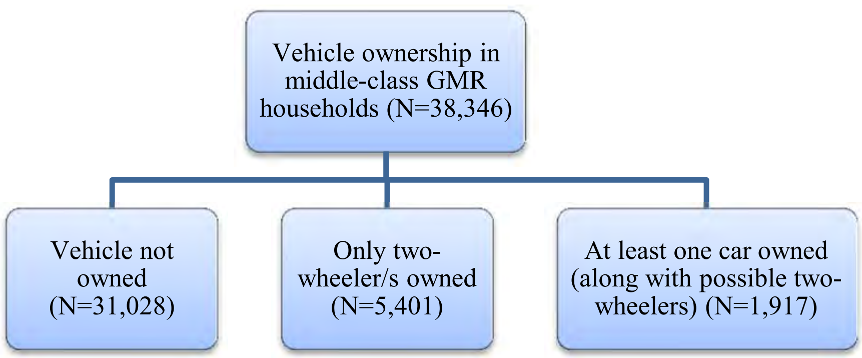

FIGURE 4.2 Vehicle ownership choice-set for the GMR.

For the purpose of this analysis, cars include all classes of privately held motorized four-wheelers including sedans, coupes, jeeps, mini-vans, and SUVs. TWs include all classes of privately held motorized two-wheelers including mopeds, scooters, and motorcycles (see section 1.1.3 for details on cars and TWs in India).

4.4.2 Variables Used

A variety of factors influence vehicle ownership in a household including life cycle, socio-demographic, travel characteristics, and other variables that have potential policy implications such as jobs and housing location, density, distance to transit, and trip start time. The model presented here used twenty-two explanatory variables exploring various facets of the factors affecting household vehicle ownership. Table 4.1 shows basic statistics for the variables used in the modeling including the mean, the standard error of the mean, the median, standard deviation, and the range for all interval and ratio variables. For dummy (nominal) variables, the mode is reported along with a percentage showing how many households reported the condition “1”.

Though some variables entered the model in the natural log form, e.g., per capita household income, they are reported in their regular form in this table to help the reader intuitively understand the nature of these variables.

TABLE 4.1 Variable Overview

Variable Category	Variable	Valid N	Missing	Mean	Std. Error of Mean	Median	Std. Deviation	Range	Mode	Valid Percent for "1"
Life cycle	Age of primary wage earner	36,513	1,833	47	0.06	46	12	94	45	
	Number of children in household up to (and including) 5 years	38,346	-	0.1	0.002	0	0.3	3	0	
	Marital status of primary wage earner (married=1, other=0)	36,513	1,833	-	-	-	-	-	1	89%
Socio-demographic	Educational attainment of primary wage earner (college education / technical diploma=1, other=0)	36,513	1,833	-	-	-	-	-	0	23%
	Occupational status of primary wage earner (full or part time / self-employed=1, other=0)	36,513	1,833						1	79%
	Per capita annual household income (₹)	38,346	-	36,111	125	30,000	24,369	535,263	22,500	
	Number of persons in the household	38,346	-	4.42	0.008	4	1.66	20	4	
	Type of residence (apartment / independent house=1, other=0)	38,346	-	-	-	-	-	-	0	44%
	Number of rooms	38,346	-	2.15	0.005	2	0.93	9	2	
	Sex of primary wage earner (male=1, female=0)	36,513	1,833	-	-	-	-	-	1	92%
Travel	Primary wage earner's number of trips from travel dairy	36,513	1,833	1.6	0.006	2	1.1	10	2	
	Network distance traveled for home-based trips from travel diary by primary wage earner in kilometers (km)	21,181	17,165	16.8	0.119	9.4	17.3	107	0	
Policy	Dummy for housing location (Island Mumbai=1, Suburban Mumbai or RoR=0)	38,346	-	-	-	-	-	-	0	17%
	Dummy for housing location (RoR=1, Greater Mumbai=0)	38,346	-	-	-	-	-	-	0	45%
	CBD dummy for primary wage earner's work location (RoR=1, Greater Mumbai=0)	38,346	-	-	-	-	-	-	0	33%
	Housing density (households / km^2) at housing location	38,346	-	12,010	91	6,315	17,855	145,311	17,355	
	Job density (jobs / km^2) at primary wage earner's work location	36,413	1,933	39,457	428	10,547	81,678	568,240	64,338	
	Euclidean (straight line) distance to nearest rail station (in km) from home location	38,346	-	1.58	0.01	1.12	2.01	25	1	
	Usual trip start time from home to work of primary wage earner between 8.31am and 10.30am (yes=1, no=0)	29,481	8,865	-	-	-	-	-	0	40%
	Usual trip start time from work to home of primary wage earner between 4.31pm and 7.30pm (yes=1, no=0)	29,481	8,865	-	-	-	-	-	0	40%
	Usual trip start time from work to home of primary wage earner between 7.31pm and 10.30pm (yes=1, no=0)	29,481	8,865	-	-	-	-	-	0	43%

The model presented in this chapter was run by fixing parameters for one of the alternatives, i.e., households not owning a vehicle, and comparing the utility derived from the other two choices – having only TW/s or at least one car. The utility equations had individual specific variables, as presented in table 4.1, rather than alternative specific variables.

4.4.3 Car and Two-Wheeler Ownership

A MNL vehicle ownership model was run and results across life cycle, socio-demographic, travel characteristics, and policy variables are discussed here. Table 4.2 reports parameter estimates for households that have at least one car, and households that have only two-wheeler/s (TW/s). Standard errors of the estimates and the t-values are also reported. The model outcome shows that overall 20,513 observations were used in the model, and the log-likelihood changed from the null model to the final model by about half.

Many of the variables used in the model had missing values. Particularly, 45% of the values for network distance traveled for home-based trips by primary wage earner were missing. These households were not used to estimate the model. Some households had missing information for primary wage earner's age, marital status, educational attainment, occupational status, number of trips, and sex. Some others were missing information on trip start times for the primary wage earners. Such households also were not included in the model. Overall, 53% of the households entered the model, yet with enough households to estimate a MNL model, this was not an issue.

4.4.3.1 Life-cycle Impacts

If the primary wage earner was married, it had significant positive impact on household vehicle ownership. The presence of young children (0 to 5 years) increased utility derived from cars and TWs – more so for cars. In the case of Mumbai, utility from car ownership increased marginally with the primary wage earner's age, but decreased slightly for TW ownership. This suggests that when a household buys a vehicle, TW ownership is preferred by younger people, whereas car ownership is preferred by slightly older people. This is likely indicative of buying power increasing with age, and other factors such as safety and travel comfort getting more significant at upper ages.

4.4.3.2 Socio-demographic Considerations

Those primary wage earners who had a college education or a technical diploma derived higher utility from car ownership, and to some extent from TW ownership, than those with less education, i.e., higher education makes positive contribution to the utility function. The full-time, part-time or self-employed occupational status of the primary wage earner predicted positive utility from TW ownership. Though the sign is positive for car owning households, the insignificance (p=0.11) is indicative of a breadth of employment options that can raise household earnings. Many of these sources are informal and/or innovative strategies, such as investing in the stock market from a home-based office, which do not fall into standard occupation categories.

Per capita annual household income is an excellent predictor of vehicle ownership. This model shows that utility from car ownership is high for higher income groups; it was positively linked to TW ownership too but did not have as high an impact. Utility from car ownership increases with the number of persons in the household, more so than in the case of TW/s. This makes intuitive sense given that very large households might find it difficult to travel on a TW.

If the housing type was an apartment or an independent house, the household derived very high utility from car ownership, much more so than from TW ownership. The positive sign on both of these coefficients is suggestive of households having 'arrived'; there are notions of status and higher buying power evident with apartment and independent house living. In Mumbai owning (or even renting) an apartment is as indicative of wealth as individual home ownership in other parts of the world. In a similar vein, households who had bigger houses, measured as greater number of rooms, derived higher utility from car ownership, more so than those that only owned TW. Primary wage earning males derived higher utility from TW ownership in comparison to car ownership.

4.4.3.3 Travel Impacts

If the primary wage earner made more trips in day, across all travel modes, the household derived slightly more utility from TW ownership, than car ownership. Typically, households that have members making more trips in a day tend to have lower per capita incomes, in comparison to those who make fewer trips (see tables 3.1 and 3.2). Many trips that the primary wage earner might undertake in more developed countries e.g., picking up groceries, are made by hired help in India. In TW only households, there is less buying power for outsourcing trips to others.

If the primary wage earner travels longer distances (calculated along the street network), the household's utility from vehicle ownership decreases – more so for TWs than for cars. Longer trips by private modes entail higher out-of-pocket operating expenses since the cost of gasoline relative to incomes is higher in India than, for example, in the United States. Not surprisingly, TW users are more negatively impacted by travel distance than car users. Further, very long trips are uncomfortable and unsafe given the severe traffic congestion. A select segment of primary wage earners nevertheless commute using a private vehicle for very long distances in the GMR. On average, however, primary wage earners who live farther from destinations such as work, tend to rely on public modes (see table 3.2).

4.4.3.4 Home and Job Location in the GMR, Density, Transit Proximity, and Other Considerations

Applying the spatial definitions that MMRDA utilizes in delineating the city-region, the model used dummy variables to show how housing location in Island Mumbai versus in Suburban Mumbai / Rest of the Region (RoR) impacted utility. Households located in Island Mumbai derive positive utility from car ownership. The housing in Island Mumbai tends to be the most expensive in the GMR, unless it is subsidized housing. Therefore, the positive utility from car ownership for Island Mumbai households may be reflective of high status households valuing cars regardless of the pressures that density can put on their use. However, TW ownership is high all over the GMR (see figure 4.1), hence, though positive, the coefficient for TW only households remains insignificant.

TABLE 4.2 Multinomial Model Outcomes for Vehicle Ownership

Variable Category	Variable	Estimates for households owning at least one car (along with possible TW/s)	Std Err	t-value	Estimates for households owning only TW/s	Std Err	t-value
	Constant	-25.6***	1.09	-23.5	-9.82***	0.627	-15.65
Life cycle	Age of primary wage earner	0.019***	0.0036	5.28	-0.00945***	0.00231	-4.08
Life cycle	Number of children in household up to (and including) 5 years	0.358***	0.117	3.05	0.228***	0.0645	3.54
Life cycle	Marital status of primary wage earner (married=1, other=0)	0.421**	0.184	2.29	0.157	0.0988	1.58
Socio-demographic	Educational attainment of primary wage earner (college education / technical diploma=1, other=0)	1.1***	0.0787	14.01	0.416***	0.0486	8.57
Socio-demographic	Occupational status of primary wage earner (full or part time / self-employed=1, other=0)	0.798	0.504	1.59	0.597***	0.207	2.89
Socio-demographic	Natural log of per capita annual household income	1.54***	0.0753	20.39	0.602***	0.0484	12.43
Socio-demographic	Number of persons in the household	0.346***	0.0248	13.92	0.176***	0.0163	10.77
Socio-demographic	Type of residence (apartment / independent house=1, other=0)	1.47***	0.107	13.69	0.327***	0.0497	6.59
Socio-demographic	Number of rooms	0.502***	0.0391	12.84	0.274***	0.0259	10.57
Socio-demographic	Sex of primary wage earner (male=1, female=0)	0.723**	0.283	2.55	0.895***	0.181	4.93
Travel	Primary wage earner's number of trips from travel dairy	0.133**	0.0607	2.2	0.215***	0.0341	6.3
Travel	Natural log of network distance traveled for home-based trips from travel diary by primary wage earner in kilometers (km)	-0.225***	0.0312	-7.22	-0.271***	0.0194	-13.94
Policy	Dummy for housing location (Island Mumbai=1, Suburban Mumbai or RoR=0)	0.55***	0.107	5.14	0.0355	0.0742	0.48
Policy	Dummy for housing location (RoR=1, Greater Mumbai=0)	-0.441***	0.0993	-4.44	0.395***	0.0613	6.44
Policy	CBD dummy for primary wage earner's work location (RoR=1, Greater Mumbai=0)	0.432***	0.111	3.88	0.158**	0.0671	2.35
Policy	Natural log of housing density (households / km^2) at housing location	0.0066	0.0298	0.22	-0.0555***	0.0163	-3.41
Policy	Natural log of job density (jobs / km^2) at primary wage earner's work location	-0.0598**	0.023	-2.6	-0.0717***	0.0134	-5.36
Policy	Natural log of Euclidean (straight line) distance to nearest rail station (in km) from home location	0.209***	0.0537	3.9	0.117***	0.0313	3.73
Policy	Usual trip start time from home to work of primary wage earner between 8.31am and 10.30am (yes=1, no=0)	0.225***	0.0744	3.02	0.108**	0.0439	2.46
Policy	Usual trip start time from work to home of primary wage earner between 4.31pm and 7.30pm (yes=1, no=0)	0.217*	0.121	1.79	-0.124**	0.0609	-2.04
Policy	Usual trip start time from work to home of primary wage earner between 7.31pm and 10.30pm (yes=1, no=0)	0.495***	0.121	4.09	-0.0502	0.0609	-0.82
Model Outcomes	Number of observations:	20,513					
Model Outcomes	Null log-likelihood:	-22,535.834					
Model Outcomes	Final log-likelihood:	-10,704.317					
Model Outcomes	Likelihood ratio test:	23,663.033					
Model Outcomes	Adjusted rho-square:	0.523					

Notes: 1) Estimated using the open-source software BIOGEME 2.0 (Bierlaire, M., 2010)
2) *** (p = 0.00), ** (0.00 < p ≤ 0.05), * (0.05 < p ≤ 0.1)

Another dummy compares housing location between the RoR and Greater Mumbai. The parameter estimates show that households located in the RoR have negative utility from car ownership, but positive utility from TW ownership. However, if the RoR was the work location for the primary wage earner, the household derived positive utility from both car and TW ownership, with greater utility from car ownership. This is a pertinent finding for the GMR which is seeing the suburbanization of jobs (see figure 3.1). Many jobs that are locating in urban peripheries create periphery to periphery commutes (see table 3.3).

At the housing location, higher housing density, calculated as households / km^2, implied lower utility from TW ownership; the car coefficient was insignificant. At the work location for the primary wage earner, utility derived from vehicle ownership was negative for higher job densities, calculated as jobs / km^2. Since travel options by transit modes are amply supplied in denser locations, utility of vehicle ownership is lower for these work locations.

There was no information on bus stops and other intermediate public transportation options available to households in the dataset. Compiling data on rail stations and using straight line distance from the centroid of the household's TAZ location to the nearest railway station, the model shows that the farther away a household was from the station location, the more utility it derived from vehicle ownership. In the case of Mumbai, transit networks are rich in denser areas, but options for travel rapidly decline in low density areas located farther from trunk lines. Car owners derive slightly higher utility in comparison to TW owners if they are located farther from transit, which is likely indicative of convenience, comfort and safety that car owners value.

If the primary wage earner started the home-based work trip during the am peak (between 8.31am and 10.30am), the household's utility from vehicle ownership increased – more so from car ownership than from TW ownership. For primary wage earner's work-based home trips by car in the primary pm peak (between 4.31pm and 7.30pm), or during the second extended pm peak (between 7.31pm and 10.30pm), utility from car ownership increased. However, utility for work-based home trips decreased for TW only households in the primary evening peaks.

This model does not capture feedback effects such as the possibility that more cars result in more congestion and nudge people towards two-wheelers, which are easier to maneuver in traffic. In reference to car-ownership in urban peripheries, it is likely that some households choose to have more two wheelers since they allow for shorter commute times (see tables 3.4, 3.5 and 3.6), and lower operating costs; this may also hold true in other dense locations. Also, the data used in these models likely under reports trips for informal work destinations, e.g., tutoring children, and weekend trips (see section 2.4). Similarly, the sample is biased towards male respondents, and though in Mumbai most primary wage earners are male, the use of this variable in the model could impact the results.

4.5 TWO-WHEELER AND CAR OWNERSHIP SENSITIVITY

In this section, a series of sensitivity analyses are presented using sample enumeration. For each of the graphs, all other variables predicting vehicle ownership for only two-wheeler and at least one car choice are held constant, but for the one being tested. The sensitivity analysis presented in figure 4.3 shows how the probability of vehicle ownership changes with increase in per capita annual household income. As incomes grow, all else being equal in the model, vehicle ownership will rise – much more rapidly for cars than two-wheelers.

Per capita income is a robust predictor of vehicle ownership. Though the percentage of households that would likely have a TW or at least one car is small in Mumbai today, the impact of growing income is evident in figure 4.3. In a city-region like Mumbai, which has good transit supply and a tradition of transit use, this finding is revealing, because even with a 200% hike in per capita income only 29% of households are predicted to have vehicles – leaving 71% of middle-class households without a private vehicle.

If the per capita annual household income mean was around ₹ 36,000 ($PPP 2,250 for 2006), then a household had a 6% probability of owning at least one car and a 15% probability of owning only two-wheelers. However, if mean income doubles ₹ 72,000 ($PPP 3,275 for 2011), then a household's probability of owning at least one car goes up to 11%, and the probability of owning only two-wheelers goes up to 18% (see table 1.1).

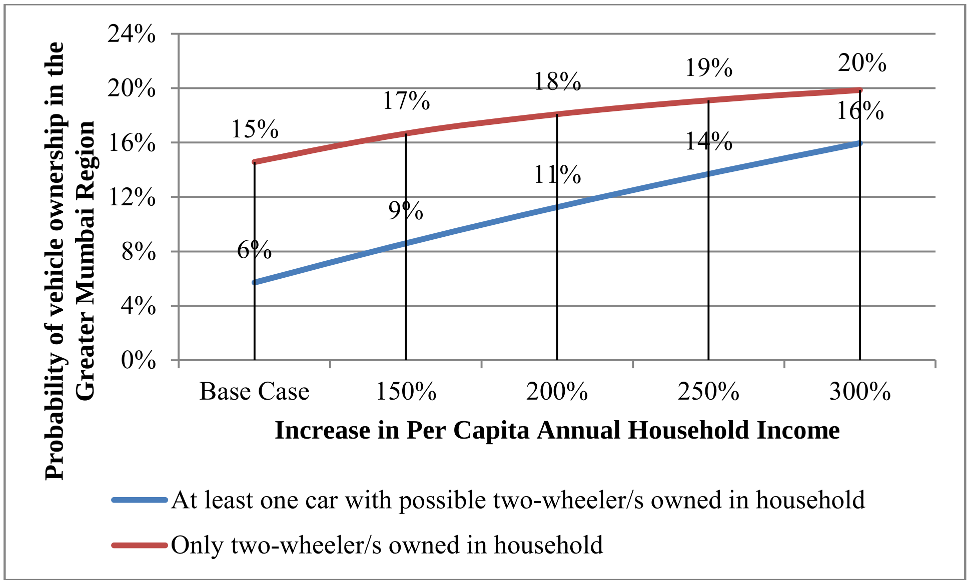

FIGURE 4.3 Sensitivity of vehicle ownership to per capita annual household income.

Figure 4.4 shows how additional number of trips will change vehicle ownership probability. This sensitivity looks at increased trips across all modes. There is a much more pronounced growth in two-wheeler ownership rates with growing number of trips. Car ownership remains roughly constant even with growing numbers of trips per day.

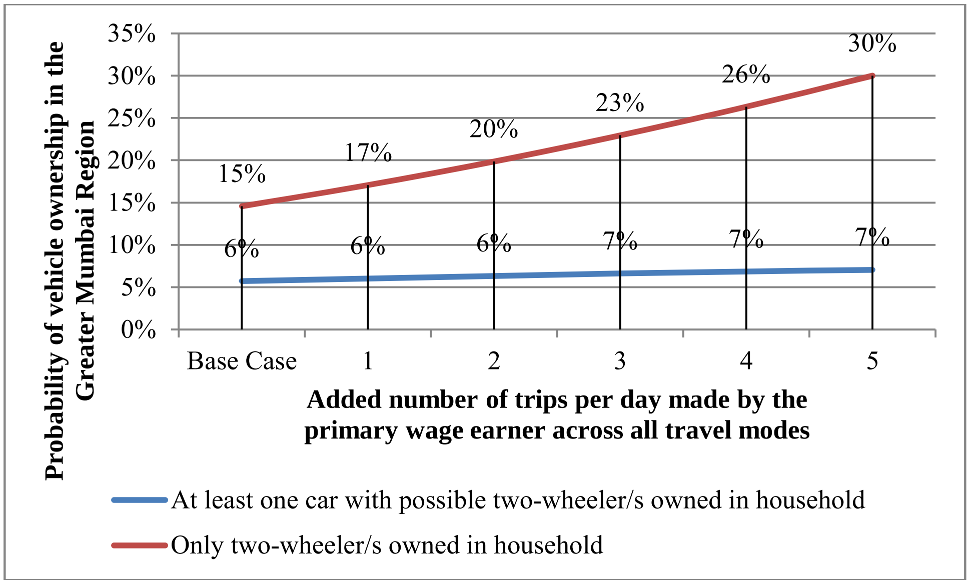

FIGURE 4.4 Sensitivity of vehicle ownership to additional number of trips made by the primary wage earner across all travel modes.

Figure 4.5 shows how vehicle ownership changes with distance of travel for the primary wage earner of the household. Two-wheeler ownership rates drop marginally the farther the primary wage earner travels from home, whereas car ownership rates remain mostly constant. Likely, operating costs enter the decision making process, and those in the emergent middle-class, who typically have only two-wheelers, are more impacted by distance.

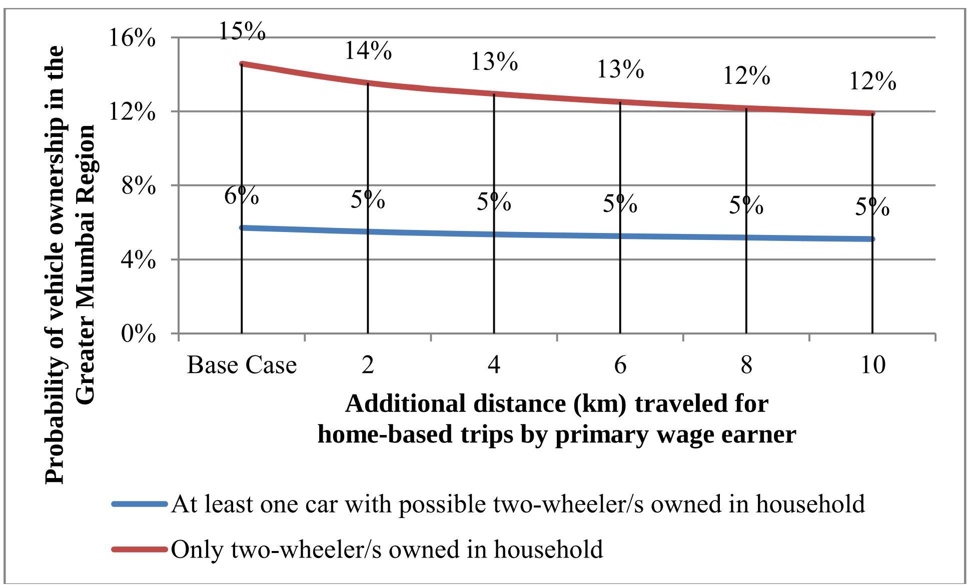

FIGURE 4.5 Sensitivity of vehicle ownership to additional distance (km) traveled for home-based trips by the primary wage earner.

Figure 4.6 highlights how distance to rail transit impacts vehicle ownership. On average, as distance to rail transit grows, there is a rise in the probability of two-wheeler and car ownership. Recall that the dataset did not have information on bus transit or intermediate public transportation modes such as rickshaws.

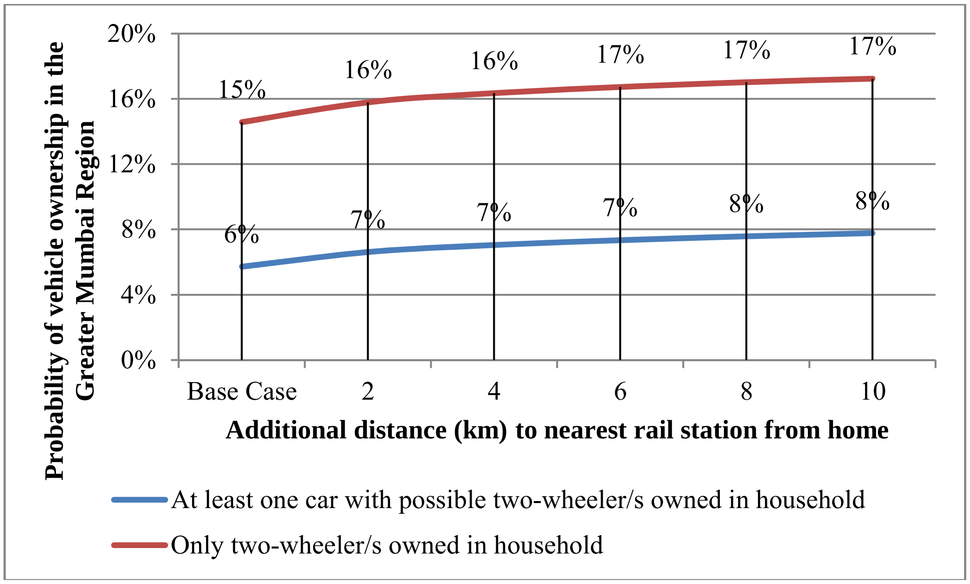

FIGURE 4.6 Sensitivity of vehicle ownership to additional distance (km) to nearest railway station from home location.

Figure 4.7 shows how vehicle ownership probability changes with increasing job density at the work location. As job density goes up, ownership rate for two-wheelers drops marginally. However, car ownership rates remain constant.

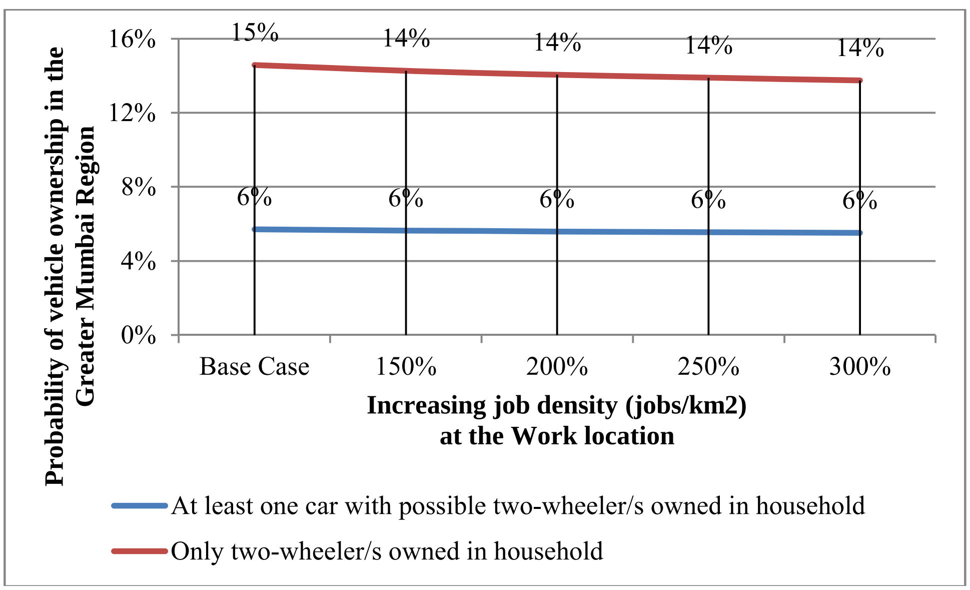

FIGURE 4.7 Sensitivity of vehicle ownership to increasing job density at the work location.

At the margin of vehicle ownership, changes from transit supply and density increases at work locations will contain two-wheeler growth. However, car ownership is mostly inelastic and will grow with rising incomes, all else begin equal.

4.6 POLICY DISCUSSION

The analysis illustrated the sensitivity of vehicle ownership not only to classic life cycle and socio-demographic variables, but also to land use variables such as density, proximity to transit, and jobs-housing locations in the GMR.

This analysis suggests that increasing the supply of transit should decrease the need for vehicle ownership. Though the model looked only at rail-based transit, further work on rubber-based transit and IPT modes should prove insightful. As densities for jobs and housing increase, the model suggests that vehicle ownership utility goes down. Therefore, land use policies that encourage managed agglomeration such as higher floor-area ratios should be considered.

Car owners who live in the urban core but work in the urban periphery derive positive vehicle utility. With other effective travel options provided, policies that look at cordon pricing might help contain some car travel. However, TW owners who live and work in the urban periphery derive higher vehicle utility, and policies for cordon pricing might not contain the expansion of TW markets for trips that are periphery to periphery. Adding and regulating other travel options such bus as IPT modes might reduce TWs in these peripheral locations.

Time of travel pricing strategies might help contain travel by private modes, especially in the morning peak since both car and TW owners derive positive utility from traveling during the morning rush hour. During the early hours of the evening peak, pricing car travel could be considered, after further analysis. Further, staggered working hours for certain kinds of jobs, especially in the service economy, might help lessen loads on the network.

CHAPTER 5

The Impact of Suburbanization on Car and Two-wheeler Use in Mumbai

5.1 TRANSPORTATION IMPACTS OF SUBURBANIZATION

Urban India is rapidly growing as people dream of better lives and move from villages and towns to cities. However, growth in areas within city municipal boundaries is often constrained due to regulations limiting higher floor-area ratios. Thus, much of the new growth follows transportation corridors outward to secondary centers, or 'escapes' to the urban peripheries, where existing small and medium towns become anchors for agglomeration. Often new growth in the periphery leapfrogs; with open spaces getting filled in over time. Many peripheral areas become bedroom communities for the working poor and emergent middle-class, yet are rarely supplied with adequate infrastructure such as roads or bus transit.

This chapter focuses on how the nature of suburbanization is affecting vehicle use in the Greater Mumbai Region (GMR). As incomes grow, vehicle regulatory burdens and user costs get lower, increasing households' willingness to use vehicles, especially for non-discretionary work trips. The lack of efficient travel options adds to the need for private vehicle use. Higher private vehicle use impacts quality of life issues such as time spent commuting, accident rates, noise pollution, air pollutants, and greenhouse gas emissions.

This chapter is organized as follows: In the following section, a short overview of suburbanization experiences in the developed and developing world cities is presented. The second section briefly discusses the data used, presents a spatial analysis of vehicle use in the GMR, discusses characteristics of private mode trips, and conceptualizes vehicle use as a dependent variable for analysis. The third section presents the model specifications as well as model findings for vehicle kilometer traveled (VKT) and person kilometer traveled (PKT) models for cars and two-wheelers. The fourth section closes with a policy discussion.

5.1.1 Suburbanization in the Developing and Developed World Cities

In the 1970s policy makers in India decided to encourage the de-congesting of cities, replicating practice from the developed world. With the view of encouraging new growth outside the congested core city, incentives such as higher floor-area ratio (FAR) were put into many municipal building codes for peri-urban areas, while constraining FAR to similar levels in city cores (Nallathiga, 2006, Bertaud and Brueckner, 2005). In the 40 years since then in most Indian cities, the urban periphery has experienced considerable development. Agglomerative centers are growing around existing small and medium towns in urban peripheries, but there are also instances of leapfrog development. Households with financial means build islands of affluence in suburbs with private infrastructure systems, thus forming gated communities. On the other hand, the suburbanization of the poor and marginalized to the fringes of metropolises in the contemporary Indian City constitutes the larger trend in suburbia formation. Most of suburbia is severely undersupplied with infrastructure, and the farther one moves away from employment sub-centers, there is a tendency for household incomes to fall (see table 3.1).

Therefore, metropolitan regions in India are going through a phase of "splintering urbanism" (Graham and Marvin, 2001). This nature of urbanization raises questions of social, economic and environmental equity. However, these concerns, with unequal distribution of public sector goods, along with the impact of suburbanization on vehicle use, are global. For example, Cervero and Day (2008) find similar concerns with equity and private mobility in Shanghai, whereas Cervero and Wu (1998) document how the suburbanization of the San Francisco Bay Area resulted in higher VMT. This connection between suburbanization, vehicle use and infrastructure is an appropriate site to locate scholarship on transportation sector greenhouse gas reductions (e.g., Winkelman, et al., 2010).

Suburban needs for transport are also severely under provided (Dimitriou and Gakenheimer, Eds., 2011). Most peri-urban locations do not have adequate bus transit for the households in these geographies. Thus, in a path dependent model, many households move from relying on unreliable intermediate public transportation such as a rickshaw to buying their first motorized two-wheeler. With growing incomes in the emergent middle-class, and with the lowering cost-barriers to entry for two-wheeler ownership, there is a large increase of mopeds, scooters, and motorcycles in India's suburbs. Over time, as members of households gain better access to opportunities for education and employment, incomes grow, household sizes shrink further, making car ownership an option (see figure 1.16).

This spatial aspect of growth of motorized two-wheelers and cars has not been looked at in any detail in the literature, although some work has examined paths toward motorization (e.g., Ni, et al., 2010, Weinert, et al., 2007). This chapter asks the research question, how do home / work location and land use interact with socio-demographic factors to drive car and two-wheeler use in middle-class households in the GMR?

5.2 VEHICLE USE IN THE GREATER MUMBIA REGION

5.2.1 Household Travel Survey Data

The data used for this chapter is from a household travel survey conducted between April 2005 and April 2006 in the GMR by the MMRDA. Along with various socio-economic and travel questions, the respondents were asked to complete a one-day travel diary. The complete dataset contains information on almost 66,000 households, and represents a random 1.5% sample of the total population within the GMR (LEA International Limited, et al., 2008, unpublished report). Key features of this dataset are described in detail in sections 2.2, 2.3 and 2.4 in chapter 2.

5.2.2 The Spatial Distribution of Vehicle Use

As documented in earlier chapters, the RoR is a large area with somewhat diffused urban agglomerations that are governed by various local bodies, and is composed of bedroom communities along with some nodes of industry and employment.

Figure 5.1 shows the spatial nature of private vehicle use in the GMR. Focusing only on the top quintile, shown by large blue circles, it becomes clear that the highest vehicle use is concentrated in Greater Mumbai along the transportation corridors, and in secondary cities such as Thane and Navi Mumbai. However, motorized two-wheeler (TW) use is much more ubiquitous, and shows up in all urban agglomerations – both within Greater Mumbai and outside. It is especially noteworthy that TW use follows the suburbanization of the region.

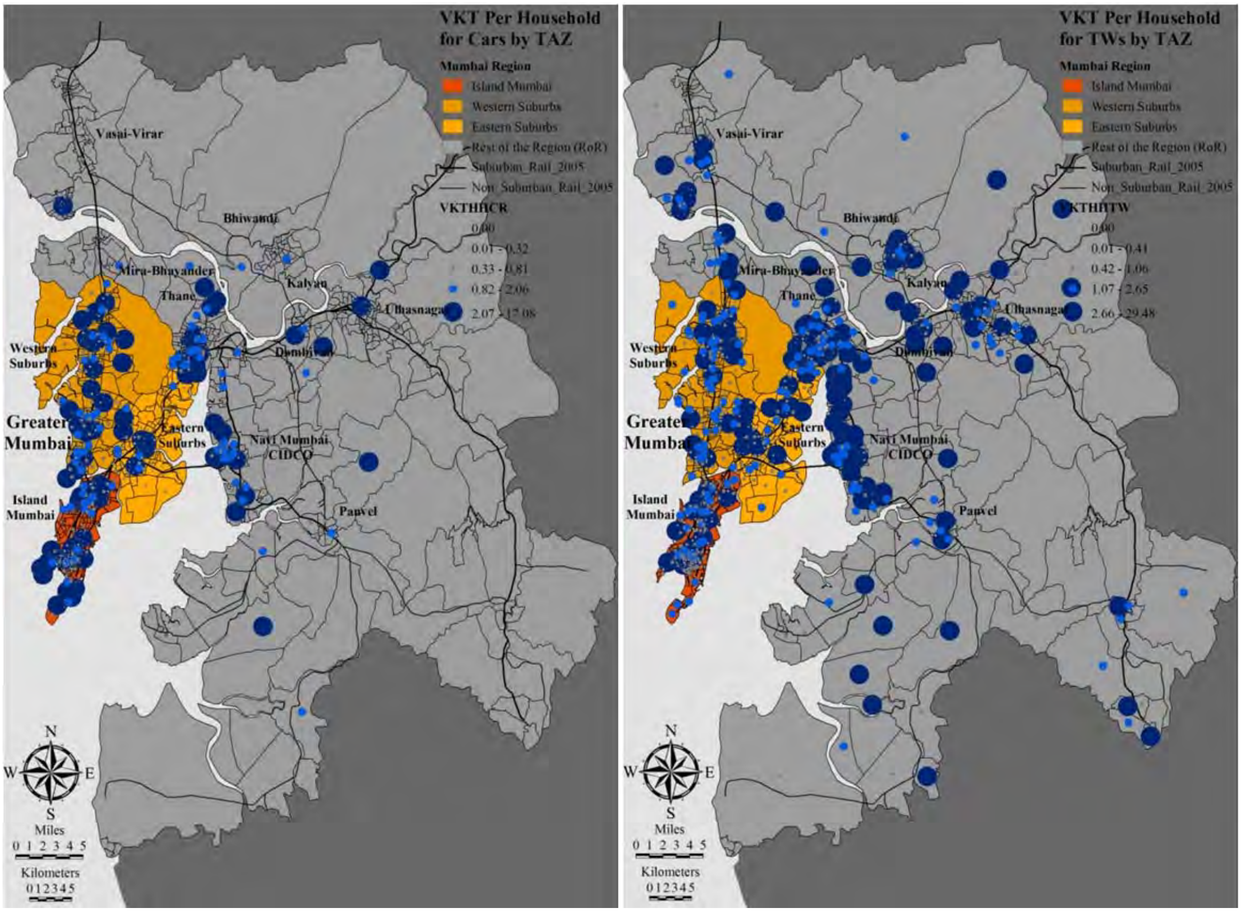

FIGURE 5.1 VKT per household for cars (left) and motorized two-wheelers (TWs) (right) in the Greater Mumbai Region (GMR); shown by household TAZ in quintiles, where large blue circles show top quintile.

5.2.3 Home-based Trips by Cars and TWs in the GMR

For the purpose of this analysis, private mode trips are all trips that were reported under four categories in the dataset, namely car (as driver), car (as passenger), two-wheeler (as driver), and two-wheeler (as passenger). Generally, cars include all classes of privately held motorized four-wheelers including sedans, coupes, jeeps, mini-vans, and SUVs. TWs include all classes of privately held motorized two-wheelers including mopeds, scooters, and motorcycles (refer to section 1.1.3 for details on cars and TWs in India).

The dataset reported 24-hour workday travel diaries for the household members. Of the total 182,586 trips that the middle-class made on a workday, 13,826 trips (7.6%) were made using a car or a two-wheeler where the trip maker was either a driver or a passenger. A little over 10% of these total private mode trips were non-work related, but were for school, shopping, recreation, etc. Therefore, the dataset reports that most of the trips were home-based work trips and work-based home trips. For this analysis, all trip purposes have been included since the research focus is on total household vehicle use. It is likely that some trips are underreported (see sections 2.3 and 2.4). For example, trips made running errands during a work day or casual trips for shopping may have been underreported. Therefore, the use variables constructed in this chapter should be interpreted with some caution, since they might underestimate vehicle use.

Figure 5.2 and table 5.1 show how the 13,826 trips are distributed by the four modal categories in which the data were collected. Only a fourth (26%) of the total private mode trips are by car, the rest three-fourths (74%) are by two-wheeler. Of the total mileage driven on a workday by the private modes, 34% (29,812 km or 18,524 miles) is by cars and 66% (57,591 km or 35,785 miles) is by TWs. In terms of total reported travel time, cars make up for 33% (1,816 travel hours), whereas TWs make up 67% (3,661 travel hours) in the GMR.

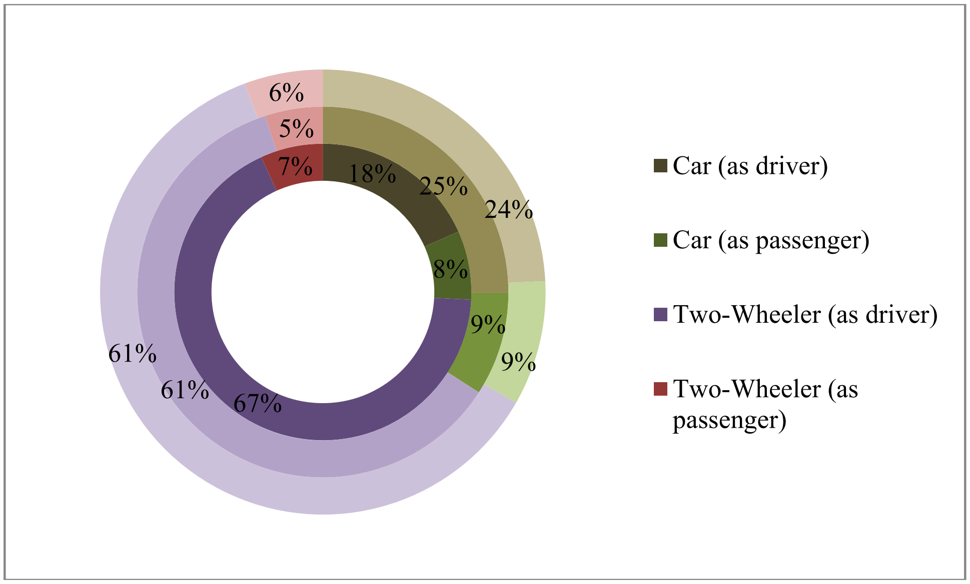

FIGURE 5.2 Private vehicle travel in the GMR – percent distributions, where inner circle shows trips across private modes, middle circle shows distance traveled (in km), outer circle shows hours traveled.

Table 5.1 highlights splits by the four modes in terms of number of trips, distance traveled (in km) and hours traveled. Within the two private mode categories driver-only trips are a large percentage; 71% for car trips and 91% for two-wheeler trips. Car travel tends to have more passengers than two-wheeler travel. This percentage split also generally holds true for the distance traveled and time traveled.

TABLE 5.1 Distribution of Trips, Distance Traveled and Hours Traveled by Private Mode

	Number of trips		Distance traveled (in km)		Hours traveled	
	Number	Percentage	Number	Percentage	Number	Percentage
Two-Wheeler (as driver)	9,316	91%	53,198	92%	3,348	91%
Two-Wheeler (as passenger)	941	9%	4,393	8%	313	9%
Two-Wheeler sub-total	10,257		57,591		3,661	
Per Two-Wheeler Trip			5.6		0.36 (21 minutes)	
Car (as driver)	2,531	71%	21,903	73%	1,329	73%
Car (as passenger)	1,038	29%	7,909	27%	497	27%
Car sub-total	3,569		29,812		1,826	
Per Car Trip			8.4		0.51 (31 minutes)	

Based on the preceding analysis, which looks at the spatial and total distribution of private mode travel in the GMR, it is possible to glean some patterns of private travel in the GMR. Two-wheeler trip makers are in all areas but tend to make shorter trips, whereas car trip makers are in the urban core areas and tend to make longer trips (also see tables 3.3, 3.4, 3.5). Yet, as the previous chapter shows, car ownership utility decreases with increasing distance of travel (table 4.2, figure 4.5). Another important highlight is the extent of single vehicle occupancy in the GMR, with two-wheelers mostly being driven without passengers.

5.2.4 Conceptualizing Vehicle Kilometers Traveled (VKT) and Person Kilometers Traveled (PKT) models for the GMR

Vehicle use can be understood in multiple ways including the amount of mileage that is put on a vehicle's odometer i.e., how far a vehicle travels for a given time period. Using this measure as the dependent variable translates into vehicle kilometers traveled (VKT) models for cars and two-wheelers in this chapter. Since the household is the unit of analysis for vehicle consumption, the dependent variable is the total sum of kilometers that all household members put on the owned vehicles in the two categories – cars and two-wheelers.

There is another approach to understanding vehicle use; how many person kilometers it logs in a given time period. Using this measure as the dependent variable translates into person kilometer traveled (PKT) models. Similar to VKT models, PKT models for cars and two-wheelers also use the total sum of all 'person miles' inclusive of driver and any other passenger/s in a household as the dependent variable. To illustrate the difference, if a vehicle is driven by the household's primary wage earner, but s/he also carries two passengers on this particular trip, VKT for that trip will be the street network distance traveled. However, PKT will be three times the street network distance traveled.

For the purpose of this analysis, only private mode VKT and PKT were analyzed. For an overall estimate of vehicle use all modes are considered, however, this research is about cars and TWs, and information on transit was not part of the data available. Each of these dependent variable measures becomes important for various kinds of policy framing. If there is a need for policies for single versus high-occupancy vehicle use and for understanding individual and household behavior, then a PKT model may provide a more fine-grain understanding of the contributing factors for vehicle use. If the models were going to inform policies for greenhouse gas emissions, then a VKT model could provide better information about what drives up vehicle use.

5.3 MODEL SPECIFICATION AND RESULTS

5.3.1 Model Specification

Since the focus of this analysis was to develop a better understanding of vehicle 'consumption' in the Indian middle-class, the modeling strategy involved identification of factors believed to explain the amount of vehicle use, such home and work location, socio-economic variables and trip characteristics. Specifically, the hypothesis was that travel consumption is a function of density of housing or jobs, location within the core or periphery of the metropolitan region, proximity to transit, occupational status of the primary wage earner, number of employed people in the household, per capita income, and some trip characteristics such as trip start time, speed, mode of travel, transportation budget, and primary wage earner's trips per day.

Only private vehicle use is factored in building the dependent variable since the unit of analysis is the household use of private vehicles. When the 13,826 private mode trips were aggregated by household, 5,101 households showed up that had some amount of car and/or two-wheeler use.

The specified models are log-log ordinary least squares regressions, where the dependent variable is the total sum of vehicle or person miles traveled in the household by car or two-wheeler. The coefficients of all independent variables, not including dummies, can be interpreted as elasticities. Separate models for the two modes are presented in the next section. The dataset had information on which Traffic Analysis Zone (TAZ) a household lived in, as well as the origin and destination TAZ information for each trip. Trip lengths were calculated by figuring out the shortest distance traveled between the origin and destination TAZ centroid on the street network. For trips that started and ended in the same TAZ, the area of the TAZ was used to compute the radius of an equivalent circle, which was used as the trip length.

Figure 5.3 shows various aspects of the physical environment, socio-demographic factors, and trip / travel characteristics that were used as independent variables to predict the workday use of cars or two-wheelers. The dataset reported person, work location and trip attributes of the primary wage earner of the household. Assuming that the primary wage earner will likely have sway over decisions regarding vehicle ownership and use in a household, their work location and trip characteristics for the home-based work trip were used as predictors of vehicle use. As discussed in section 5.2.3, given that most of the trips reported by private modes were work-trips, using the non-discretionary work trip as a predictive input for vehicle consumption seemed justified.

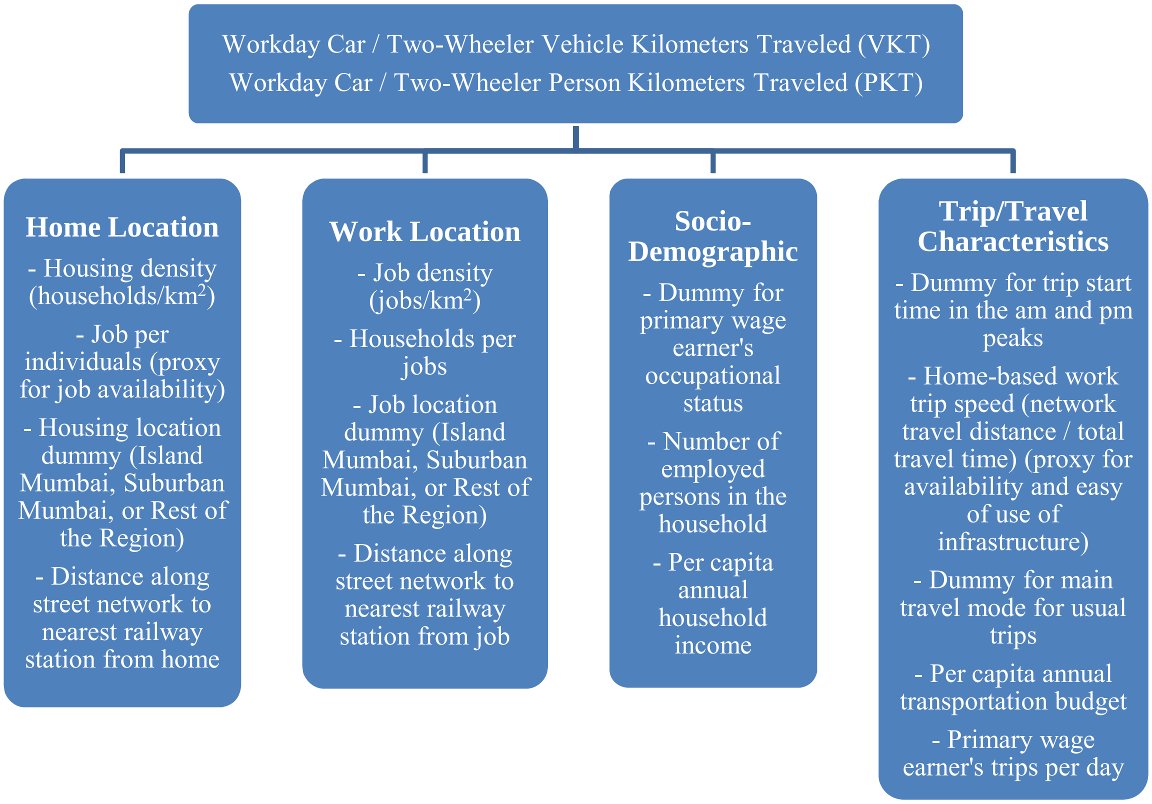

FIGURE 5.3 Factors affecting private vehicle VKT and PKT.

In a synthesis of the literature, Ewing and Cervero (2001) discuss the multitude of measures and attributes that have been used to understand the connection between the built environment and travel, and show that the interactions are highly complex. However, given the limitations of the data in hand, simpler measures were used to understand environmental attributes at home and work TAZs. For example, housing density (calculated as households / km^2) and job density (calculated as jobs / km^2) were used to explain the extent of agglomeration for housing and jobs. Various accessibility indices for jobs and housing were computed, based on reported trip ends in the dataset, but did not prove significant in the model. A land use dataset with variables showing retail, office, and housing built areas by TAZ might be better predictors, and might also help develop an understanding of how mixing of land uses impacts vehicle use. However, assembling such data was a task beyond the resources available for this dissertation.

Proximity of transit was measured by calculating the shortest street network distance from TAZ centroid to nearest railway station, since (a) the street network was not detailed enough to locate individual households, and (b) information on other forms of transit such as bus stops was not available. For a few of the very large TAZs, it is likely that these distances are erroneous, yet given that most of the private mode travel is in smaller TAZs, there is reasonable confidence in such a measure for proximity to transit.

Zegras (2010) used a variety of built environment variables to predict VKT in Santiago de Chile, and in the ordinary least square models also used the expected value of vehicle ownership from a logit model as a right hand side variable. To correct for the endogeneity, a selectivity bias correction factor was included. In the previous chapter on vehicle use in the Indian middle-class, a multinomial logit model on vehicle ownership for cars and two-wheelers was built. However, expected vehicle ownership and selectivity bias correction variables were not significant.

Using trip characteristics, which are endogenous variables, such as trip start time dummy and speed for the home-based work trips is a limitation of this analysis. However, given the lack of robust network data (capacity, uncongested speeds) in the dataset, and given that only the home-based work trip for the primary wage earner was used for these variables, their inclusion seems practical as a rough measure of availability and ease of use of the infrastructure. Other travel attributes such as usual main travel mode dummy, per capita annual transportation budget and primary wage earner's trips per day are not part of the trip diary, but come from a secondary linked dataset that reports person attributes. The results of the VKT and PKT models for car use and two-wheeler use are presented in tables 5.3.2 and 5.3.3 respectively.

5.3.2 Results of VKT and PKT models for Cars in the GMR

Table 5.2 shows car use models, where model 1 is the full VKT car use model and model 1.1 is a reduced model where speed for home-based work trip is not included. Similarly, model 2 is the full PKT car use model, while model 2.1 is the reduced model without speed as an independent variable. Appendix 4 presents detailed statistical outputs for all car and TW models discussed in this chapter.

At the home location, housing density is measured as households / km^2 and local job availability is measured as job per individuals. At the primary wage earner's work location, households per jobs is an indicator of balance between housing and jobs, and job density is measured as jobs / km^2. As density of housing or jobs increases at both the household location and the work location for the primary wage earner, car use decreases. As the balance between housing and jobs at the primary wage earner's work location gets better, and job availability at the housing location increases, car use goes down. Dense places have more urban amenities and the nature of mixed land use in Mumbai implies shorter trips.

If the GMR is divided into Island Mumbai, Suburban Mumbai and Rest of the Region (see figure 2.1), car users living in Suburban Mumbai tend to have higher VKT and PKT. However, primary wage earners who work in Island Mumbai tend to have higher VKT and PKT for cars. Those who live in Suburban Mumbai might access jobs at both ends, but those who work in Island Mumbai probably live outside the CBD and make trips south, increasing car use. However, this is only part of the story since proximity to other travel options such as transit is an important factor affecting vehicle use. In the GMR, as distance to a railway station from the primary wage earner's work location increases so does vehicle use.

Rising incomes signify higher money value of time and the need for creature comforts while traveling; both these needs are met in car travel. The earning potential of a household, measured as number of employed persons, tends to positively influence vehicle use; this is also true for per capita annual household income, though the coefficients are insignificant. These two measures seem to be similar but capture different notions of household income. Number of employed persons is a better measure of formal employment in Mumbai. However, per capita household income captures formal and informal income in a household (see section 2.4).

If the primary wage earner has a full time or part time job, or is self-employed, the vehicle use in the household goes up. This is an interesting variable, explaining vehicle use well, since those who are employed make more trips in Indian cities such as Mumbai. Particularly, those who are self-employed tend to run more errands during a 24-hour day, e.g., a self-employed interior designer might make multiple trips to vendors, client sites, and sub-contractors.

TABLE 5.2 Car Use Models (VKT and PKT)

Variable Category	Car Use Models	Workday Vehicle Kilometers Traveled (VKT)						Workday Passenger Kilometers Traveled (PKT)					
		MODEL 1			MODEL 1.1			MODEL 2			MODEL 2.1		
		Beta (Sig.)	Standard Beta	T-Statistic	Beta (Sig.)	Standard Beta	T-Statistic	Beta (Sig.)	Standard Beta	T-Statistic	Beta (Sig.)	Standard Beta	T-Statistic
	(Constant)	-1.18 (0.05)		-1.95	1.37 (0.15)		1.45	-1.00 (0.09)		-1.69	0.04 (0.04)		2.08
Home Location (at home TAZ)	Households per km^2 (housing density)	-0.07 (0.00)	-0.07	-3.24	-0.11 (0.00)	-0.12	-3.21	-0.07 (0.00)	-0.08	-3.41	-0.11 (0.00)	-0.12	-3.39
	Job per individuals (proxy for job availability)	-0.07 (0.01)	-0.06	-2.47	-0.21 (0.00)	-0.17	-4.78	-0.06 (0.04)	-0.04	-2.03	-0.19 (0.00)	-0.15	-4.46
	Dummy variable for household location (Suburban Mumbai = 1, Island Mumbai and Rest of Region = 0)	0.22 (0.00)	0.09	3.88	0.36 (0.00)	0.15	4.15	0.18 (0.00)	0.07	3.31	0.29 (0.00)	0.12	3.49
Work Location (at work TAZ)	Households per jobs	-0.10 (0.00)	-0.11	-4.28	-0.23 (0.00)	-0.24	-6.16	-0.10 (0.00)	-0.10	-4.26	-0.24 (0.00)	-0.24	-6.59
	Jobs per km^2 (job density)	-0.06 (0.01)	-0.08	-2.81	-0.12 (0.00)	-0.17	-3.80	-0.05 (0.01)	-0.07	-2.65	-0.12 (0.00)	-0.17	-4.06
	Dummy variable for job location (Island Mumbai = 1, Suburban Mumbai and Rest of Region = 0)	0.21 (0.00)	0.08	2.96	0.01 (0.86)	0.01	0.18	0.24 (0.00)	0.09	3.34	0.00 (0.97)	0.00	0.03
	Distance along street network to nearest railway station	0.06 (0.09)	0.04	1.70	0.32 (0.01)	0.13	2.82	0.07 (0.06)	0.05	1.87	0.29 (0.01)	0.11	2.66
Socio-Demographic	Number of employed persons in the household	0.28 (0.00)	0.11	4.89	0.18 (0.05)	0.07	1.95	0.56 (0.00)	0.21	10.03	0.49 (0.00)	0.18	5.70
	Per capita annual household income (in ₹)	0.04 (0.38)	0.02	0.88	0.05 (0.52)	0.02	0.64	0.03 (0.54)	0.01	0.61	0.03 (0.66)	0.02	0.44
	Dummy for primary wage earner's occupational status (1=Full / part time job or self-employed, 0=Other)	0.65 (0.03)	0.05	2.17	0.28 (0.56)	0.02	0.59	0.58 (0.06)	0.04	1.87	0.24 (0.61)	0.02	0.51
Trip / Travel Characteristics	Main mode for usual trip (1=Private modes, 0=Other modes)	0.15 (0.04)	0.05	2.12	0.14 (0.19)	0.05	1.33	0.21 (0.00)	0.07	3.27	0.25 (0.01)	0.08	2.52
	Per capita annual transportation budget	0.07 (0.12)	0.04	1.55	0.13 (0.08)	0.07	1.76	0.08 (0.06)	0.04	1.92	0.11 (0.11)	0.06	1.59
	Speed (network travel distance / total travel time) (proxy for availability and ease of use of infrastructure)	0.93 (0.00)	0.75	34.32	-	-	-	0.92 (0.00)	0.73	35.09	-	-	-
	Dummy for usual trip start time for work of primary wage earner between 7.31am and 10.30am (Yes=1, No=0)	0.14 (0.04)	0.04	2.05	0.20 (0.07)	0.06	1.84	0.07 (0.33)	0.02	0.98	0.11 (0.27)	0.04	1.10
	N (Households)	809			809			910			910		
	R^2	0.65			0.12			0.64			0.14		

Car use goes up if the individual reported that s/he travels in a private mode for usual trips (not the travel day diary). Though circuitous, this variable shows that higher use of any privately owned mode signifies higher car use. As the per capita annual transportation budget of the household increases, so does vehicle use. This variable includes costs for all forms of travel including bus, rail, shared cabs, rickshaws, two-wheelers and cars. Car users who start the usual morning trip between 7.31 am and 10.30 am have higher VKT and PKT.

Speed was calculated as the shortest network travel distance divided by the total travel time reported for the home-based work trip of the primary wage earner. This variable has the highest explanatory power for the models, and is positively related with vehicle use. Higher speeds are used here as a rough proxy for quality and the ease of use of infrastructure – better infrastructure quality drives up car use. The speed variable suggests that the effectiveness of private travel clearly impacts extent of car use (also see table 3.6).

In table 5.2 the second set of car use models for VKT (model 1.1) and PKT (model 2.1) drops this variable to test for sign constancy and relative impacts of the remaining variables. Though explanatory power gets distributed over the remaining variables, the signs hold for all remaining independent variables, though significance falls for a few variables.

5.3.3 Results of VKT and PKT models for Two-Wheelers in the GMR

Table 5.3 shows two-wheeler (TW) use models, where model 3 is the full VKT TW use model and model 3.1 is a reduced model where speed for home-based work trip is not included. Similarly, model 4 is the full PKT TW use model, while model 4.1 is the reduced model without speed as an independent variable.

The availability of other travel options such as transit can be an important factor for discouraging vehicle use. In the GMR, the closer a household is to a railway station the less it uses a TW. Unfortunately, there was no information on bus networks in the dataset; the explanatory power of this variable will potentially go up if such information were available.

Similar to the car use models, at the home location, housing density is measured as households / km^2 and local job availability is measured as job per individuals. At the primary wage earner's work location, households per jobs is an indicator of balance between housing and jobs, and job density is measured as jobs / km^2. As density of housing or jobs increases at both the household location and the work location for the primary wage earner, TW use decreases. As the balance between housing and jobs at the primary wage earner's work location gets better, TW use goes down. The coefficient is positive but insignificant for job availability at home location. For TW owners, who tend to live all across the GMR, the co-location of jobs and housing might not necessarily mean that the best jobs are available near the home location. Therefore, in spite of plenty of jobs at the home location, travel on TW might go up if it is undertaken to get to another preferred location. This is interesting because many of the new TW owners are young professionals entering the service sector of the economy.

TABLE 5.3 Two-Wheeler Use Models (VKT and PKT)

Variable Category	Two-Wheeler Use Models	Workday Vehicle Kilometers Traveled (VKT)						Workday Passenger Kilometers Traveled (PKT)					
		MODEL 3			MODEL 3.1			MODEL 4			MODEL 4.1		
		Beta (Sig.)	Standard Beta	T-Statistic	Beta (Sig.)	Standard Beta	T-Statistic	Beta (Sig.)	Standard Beta	T-Statistic	Beta (Sig.)	Standard Beta	T-Statistic
	(Constant)	-0.16 (0.60)		-0.53	1.09 (0.00)		2.42	-0.08 (0.81)		-0.25	1.17 (0.01)		2.59
Home Location (at home TAZ)	Distance along street network to nearest railway station	0.07 (0.00)	0.04	3.10	0.04 (0.24)	0.02	1.17	0.07 (0.00)	0.05	3.26	0.04 (0.23)	0.02	1.21
	Households per km^2 (housing density)	-0.08 (0.00)	-0.10	-6.56	-0.10 (0.00)	-0.14	-5.99	-0.07 (0.00)	-0.09	-5.78	-0.09 (0.00)	-0.12	-5.54
	Job per individuals (proxy for job availability)	0.02 (0.20)	0.02	1.29	-0.19 (0.00)	-0.13	-7.06	0.02 (0.19)	0.02	1.32	-0.19 (0.00)	-0.13	-7.09
	Dummy variable for household location (Island Mumbai = 1, Suburban Mumbai and Rest of Region = 0)	0.08 (0.10)	0.02	1.63	0.10 (0.18)	0.03	1.34	0.07 (0.19)	0.02	1.33	0.08 (0.29)	0.02	1.07
Work Location (at work TAZ)	Households per jobs	-0.10 (0.00)	-0.09	-6.43	-0.26 (0.00)	-0.23	-11.67	-0.10 (0.00)	-0.09	-6.19	-0.26 (0.00)	-0.23	-11.56
	Jobs per km^2 (job density)	-0.05 (0.00)	-0.08	-5.07	-0.06 (0.00)	-0.10	-4.34	-0.05 (0.00)	-0.08	-5.34	-0.07 (0.00)	-0.10	-4.56
	Dummy variable for job location (Suburban Mumbai = 1, Island Mumbai and Rest of Region = 0)	0.28 (0.00)	0.11	8.35	0.42 (0.00)	0.17	8.77	0.25 (0.00)	0.10	7.66	0.40 (0.00)	0.16	8.28
Socio-Demographic	Number of employed persons in the household	0.21 (0.00)	0.08	6.22	0.18 (0.00)	0.07	3.65	0.33 (0.00)	0.12	9.90	0.30 (0.00)	0.11	6.02
	Per capita annual household income	-0.07 (0.03)	-0.03	-2.19	-0.10 (0.03)	-0.05	-2.17	-0.08 (0.01)	-0.04	-2.59	-0.12 (0.01)	-0.06	-2.68
Trip / Travel Characteristics	Main mode for usual trip (1=Private modes, 0=Other modes)	0.16 (0.00)	0.06	4.99	0.07 (0.15)	0.03	1.46	0.24 (0.00)	0.09	7.29	0.14 (0.00)	0.06	3.03
	Primary wage earner's number of trips per day	0.45 (0.00)	0.09	7.40	0.29 (0.00)	0.06	3.29	0.43 (0.00)	0.09	7.07	0.28 (0.00)	0.06	3.11
	Per capita annual transportation budget	0.17 (0.00)	0.09	6.05	0.28 (0.00)	0.14	6.64	0.17 (0.00)	0.09	6.06	0.30 (0.00)	0.15	7.09
	Speed (network travel distance / total travel time) (proxy for availability and ease of use of infrastructure)	0.79 (0.00)	0.72	55.89	-	-	-	0.79 (0.00)	0.72	55.79	-	-	-
	Dummy for usual trip start time from work to home for primary wage earner between 4.31pm and 7.30pm (Yes=1, No=0)	0.15 (0.00)	0.06	5.01	0.22 (0.00)	0.09	4.94	0.12 (0.00)	0.05	4.02	0.19 (0.00)	0.08	4.20
	N (Households)	2,684			2,684			2,729			2,729		
	R^2	0.60			0.13			0.59			0.13		

If the GMR is divided into Island Mumbai, Suburban Mumbai and Rest of the Region, TW users living in Island Mumbai seem to have higher VKT and PKT; however, the significance of this variable is generally low. Primary wage earners who work in Suburban Mumbai tend to have higher VKT and PKT for TWs. Many locations in Suburban Mumbai are not conveniently located near the highways or rail corridors. For those wage earners making trips to such locations, TW use will likely go up. Also, those who live in Suburban Mumbai might work in Island Mumbai and the Rest of the Region.

The earning potential of a household, measured as number of employed persons, tends to positively influence TW use. This variable only reflects formal employment, whereas per capita income reflects both formal and informal sector employment (see section 2.4 on a discussion on informality). TW use is negatively linked with per capita annual household income. This suggests that when other travel options are limited, households at the margin of accruing benefits from private mobility start using TWs, or that as incomes grow higher, TW use drops.

If the primary wage earner reported using any privately held vehicle for usual trips, then they had higher VKT and PKT. This is indicative of higher TW use in households who might own a fleet of vehicles. Related is the primary wage earner's number of daily trips by any travel mode; as this number goes up, the TW use of the household increases.

As the per capita annual transportation budget of the household increases, so does vehicle use. This is an interesting variable because it includes costs for all forms of travel including bus, rail, shared cabs, rickshaws, two-wheelers and cars. TW users who start the usual evening trip between 4.31pm and 7.30pm have higher VKT and PKT. Higher TW use can come from longer trips undertaken to get back home, and some extent of trip chaining to run errands before heading home for the day.

Speed was calculated as the shortest network travel distance divided by the total travel time reported for the home-based work trip of the primary wage earner. Higher speeds are used here as a rough proxy for quality and the ease of use of infrastructure – better infrastructure quality drives up TW use. The speed variable suggests that the effectiveness of private travel clearly impacts extent of TW use (also see table 3.6). However, the second set of TW use models for VKT (model 3.1) and PKT (model 4.1) removes this variable to test for sign constancy and relative impacts of remaining variables. The behavior of the other independent variables generally holds.

5.4 POLICY DISCUSSION

The vehicle use models show that policies encouraging well-managed urban agglomeration, through higher floor-area ratios, both at the home and work locations, should results in lower vehicle use. Further, the models show that a mix of jobs and housing results in lower vehicle use. Thus, single-use zones or special economic zones might need rethinking, and better planning of jobs and housing in the same location should bring down vehicle use. This could be achieved through minimum mix ratios for retail, office, and residential space.

The models suggest that policies encouraging transit at work and hosing locations should be encouraged. Unfortunately, data on transit modes such as buses, and other modes such as rickshaws and shared vans were not available for this research. At the work locations, if densities justify it, high capacity services such as bus-rapid transit systems, or rail might cut down private travel. At home locations, which may not have very high densities, feeder systems to trunk-line transit systems in the form of regular buses, and well-regulated and efficient IPT modes should be encouraged.

Finally, the car use models suggest that time-of-day and cordon road pricing strategies could manage cars entering Island Mumbai. However, since this dummy is insignificant for the PKT models, such cordon pricing would ideally be designed after further careful analysis – particularly if the strategy also involves incentives for carpools. Work place strategies such as staggered work times or remote working may also work in certain service sector jobs, and could help manage peak hour travel demand.

Chapter 6

Conclusions

6.1 OVERVIEW

Changes in the nature of employment in urban India together with land use controls have resulted in the creation of employment concentrations in downtown and peripheral nodes. Econometric models run with data from the Greater Mumbai Region (GMR) show how sub-center formation and lack of travel options, coupled with better education, service sector jobs, and higher incomes, is racking up demand for private vehicles. Much of the emergent middle-class is driven first to buy motorized two-wheelers (TWs) due to lack of travel options in the periphery of Greater Mumbai. As households get used to having TWs, the shift to car ownership becomes a matter of time and question of affordability, making the shift back to transit difficult.

The analyses presented in this dissertation were carried out at a disaggregate household level using a dataset from the Greater Mumbai Region (GMR) from which middle-class households were extracted. The dataset allowed an examination of motor vehicle ownership and use among the Indian middle-class, in the context of a city-region that has a long history and culture of transit use, both rail and bus. The mode split for emergent and established middle-class trips analyzed in this research shows that 50% of the sample walked or biked, 25% used rail, 13% traveled by bus; only 6% used TWs, 4% used intermediate public transportation (IPT) modes such as rickshaws, and 2% used cars. Thus, most emergent and established middle-class people in the GMR walk or bike or use transit for the trips they make. Nevertheless, the impacts of the 8% using personal motorized transport are substantial, and the motorization rate is growing rapidly.

This dissertation has examined three research questions to better understand why the middle-class in India is increasingly driven to buying and using cars and TWs:

(1) How does work location influence travel by public and private modes?
(2) What factors encourage vehicle ownership in middle-class households?
(3) What factors drive up vehicle use in middle-class households?

The 38,352 middle-class households used in this research made 40,301 interzonal home-based work trips, which were used to analyze work location's influence on travel by public and private modes. This was done by comparing trips that ended in a work destination either in just Island Mumbai, or in all Greater Mumbai – both of which act as sub-centers. Socio-economic and transportation indicators were compared for trip destinations in sub-centers versus the remaining areas of the GMR, and T-test (α=0.01, 2-tail) were used to examine how different indicator means were across the samples. To analyze vehicle ownership choice, a multinomial logit model used 20,513 households, who either had no vehicles, only TW/s (but no car/s), or at least one car (along with the possibility of TW/s). Vehicle use was analyzed using the 5,101 households, whose members made trips on TWs or in cars. These were log-log ordinary least square models for vehicle kilometers traveled (VKT) and person kilometers traveled (PKT).

6.2 RESEARCH FINDINGS FROM THE GREATER MUMBAI REGION (GMR)

6.2.1 Work Location and Travel

Spatial analysis shows that Island Mumbai, with its high concentration of jobs, acts as a traditional CBD, as does the Greater Mumbai region, which includes Island Mumbai plus the Western and Eastern Suburbs. According to this conception, Island Mumbai as CBD attracts 31% (1 million) of the total middle-class work related trips in the region, whereas Greater Mumbai as CBD attracts 67% (2.3 million) of the total middle-class work related trips in the region. However, the 0.6 million middle-class work related destinations in the urban periphery are interesting from a policy perspective not only because they are growing rapidly, but also because these areas tend to have appreciably lower supply of travel options.

Middle-class commuters to peripheral job destinations came from larger households, with more earning members, with lower incomes, and less education. They had lower transportation budgets but higher out-of-pocket trip costs, and had few cars but more TWs. Commuters going to these locations in the periphery of Greater Mumbai tended to make more home-based work trips in a day, though they traveled shorter durations and distances than their counterparts traveling to destinations in Greater Mumbai.

Travel mode share between zones comprised of Island Mumbai as CBD, Western / Eastern Suburbs as first ring suburbs, and RoR as the urban periphery showed that most walk / bike trips and IPT trips were intrazonal. Trips by cars, TWs, and buses were not as concentrated within zones, whereas train travel in the GMR was largely interzonal.

6.2.2 Vehicle Ownership

The spatial analysis of vehicle ownership shows that car ownership rates are highest in Island Mumbai and the Western Suburbs, the southern part of the Eastern Suburbs, and in secondary nodes such as Thane and Navi Mumbai-CIDCO. TW ownership is more spatially spread out, with high concentrations along the transportation corridors in Greater Mumbai, and in outlying nodes such as Thane, Navi Mumbai-CIDCO, Kalyan-Ulhasnagar, Bhiwandi, Vasai-Virar, and Panvel. Within the middle-class households used in the logit model, 6% households had at least one car, 15% had only TW/s, and the remaining 79% had no vehicles.

Car ownership utility increased with per capita income, housing type (independent house / apartment), primary wage earner being male, college educated, employed, and married. Utility increased with bigger housing size, the presence of children under 5, more people in the household, housing location in Island Mumbai, but work location in the urban periphery, the primary wage earner making the home-based work trip between 8.31 am to 10.30 am, the work-based home trip between 7.31 pm and 10.30 pm, and with household location farther from a rail station. Car ownership utility decreased if the housing location was in the urban periphery, if job density at work location was higher, and for longer home-based trips.

TW ownership utility increased with per capita income, if the primary wage earner was male, employed, married and college educated, and the housing / work locations were in the urban periphery. TW utility increased if housing type was independent house / apartment, for bigger housing units, the presence of children under 5, more people in the household, greater trips per day by primary wage earner, and housing location farther from a rail station. TW utility decreased with longer travel distance for home-based trips, when work-based home trip were made between 4.31 pm and 7.30 pm, and with declining density of jobs and housing.

6.2.3 Vehicle Use

The spatial analysis of vehicle use shows that car use is higher in Island Mumbai and in the Western Suburbs, with some car use also evident in the Eastern Suburbs, and in secondary nodes such as Thane and Navi Mumbai-CIDCO. In comparison, TW use is mostly in the urban periphery nodes such as Thane, Navi Mumbai-CIDCO, Kalyan, Ulhasnagar, and Bhiwandi. Car trips are longer, usually with passengers, and are mostly concentrated within Greater Mumbai. TW trips are shorter, drive-alone trips and are all across the GMR's populated geography.

Car use increased if the primary wage earner worked full / part time or was self-employed, there were more employed members in the household, the housing location was in Western or Eastern Suburbs, but the primary wage earner worked in Island Mumbai. Car use increased if s/he started the morning trip between 7.31 am and 10.30 am, and as his/her work location got farther from a rail station. Car use went down when there was higher job density and better jobs-housing balance at the work location, and with better job availability and higher housing density at home location.

TW use went up with more employed persons in the household, with higher number of trips per day by the primary wage earner, if his/her work location was in the Western or Eastern Suburbs, if the primary wage earner began the evening trip between 4.31 pm and 7.30 pm, and if the housing location was farther from the rail station. TW use decreased with better jobs-housing balance and higher job density at the work location, with higher housing density at the home location, and with higher per capita income.

6.3 CONCLUSIONS

This dissertation shows that travel behavior in the Greater Mumbai Region (GMR) is a function of differences resulting from urban agglomeration and travel options available in the metropolitan region, coupled with changing socio-economic conditions in society. Similar to many Indian cities, Mumbai has a growing population, an expanding periphery, a dense core, inadequate infrastructure, modernization, a booming service economy, rapidly growing private vehicle fleets, and a decreasing standard of living.

Against this background, the analyses carried out in this dissertation show that households' demand for private vehicles goes up with socio-economic factors such as college education, service sector employment, higher incomes, bigger households, and bigger housing units. If people live or work in the urban periphery, they tend to own and use motorized two-wheelers. Car users tend to live in urban cores, but travel to CBD and urban periphery job locations. Households segue into private vehicles when members tend to make more trips in a day, or travel in the morning or evening peak hours. Vehicle use goes down with higher density of housing and jobs, better jobs-housing balance, and proximity of home and work to rail transit in the GMR.

Land use policies such as managed higher densities, mixed-use zoning and jobs-housing balance are important for reducing private travel. As the economy matures, specialized nodes for manufacturing and knowledge-processing are being proposed. However, policies should look at planning these nodes to be interdependent sustainable sub-centers, with effective densities to supply an appropriate mix of public transit options, and the mixing of land uses to create multi-directional flows on networks – both within nodes and between them. Commuters to and from these locations might not only find it convenient to travel between nodes in a polycentric metropolitan region, but also might find the right mix of jobs, schools, retail and entertainment within a reasonable distance from housing locations.

Specific transportation policies such as pricing private travel across cordons, or by time-of-use, or using carpool lanes should be considered for certain locations such as the dense Island Mumbai CBD. Detailed analyses should inform any pricing policies, so that those without other travel options are not impacted negatively. The intermediate public transportation (IPT) market in India is diverse with rickshaws, shared rickshaws of various sizes, shared SUVs and jeeps, shared vans, and small buses moving travelers between locations. Often these travel options are the only means for people in urban peripheries who make periphery-periphery, periphery-suburb, and suburb-periphery trips. Private bus companies also operate in this environment where demand is not met by the public bus agencies. Rather than stop these services, regulations should be developed for maximum fares, basic level of service, and licensing so that IPT modes keep providing much needed mobility options for those living in areas with minimal public transit options.

As planning institutions and external funding agencies discuss sustainable urbanism for cities in India, as well as in other emerging economies, the lessons from the Mumbai case find broader applications. Objectives such as sustainable urbanism can be promoted through rethinking land use strategies and increasing the supply of transportation infrastructure as discussed above. If middle-class households are to move towards sustainable travel behaviors, the need to shorten commute trips, and the provision of non-private travel modes, is critical.

With appropriate contextualization, lessons from Mumbai have applications in many other cities in emerging economies. Many urban policy issues in emerging economies are similar in conception, though specifics might be different. Problems of rapid urbanization, growing populations, societies with higher incomes, motorization, and congested transportation networks are common in many cities. Policy lessons highlighted in this dissertation, which point to land use strategies such as managed densification, mixed-zone land uses, and jobs-housing balance, along with transportation polices to price car trips during peak times and the provision of public sector transit options, when applied with appropriate research and contextualization should contain the rapid growth of private vehicle fleets, encourage sustainable travel behaviors, and move cities towards sustainability.

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Appendix 1

Statistical Test Outputs for Employment Center Indicators

Notes:
These outputs are based on work done with SPSS (v 13), 2004.

Geographies
ISMUM = Island Mumbai
GRMUM = Greater Mumbai

Variables
PERHH = Persons per household
EARNHH = Earning persons per household
HHINCAUL =Median annual household income
PERCAPITAINC = Per capita annual household income
TCOSTAUL = Transportation budget (annual)
TRIPCOST2 = Out-of-pocket trip cost from travel diary
CARAVIL = Cars in household (owned + available for use)
TWAVIL = Two-wheelers in household (owned + available for use)
NTRIPS = Primary wage earner's number of trips on travel diary day
TOTALTIME = Total time (travel time + waiting time) in minutes for home-based work trip by primary wage earner
DISTANCENT = Distance traveled (in km) for home-based work trip by primary wage earner, calculated along street network
SPEED = Speed in km/hr (calculated as network distance / travel time) by main mode of travel for home-based work trips
MAINMODE3.1 = Main mode of travel for home-based work trip by primary wage earner based on information in the travel diary

1.1 T-TESTS FOR SOCIO-ECONOMIC AND TRANSPORTATION INDICATORS (ISMUM=1, RoR=0) (SEE CHAPTER 3 TABLES 3.1 AND 3.2)

Group Statistics

	ISMUM	N	Mean	Std. Deviation	Std. Error Mean
PERHH	1	13886	4.66	1.762	.015
	0	26415	4.67	1.747	.011
EARNHH	1	13886	2.08	1.090	.009
	0	26415	2.14	1.081	.007
HHINCAUL	1	13886	160821.69	92375.260	783.912
	0	26415	155040.32	86917.056	534.786
PERCAPITAINC	1	13886	38077.13	24766.098	210.169
	0	26415	36804.90	23660.464	145.579
TCOSTAUL	1	13830	4805.43	4106.701	34.921
	0	26174	4638.66	4263.886	26.355

TRIPCOST2	**1**	4694	8.23	9.405	.137
	0	8422	8.59	7.082	.077
CARAVIL	**1**	13886	.08	.315	.003
	0	26415	.06	.265	.002
TWAVIL	**1**	13886	.14	.379	.003
	0	26415	.22	.473	.003
NTRIPS	**1**	13886	2.10	.445	.004
	0	26414	2.21	.630	.004
TOTALTIME	**1**	13886	55.72	33.143	.281
	0	26415	39.37	28.938	.178
DISTANCENT	**1**	13886	21068.06	19537.598	165.799
	0	26415	11990.84	13023.804	80.133

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference Lower	Upper
PERHH	Equal variances assumed	.726	.394	-.448	40299	.654	-.008	.018	-.056	.039
	Equal variances not assumed			-.447	28008.798	.655	-.008	.018	-.056	.039
EARNHH	Equal variances assumed	8.329	.004	-5.836	40299	.000	-.066	.011	-.096	-.037
	Equal variances not assumed			-5.821	28010.017	.000	-.066	.011	-.096	-.037
HHINCAUL	Equal variances assumed	10.699	.001	6.209	40299	.000	5781.373	931.174	3382.714	8180.032
	Equal variances not assumed			6.092	26768.734	.000	5781.373	948.954	3336.856	8225.890
PERCAPITAINC	Equal variances assumed	16.295	.000	5.047	40299	.000	1272.222	252.062	622.922	1921.522
	Equal variances not assumed			4.976	27123.158	.000	1272.222	255.664	613.628	1930.816
TCOSTAUL	Equal variances assumed	44.947	.000	3.768	40002	.000	166.777	44.260	52.766	280.788
	Equal variances not assumed			3.812	29084.184	.000	166.777	43.750	54.077	279.477
TRIPCOST2	Equal variances assumed	5.672	.017	-2.473	13114	.013	-.360	.146	-.735	.015
	Equal variances not assumed			-2.286	7699.365	.022	-.360	.157	-.766	.046
CARAVIL	Equal variances assumed	131.077	.000	5.739	40299	.000	.017	.003	.009	.025
	Equal variances not assumed			5.441	24367.704	.000	.017	.003	.009	.025
TWAVIL	Equal variances assumed	1346.230	.000	-18.537	40299	.000	-.086	.005	-.098	-.074
	Equal variances not assumed			-19.832	33933.446	.000	-.086	.004	-.097	-.075
NTRIPS	Equal variances assumed	1602.863	.000	-19.626	40298	.000	-.118	.006	-.133	-.102
	Equal variances not assumed			-21.792	37006.041	.000	-.118	.005	-.132	-.104
TOTALTIME	Equal variances assumed	669.325	.000	51.192	40299	.000	16.341	.319	15.519	17.163
	Equal variances not assumed			49.090	25123.260	.000	16.341	.333	15.483	17.198
DISTANCENT	Equal variances assumed	4129.931	.000	55.587	40299	.000	9077.225	163.297	8656.581	9497.869
	Equal variances not assumed			49.293	20540.355	.000	9077.225	184.149	8602.845	9551.605

1.2 T-TESTS FOR SOCIO-ECONOMIC AND TRANSPORTATION INDICATORS (GRMUM=1, RoR=0) (SEE CHAPTER 3 TABLES 3.1 AND 3.2)

Group Statistics

	GRMUM	N	Mean	Std. Deviation	Std. Error Mean
PERHH	1	29115	4.61	1.720	.010
	0	11186	4.82	1.826	.017
EARNHH	1	29115	2.09	1.080	.006
	0	11186	2.20	1.091	.010
HHINCAUL	1	29115	159377.64	89993.497	527.415
	0	11186	150927.95	85605.873	809.406
PERCAPITAINC	1	29115	38270.21	24804.406	145.369
	0	11186	34570.29	21757.770	205.720
TCOSTAUL	1	28859	4830.36	4264.999	25.106
	0	11145	4349.22	4047.094	38.336
TRIPCOST2	1	10520	8.21	8.139	.079
	0	2596	9.50	7.279	.143
CARAVIL	1	29115	.07	.290	.002
	0	11186	.06	.267	.003
TWAVIL	1	29115	.16	.405	.002
	0	11186	.29	.522	.005
NTRIPS	1	29115	2.10	.445	.003
	0	11185	2.36	.794	.008
TOTALTIME	1	29115	49.63	31.615	.185
	0	11186	32.95	27.492	.260
DISTANCENT	1	29115	17182.35	17116.387	100.312
	0	11186	9746.57	11787.265	111.449

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
PERHH	Equal variances assumed	26.880	.000	-11.063	40299	.000	-.215	.019	-.265	-.165
	Equal variances not assumed			-10.772	19250.142	.000	-.215	.020	-.267	-.164
EARNHH	Equal variances assumed	32.308	.000	-9.470	40299	.000	-.114	.012	-.145	-.083
	Equal variances not assumed			-9.431	20111.293	.000	-.114	.012	-.145	-.083
HHINCAUL	Equal variances assumed	2.160	.142	8.554	40299	.000	8449.695	987.785	5905.208	10994.182
	Equal variances not assumed			8.746	21229.248	.000	8449.695	966.077	5961.022	10938.367
PERCAPITAINC	Equal variances assumed	111.380	.000	13.860	40299	.000	3699.930	266.950	3012.279	4387.580
	Equal variances not assumed			14.688	22945.826	.000	3699.930	251.898	3051.028	4348.831
TCOSTAUL	Equal variances assumed	15.538	.000	10.259	40002	.000	481.139	46.901	360.324	601.953
	Equal variances not assumed			10.499	21244.052	.000	481.139	45.825	363.091	599.187
TRIPCOST2	Equal variances assumed	.155	.694	-7.401	13114	.000	-1.294	.175	-1.744	-.843
	Equal variances not assumed			-7.916	4341.573	.000	-1.294	.163	-1.715	-.873
CARAVIL	Equal variances assumed	26.417	.000	2.572	40299	.010	.008	.003	.000	.016

	Equal variances not assumed			2.666	21856.811	.008	.008	.003	.000	.016
TWAVIL	Equal variances assumed	2267.629	.000	-26.953	40299	.000	-.132	.005	-.145	-.120
	Equal variances not assumed			-24.128	16622.131	.000	-.132	.005	-.146	-.118
NTRIPS	Equal variances assumed	6613.509	.000	-41.078	40298	.000	-.258	.006	-.274	-.242
	Equal variances not assumed			-32.428	13969.401	.000	-.258	.008	-.278	-.237
TOTALTIME	Equal variances assumed	481.186	.000	49.121	40299	.000	16.680	.340	15.806	17.555
	Equal variances not assumed			52.255	23143.575	.000	16.680	.319	15.858	17.503
DISTANCENT	Equal variances assumed	2196.807	.000	42.258	40299	.000	7435.781	175.963	6982.507	7889.054
	Equal variances not assumed			49.590	29268.669	.000	7435.781	149.945	7049.524	7822.038

1.3 ASSOCIATION TESTS FOR TRIPS TO CBD, SUBURBS AND PERIPHERY (ISLAND MUMBAI = 'CBD', WESTERN AND EASTERN SUBURBS = 'SUBURBS', REST OF THE REGION (ROR) = 'PERIPHERY') (ORINGS = ORIGINS, DRINGS – DESTINATIONS) (SEE CHAPTER 3 TABLE 3.3)

Chi-Square Tests

MAINMODEP3.1	COUNT		Value	df	Asymp. Sig. (2-sided)
NMT	1	Pearson Chi-Square	18037.678	4	.000
		Continuity Correction			
		Likelihood Ratio	18489.621	4	.000
		Linear-by-Linear Association	9136.990	1	.000
		McNemar-Bowker Test	30.418	3	.000
		N of Valid Cases	9318		
IPT	1	Pearson Chi-Square	2048.142	4	.000
		Continuity Correction			
		Likelihood Ratio	1771.477	4	.000
		Linear-by-Linear Association	1093.277	1	.000
		McNemar-Bowker Test	27.048	3	.000
		N of Valid Cases	1320		
BUS	1	Pearson Chi-Square	6673.512	4	.000
		Continuity Correction			
		Likelihood Ratio	6173.780	4	.000
		Linear-by-Linear Association	3857.213	1	.000
		McNemar-Bowker Test	88.972	3	.000
		N of Valid Cases	5929		
TRAIN	1	Pearson Chi-Square	678.823	4	.000
		Continuity Correction			
		Likelihood Ratio	680.952	4	.000
		Linear-by-Linear Association	489.613	1	.000
		McNemar-Bowker Test	6175.489	3	.000
		N of Valid Cases	18890		
TW	1	Pearson Chi-Square	4408.785	4	.000
		Continuity Correction			
		Likelihood Ratio	4112.901	4	.000
		Linear-by-Linear Association	2593.545	1	.000
		McNemar-Bowker Test	129.001	3	.000
		N of Valid Cases	3520		
CAR	1	Pearson Chi-Square	1199.544	4	.000
		Continuity Correction			
		Likelihood Ratio	1131.127	4	.000
		Linear-by-Linear Association	745.996	1	.000
		McNemar-Bowker Test	34.717	3	.000
		N of Valid Cases	1324		

							Directional Measures
MAINMODEP3.1				Value	Asymp. Std. Error	Approx. T	Approx. Sig.
NMT	Nominal by Nominal	Lambda	Symmetric	.981	.002	101.004	.000
			ORINGS Dependent	.981	.002	99.351	.000
			DRINGS Dependent	.981	.002	102.034	.000
		Goodman and Kruskal tau	Symmetric				
			ORINGS Dependent	.968	.003		.000
			DRINGS Dependent	.968	.003		.000
		Uncertainty Coefficient	Symmetric	.943	.005	168.434	.000
			ORINGS Dependent	.944	.005	168.434	.000
			DRINGS Dependent	.942	.005	168.434	.000
IPT	Nominal by Nominal	Lambda	Symmetric	.885	.014	25.769	.000
			ORINGS Dependent	.882	.015	23.928	.000
			DRINGS Dependent	.888	.014	26.989	.000
		Goodman and Kruskal tau	Symmetric				
			ORINGS Dependent	.843	.017		.000
			DRINGS Dependent	.835	.019		.000
		Uncertainty Coefficient	Symmetric	.776	.021	31.100	.000
			ORINGS Dependent	.794	.020	31.100	.000
			DRINGS Dependent	.758	.023	31.100	.000
BUS	Nominal by Nominal	Lambda	Symmetric	.683	.010	47.425	.000
			ORINGS Dependent	.689	.010	47.458	.000
			DRINGS Dependent	.676	.010	42.651	.000
		Goodman and Kruskal tau	Symmetric				
			ORINGS Dependent	.549	.011		.000
			DRINGS Dependent	.548	.011		.000
		Uncertainty Coefficient	Symmetric	.492	.010	47.548	.000
			ORINGS Dependent	.489	.010	47.548	.000
			DRINGS Dependent	.495	.010	47.548	.000
TRAIN	Nominal by Nominal	Lambda	Symmetric	.036	.004	8.397	.000
			ORINGS Dependent	.069	.008	8.397	.000
			DRINGS Dependent	.000	.000	.	.
		Goodman and Kruskal tau	Symmetric				
			ORINGS Dependent	.022	.002		.000
			DRINGS Dependent	.013	.001		.000
		Uncertainty Coefficient	Symmetric	.018	.001	13.218	.000
			ORINGS Dependent	.018	.001	13.218	.000
			DRINGS Dependent	.018	.001	13.218	.000
TW	Nominal by Nominal	Lambda	Symmetric	.748	.011	40.218	.000
			ORINGS Dependent	.733	.013	33.798	.000

			DRINGS Dependent	.760	.010	45.258	.000
		Goodman and Kruskal tau	Symmetric				
			ORINGS Dependent	.649	.013		.000
			DRINGS Dependent	.641	.014		.000
		Uncertainty Coefficient	Symmetric	.588	.013	42.587	.000
			ORINGS Dependent	.598	.013	42.587	.000
			DRINGS Dependent	.578	.013	42.587	.000
CAR	Nominal by Nominal	Lambda	Symmetric	.619	.021	21.757	.000
			ORINGS Dependent	.602	.023	18.209	.000
			DRINGS Dependent	.634	.020	23.000	.000
		Goodman and Kruskal tau	Symmetric				
			ORINGS Dependent	.438	.022		.000
			DRINGS Dependent	.442	.022		.000
		Uncertainty Coefficient	Symmetric	.394	.020	19.584	.000
			ORINGS Dependent	.396	.020	19.584	.000
			DRINGS Dependent	.393	.020	19.584	.000

Symmetric Measures

MAINMODEP3.1			Value	Asymp. Std. Error	Approx. T	Approx. Sig.
NMT	Nominal by Nominal	Phi	1.391			.000
		Cramer's V	.984			.000
		Contingency Coefficient	.812			.000
	N of Valid Cases		9318			
IPT	Nominal by Nominal	Phi	1.246			.000
		Cramer's V	.881			.000
		Contingency Coefficient	.780			.000
	N of Valid Cases		1320			
BUS	Nominal by Nominal	Phi	1.061			.000
		Cramer's V	.750			.000
		Contingency Coefficient	.728			.000
	N of Valid Cases		5929			
TRAIN	Nominal by Nominal	Phi	.190			.000
		Cramer's V	.134			.000
		Contingency Coefficient	.186			.000
	N of Valid Cases		18890			
TW	Nominal by Nominal	Phi	1.119			.000
		Cramer's V	.791			.000
		Contingency Coefficient	.746			.000
	N of Valid Cases		3520			
CAR	Nominal by Nominal	Phi	.952			.000
		Cramer's V	.673			.000
		Contingency Coefficient	.689			.000
	N of Valid Cases		1324			

1.4 T-TESTS FOR TOTAL TRAVEL TIME (MINUTES) (ISMUM=1, RoR=0) (SEE CHAPTER 3 TABLE 3.4)

Group Statistics

MAINMODEP3.1		ISMUM	N	Mean	Std. Deviation	Std. Error Mean
NMT	TOTALTIME	1	2018	16.15	8.899	.198
		0	7300	18.30	10.783	.126
IPT	TOTALTIME	1	110	32.35	22.306	2.127
		0	1210	24.93	13.437	.386
BUS	TOTALTIME	1	1648	37.76	18.820	.464
		0	4281	43.15	23.536	.360
TRAIN	TOTALTIME	1	9064	70.97	28.818	.303
		0	9826	60.53	29.542	.298
TW	TOTALTIME	1	559	27.56	19.113	.808
		0	2961	23.28	16.900	.311
CAR	TOTALTIME	1	487	34.09	19.984	.906
		0	837	33.30	24.701	.854

Independent Samples Test

MAIN MODE P3.1			Levene's Test for Equality of Variances		t-test for Equality of Means						
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference: Lower	Upper
NMT	TOTAL TIME	Equal variances assumed	65.480	.000	-8.217	9316	.000	-2.150	.262	-2.824	-1.476
		Equal variances not assumed			-9.154	3812.770	.000	-2.150	.235	-2.755	-1.545
IPT	TOTAL TIME	Equal variances assumed	20.025	.000	5.187	1318	.000	7.428	1.432	3.734	11.122
		Equal variances not assumed			3.436	116.299	.001	7.428	2.162	1.767	13.089
BUS	TOTAL TIME	Equal variances assumed	72.173	.000	-8.314	5927	.000	-5.381	.647	-7.049	-3.714
		Equal variances not assumed			-9.171	3709.744	.000	-5.381	.587	-6.893	-3.869
TRAIN	TOTAL TIME	Equal variances assumed	57.175	.000	24.544	18888	.000	10.436	.425	9.341	11.532
		Equal variances not assumed			24.569	18829.045	.000	10.436	.425	9.342	11.531
TW	TOTAL TIME	Equal variances assumed	6.733	.010	5.367	3518	.000	4.274	.796	2.221	6.327
		Equal variances not assumed			4.935	731.884	.000	4.274	.866	2.038	6.510
CAR	TOTAL TIME	Equal variances assumed	22.398	.000	.600	1322	.549	.789	1.315	-2.604	4.182
		Equal variances not assumed			.634	1188.214	.526	.789	1.245	-2.422	4.000

1.5 T-TESTS FOR TOTAL TRAVEL TIME (MINUTES) (GRMUM=1, RoR=0) (SEE CHAPTER 3 TABLE 3.4)

Group Statistics

MAINMODEP3.1		GRMUM	N	Mean	Std. Deviation	Std. Error Mean
NMT	TOTALTIME	1	5034	17.41	9.437	.133
		0	4284	18.33	11.490	.176
IPT	TOTALTIME	1	544	26.15	15.183	.651
		0	776	25.12	14.031	.504
BUS	TOTALTIME	1	4485	39.62	19.481	.291
		0	1444	47.95	28.972	.762
TRAIN	TOTALTIME	1	16264	66.47	29.482	.231
		0	2626	59.79	30.100	.587
TW	TOTALTIME	1	1807	28.31	18.401	.433
		0	1713	19.37	14.820	.358
CAR	TOTALTIME	1	981	33.94	20.928	.668
		0	343	32.59	28.339	1.530

Independent Samples Test

MAIN MODE P3.1			Levene's Test for Equality of Variances		t-test for Equality of Means						
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
										Lower	Upper
NMT	TOTAL TIME	Equal variances assumed	58.724	.000	-4.240	9316	.000	-.919	.217	-1.478	-.361
		Equal variances not assumed			-4.174	8287.646	.000	-.919	.220	-1.487	-.352
IPT	TOTAL TIME	Equal variances assumed	.050	.823	1.268	1318	.205	1.030	.812	-1.064	3.124
		Equal variances not assumed			1.251	1109.204	.211	1.030	.823	-1.094	3.153
BUS	TOTAL TIME	Equal variances assumed	196.487	.000	-12.411	5927	.000	-8.325	.671	-10.053	-6.596
		Equal variances not assumed			-10.202	1880.863	.000	-8.325	.816	-10.429	-6.221
TRAIN	TOTAL TIME	Equal variances assumed	3.108	.078	10.746	18888	.000	6.682	.622	5.080	8.284
		Equal variances not assumed			10.586	3487.657	.000	6.682	.631	5.055	8.309
TW	TOTAL TIME	Equal variances assumed	63.076	.000	15.825	3518	.000	8.941	.565	7.485	10.397
		Equal variances not assumed			15.915	3429.287	.000	8.941	.562	7.493	10.389
CAR	TOTAL TIME	Equal variances assumed	49.146	.000	.934	1322	.350	1.352	1.447	-2.382	5.086
		Equal variances not assumed			.810	478.785	.418	1.352	1.670	-2.966	5.670

1.6 T-TESTS FOR DISTANCE TRAVELED (METERS) (ISMUM=1, RoR=0) (SEE CHAPTER 3 TABLE 3.5)

Group Statistics

MAINMODEP3.1		ISMUM	N	Mean	Std. Deviation	Std. Error Mean
NMT	DISTANCENT	1	2018	2035.10	3143.255	69.971
		0	7300	3184.66	3703.636	43.348
IPT	DISTANCENT	1	110	11407.20	16677.051	1590.094
		0	1210	5293.44	6412.931	184.359
BUS	DISTANCENT	1	1648	6973.06	7819.165	192.611
		0	4281	9860.87	8944.221	136.700
TRAIN	DISTANCENT	1	9064	29446.46	18785.865	197.320
		0	9826	22135.76	14342.275	144.687
TW	DISTANCENT	1	559	7703.76	8802.781	372.318
		0	2961	6524.07	7137.626	131.170
CAR	DISTANCENT	1	487	9217.14	8407.337	380.973
		0	837	9613.87	9278.497	320.712

Independent Samples Test

MAINMODEP3.1			Levene's Test for Equality of Variances		t-test for Equality of Means						
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference: Lower	Upper
NMT	DISTANCENT	Equal variances assumed	80.441	.000	-12.733	9316	.000	-1149.556	90.282	-1382.155	-916.957
		Equal variances not assumed			-13.966	3711.250	.000	-1149.556	82.310	-1361.682	-937.429
IPT	DISTANCENT	Equal variances assumed	161.001	.000	7.878	1318	.000	6113.753	776.040	4111.907	8115.598
		Equal variances not assumed			3.819	111.948	.000	6113.753	1600.746	1919.060	10308.446
BUS	DISTANCENT	Equal variances assumed	79.616	.000	-11.521	5927	.000	-2887.809	250.651	-3533.651	-2241.967
		Equal variances not assumed			-12.227	3392.823	.000	-2887.809	236.191	-3496.539	-2279.079
TRAIN	DISTANCENT	Equal variances assumed	703.620	.000	30.198	18888	.000	7310.704	242.095	6687.045	7934.362
		Equal variances not assumed			29.878	16917.482	.000	7310.704	244.683	6680.372	7941.036
TW	DISTANCENT	Equal variances assumed	38.135	.000	3.445	3518	.001	1179.695	342.485	297.032	2062.357
		Equal variances not assumed			2.988	703.072	.003	1179.695	394.748	160.123	2199.267
CAR	DISTANCENT	Equal variances assumed	2.840	.092	-.776	1322	.438	-396.726	511.112	-1715.167	921.715
		Equal variances not assumed			-.797	1098.257	.426	-396.726	497.992	-1681.703	888.250

1.7 T-TESTS FOR DISTANCE TRAVELED (METERS) (GRMUM=1, RoR=0) (SEE CHAPTER 3 TABLE 3.5)

Group Statistics

MAINMODEP3.1		GRMUM	N	Mean	Std. Deviation	Std. Error Mean
NMT	DISTANCENT	1	5034	2608.85	2769.712	39.037
		0	4284	3319.77	4385.085	66.997
IPT	DISTANCENT	1	544	6477.93	10183.395	436.609
		0	776	5329.72	5910.500	212.175
BUS	DISTANCENT	1	4485	7716.00	7199.680	107.506
		0	1444	13226.97	11396.332	299.903
TRAIN	DISTANCENT	1	16264	26193.94	17473.672	137.016
		0	2626	22235.50	13386.789	261.234
TW	DISTANCENT	1	1807	7802.15	7429.043	174.765
		0	1713	5560.82	7274.675	175.766
CAR	DISTANCENT	1	981	9056.11	7759.244	247.734
		0	343	10645.80	11688.979	631.146

Independent Samples Test

MAIN MODE P3.1			Levene's Test for Equality of Variances		t-test for Equality of Means						
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
										Lower	Upper
NMT	DISTANCENT	Equal variances assumed	105.899	.000	-9.491	9316	.000	-710.917	74.903	-903.894	-517.940
		Equal variances not assumed			-9.168	6998.435	.000	-710.917	77.540	-910.701	-511.133
IPT	DISTANCENT	Equal variances assumed	18.842	.000	2.582	1318	.010	1148.211	444.774	.887	2295.536
		Equal variances not assumed			2.365	798.546	.018	1148.211	485.434	-105.179	2401.601
BUS	DISTANCENT	Equal variances assumed	477.361	.000	-21.641	5927	.000	-5510.968	254.654	-6167.125	-4854.810
		Equal variances not assumed			-17.298	1827.963	.000	-5510.968	318.590	-6332.459	-4689.476
TRAIN	DISTANCENT	Equal variances assumed	382.109	.000	11.095	18888	.000	3958.445	356.780	3039.347	4877.544
		Equal variances not assumed			13.419	4216.399	.000	3958.445	294.985	3198.269	4718.621
TW	DISTANCENT	Equal variances assumed	32.006	.000	9.038	3518	.000	2241.334	248.003	1602.175	2880.493
		Equal variances not assumed			9.043	3514.301	.000	2241.334	247.864	1602.533	2880.136
CAR	DISTANCENT	Equal variances assumed	77.272	.000	-2.834	1322	.005	-1589.684	560.978	-3036.756	-142.611
		Equal variances not assumed			-2.345	451.758	.019	-1589.684	678.024	-3343.567	164.199

1.8 T-TESTS FOR SPEED (KM/ HR) (ISMUM=1, RoR=0) (SEE CHAPTER 3 TABLE 3.6)

Group Statistics

MAINMODEP3.1		ISMUM	N	Mean	Std. Deviation	Std. Error Mean
NMT	SPEED	1	2018	9.41	27.812	.619
		0	7300	13.19	19.745	.231
IPT	SPEED	1	110	20.94	23.833	2.272
		0	1210	14.43	15.273	.439
BUS	SPEED	1	1648	12.21	11.371	.280
		0	4281	16.06	15.852	.242
TRAIN	SPEED	1	9064	26.16	14.391	.151
		0	9826	25.06	14.889	.150
TW	SPEED	1	559	17.31	27.897	1.180
		0	2961	18.49	24.474	.450
CAR	SPEED	1	487	16.03	13.488	.611
		0	837	19.15	19.852	.686

Independent Samples Test

MAIN MODE P3.1			Levene's Test for Equality of Variances		t-test for Equality of Means						
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
										Lower	Upper
NMT	SPEED	Equal variances assumed	30.068	.000	-6.904	9316	.000	-3.776	.547	-5.185	-2.367
		Equal variances not assumed			-5.714	2604.219	.000	-3.776	.661	-5.479	-2.072
IPT	SPEED	Equal variances assumed	30.889	.000	4.048	1318	.000	6.512	1.609	2.362	10.662
		Equal variances not assumed			2.814	117.276	.006	6.512	2.314	.452	12.572
BUS	SPEED	Equal variances assumed	41.792	.000	-8.993	5927	.000	-3.844	.427	-4.945	-2.743
		Equal variances not assumed			-10.379	4141.129	.000	-3.844	.370	-4.798	-2.890
TRAIN	SPEED	Equal variances assumed	82.830	.000	5.121	18888	.000	1.093	.213	.543	1.642
		Equal variances not assumed			5.128	18846.799	.000	1.093	.213	.544	1.642
TW	SPEED	Equal variances assumed	.000	.983	-1.019	3518	.308	-1.177	1.155	-4.154	1.800
		Equal variances not assumed			-.932	729.044	.352	-1.177	1.263	-4.438	2.084
CAR	SPEED	Equal variances assumed	11.703	.001	-3.078	1322	.002	-3.119	1.013	-5.732	-.505
		Equal variances not assumed			-3.394	1290.960	.001	-3.119	.919	-5.489	-.748

1.9 T-TESTS FOR SPEED (KM / HR) (GRMUM=1, RoR=0) (SEE CHAPTER 3 TABLE 3.6)

Group Statistics

MAINMODEP3.1		GRMUM	N	Mean	Std. Deviation	Std. Error Mean
NMT	SPEED	1	5034	11.07	20.287	.286
		0	4284	13.90	23.366	.357
IPT	SPEED	1	544	15.43	16.196	.694
		0	776	14.64	16.286	.585
BUS	SPEED	1	4485	13.53	12.618	.188
		0	1444	19.51	19.579	.515
TRAIN	SPEED	1	16264	25.41	14.366	.113
		0	2626	26.70	16.335	.319
TW	SPEED	1	1807	17.65	20.771	.489
		0	1713	18.98	28.872	.698
CAR	SPEED	1	981	17.12	16.730	.534
		0	343	20.51	20.496	1.107

Independent Samples Test

MAIN MODE P3.1			Levene's Test for Equality of Variances		t-test for Equality of Means						
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
										Lower	Upper
NMT	SPEED	Equal variances assumed	57.555	.000	-6.265	9316	.000	-2.833	.452	-3.999	-1.668
		Equal variances not assumed			-6.195	8547.501	.000	-2.833	.457	-4.012	-1.655
IPT	SPEED	Equal variances assumed	3.616	.057	.871	1318	.384	.791	.909	-1.553	3.135
		Equal variances not assumed			.872	1172.765	.384	.791	.908	-1.551	3.133
BUS	SPEED	Equal variances assumed	87.442	.000	-13.498	5927	.000	-5.972	.442	-7.112	-4.832
		Equal variances not assumed			-10.885	1844.137	.000	-5.972	.549	-7.386	-4.557
TRAIN	SPEED	Equal variances assumed	23.459	.000	-4.179	18888	.000	-1.288	.308	-2.082	-.494
		Equal variances not assumed			-3.810	3313.210	.000	-1.288	.338	-2.160	-.417
TW	SPEED	Equal variances assumed	17.414	.000	-1.576	3518	.115	-1.331	.845	-3.507	.846
		Equal variances not assumed			-1.562	3097.279	.118	-1.331	.852	-3.526	.865
CAR	SPEED	Equal variances assumed	8.254	.004	-3.038	1322	.002	-3.389	1.115	-6.266	-.511
		Equal variances not assumed			-2.758	510.231	.006	-3.389	1.229	-6.566	-.211

Appendix 2

Why Not A Nested Logit Model for Vehicle Ownership in the GMR?

This appendix reports on a nested model structure that was conceptualized before finalizing the multinomial logit structure discussed in chapter 4, and presented in detail in appendix 3. First the nested model structure is discussed, and followed up by two tables that show results of sequential binomial models that explored each of the nests; lessons learnt from variables are discussed. The last table presents logsum checks on variables used in the sequential binomial models for the nests at the upper levels. The discussion concludes with why this form of nesting is not an appropriate method for exploring vehicle ownership for this dataset.

2.1 MODEL STRUCTURE

When conceptualizing the model structure for vehicle ownership in the Greater Mumbai Region, it became evident that a nested structure could potentially afford a more detailed view. Particularly, the question of why some households might own one or more of either two-wheelers (TWs) and/or cars was of interest. Therefore, not only the choice of owning or not owning a vehicle (level A), but also the kind of vehicle (level B) and the numbers of each kind (level C), were included in the nesting presented in figure 2.1. The nests had to have enough observations at the lowest level, and had to be mutually exclusive for the model to run. Both these conditions were met as evidenced by the sample size in each nest and the results presented in the tables.

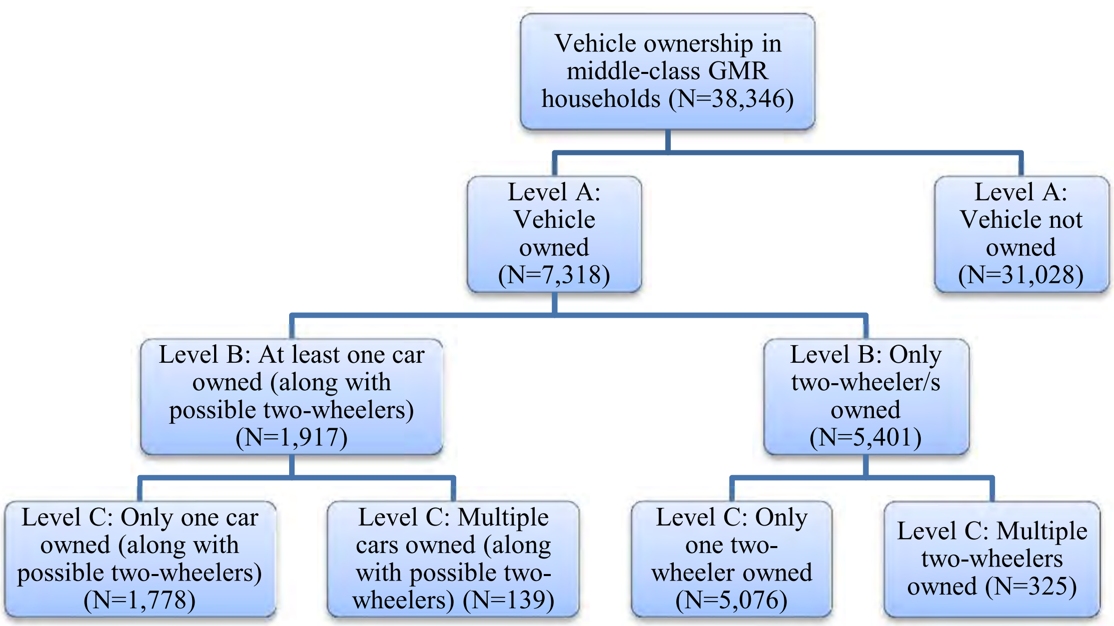


FIGURE 2.1 Nested model structure.

2.2 SEQUENTIAL MODEL RESULTS AND DISCUSSION

A series of life cycle, socio-demographic and potential policy impact variables discussing housing and job location, density, proximity to transit, per capita income and trip start times were used to run the models (also see chapter 4 and appendix 3). Table 2.1 shows results for level A where the choice was between owning and not owning a vehicle; parameters for households not owning a vehicle were fixed. This table also presents the results for level B where the choice was between the kind of vehicles in a household; only TW/s or at least one car (with possibly TW/s); parameters for households having only TW/s were fixed.

At level A and level B, which respectively predict choices between vehicle ownership (or not), and kind of vehicle ownership (only TW/s or at least one car), generally life cycle variables predict positive utility. Specifically, if the household has older groups of people, the household derives positive utility from vehicle ownership at both levels. Socio-demographic variables such as educational attainment of primary wage earner, type of residence and number of rooms also predict positive utility from vehicle ownership at these levels. Hence, if the primary wage earner is college educated (or has a technical diploma), the household lives in an apartment (or an independent house), and if the housing unit size is larger, then the household gains utility from having a vehicle. Housing location variables that situate the household in the urban periphery (Rest of the Region) and the urban suburbs (Suburban Mumbai) show that the household will derive lesser utility from vehicle ownership. Generally, the farther a household locates from the CBD, the lesser utility it derives from vehicles owned (see chapter 4 for a discussion on reasons).

Work location of the primary wage earner flips sign between the two levels. If the primary wage earner works in the CBD (Island Mumbai), the household gets lesser utility from a vehicle owned; however, this utility is positive if the household has a car. Yet if a household's primary wage earner works in the urban periphery (RoR), then the household gets positive utility from vehicle ownership at both levels. As the housing location gets denser, the utility from vehicle ownership goes down. The farther a household locates from a railway station, the higher utility it derives from vehicles owned at both levels. Per capita income is a robust and strong predictor of vehicle ownership, and the models at both the upper levels show positive utility from ownership as incomes grow. The model uses an extended version of the morning peak (between 8.31am and 11.30am). For primary wage earners who travel during these later peak hours, the utility from vehicle ownership goes up.

TABLE 2.1 Sequential Binomial Models for Level A and Level B

Variable Category	Variable	Model 1 - Level A - Households own or do not own a motorized vehicle			Model 2 - Level B - Households own only TW/s or at least one car (with possible TW/s)		
		Estimates for households owning a motorized vehicle	Std Err	t-value	Estimates for households owning at least one car (with possible TW/s)	Std Err	t-value
	Constant	-9.37***	0.36	-25.88	-11.90***	0.76	-15.65
Life cycle	Persons in household up to (and including) 24 years	0.20***	0.02	13.06	0.15***	0.04	4.13
	Persons in household from 25 to 44 years	0.20***	0.02	8.47	-0.08	0.05	-1.45
	Persons in household from 45 to 64 years	0.11***	0.03	3.44	0.26***	0.06	4.03
Socio-demographic	Educational attainment of primary wage earner (college education/technical diploma=1, other=0)	0.54***	0.04	14.99	0.68***	0.07	9.32
	Type of residence (apartment/independent house=1, other=0)	0.50***	0.04	13.11	1.05***	0.10	10.83
	Number of rooms	0.40***	0.02	19.94	0.38***	0.04	9.77
Policy	Dummy for housing location (RoR=1, Greater Mumbai=0)	-0.41***	0.06	-6.74	-1.49***	0.14	-10.96
	Dummy for housing location (Suburban Mumbai=1, Island Mumbai and RoR=0)	-0.42***	0.06	-7.26	-0.41***	0.12	-3.31
	CBD dummy for primary wage earner's work location (Island Mumbai=1, Suburban Mumbai and RoR=0)	-0.27***	0.05	-5.95	0.28**	0.10	2.69
	CBD dummy for primary wage earner's work location (RoR=1, Greater Mumbai=0)	0.57***	0.05	12.23	0.42***	0.11	3.72
	Natural log of TAZ area as a proxy for population density at housing location in km^2	-0.09***	0.01	-6.62	-0.09***	0.03	-3.00
	Natural log of Euclidean distance to nearest rail station (in km) from home location	0.27***	0.02	11.73	0.17***	0.05	3.33
	Natural log of per capita annual household income	0.59***	0.03	17.73	0.84***	0.07	12.13
	Usual trip start time for work of primary wage earner between 8.31am and 11.30am (yes=1, no=0)	0.24***	0.03	7.41	0.32***	0.07	4.57
Model Overview	Number of observations:	29,481			5,690		
	Null log-likelihood:	-20,434.67			-3,944.01		
	Final log-likelihood:	-12,809.40			-2,597.89		
	Likelihood ratio test:	15,250.55			2,692.24		
	Adjusted rho-square:	0.372			0.338		

Notes: 1) Estimated using the open-source software BIOGEME 2.0 (Bierlaire, M., 2010)
2) *** ($p = 0.00$), ** ($0.00 < p \leq 0.05$), * ($0.05 < p \leq 0.1$)

Table 2.2 shows results for level C where the choice was between owning one or multiple TW/s and cars (see figure 2.1). For each of the models run, parameters for households with single vehicle ownership were fixed. The presence of older individuals in the household shows higher utility from multiple vehicle ownership. College education (or a technical diploma) for the primary wage earner does not increase utility from multiple TWs; therefore, education may have less predicting power for the TW market in India. As the number of rooms (housing unit size) grows, so does the utility derived from owning multiple TWs and cars. Generally, housing and work location variables do not effectively predict multiple vehicle ownership. Housing location in the urban periphery (RoR) reduces utility from multiple car ownership. If the primary wage earner works in the CBD (Island Mumbai), the household derives less utility from multiple TW ownership. As households move farther from a railway station, they derive higher utility from multiple TWs. Higher per capita income again shows that it affects multiple vehicle ownership by type, i.e., utility increases for multiple vehicles as incomes rise. If the primary wage earner goes into work during the extended morning peak (between 8.31am and 11.30am) they derive higher utility from multiple TWs.

TABLE 2.2 Sequential Binomial Models for Level C

Variable Category	Variable	Model 3 - Level C - Households own single or multiple TWs (but no car/s)			Model 4 - Level C - Households own single or multiple cars (with possible TW/s)		
		Estimates for households owning multiple TWs	Std Err	t-value	Estimates for households owning multiple cars	Std Err	t-value
	Constant	-8.41***	1.73	-4.86	-13.30***	2.59	-5.13
Life cycle	Persons in household up to (and including) 24 years	0.24***	0.06	3.67	0.24**	0.12	2.06
	Persons in household from 25 to 44 years	0.82***	0.09	9.53	0.77***	0.12	6.29
	Persons in household from 45 to 64 years	0.81***	0.12	6.96	1.11***	0.17	6.64
Socio-demographic	Educational attainment of primary wage earner (college education/technical diploma=1, other=0)	-0.29*	0.17	-1.73	-0.26	0.26	-1.00
	Type of residence (apartment/independent house=1, other=0)	0.21	0.17	1.28	0.82	0.58	1.42
	Number of rooms	0.25***	0.08	3.28	0.40***	0.10	4.08
Policy	Dummy for housing location (RoR=1, Greater Mumbai=0)	-0.46	0.34	-1.33	-1.58***	0.45	-3.52
	Dummy for housing location (Suburban Mumbai=1, Island Mumbai and RoR=0)	-0.28	0.32	-0.90	-0.57	0.37	-1.56
	CBD dummy for primary wage earner's work location (Island Mumbai=1, Suburban Mumbai and RoR=0)	-0.55**	0.26	-2.14	0.57	0.38	1.53
	CBD dummy for primary wage earner's work location (RoR=1, Greater Mumbai=0)	0.09	0.22	0.42	0.66	0.42	1.57
	Natural log of TAZ area as a proxy for population density at housing location in km^2	0.03	0.05	0.58	-0.02	0.11	-0.20
	Natural log of Euclidean distance to nearest rail station (in km) from home location	0.19*	0.11	1.78	0.22	0.17	1.29
	Natural log of per capita annual household income	0.32**	0.16	2.01	0.63***	0.22	2.83
	Usual trip start time for work of primary wage earner between 8.31am and 11.30am (yes=1, no=0)	0.45***	0.15	3.05	0.38	0.24	1.61
Model Overview	Number of observations:	4,204			1,486		
	Null log-likelihood:	-2,913.99			-1,030.02		
	Final log-likelihood:	-797.15			-294.59		
	Likelihood ratio test:	4,233.69			1,470.85		
	Adjusted rho-square:	0.721			0.699		

Notes: 1) Estimated using the open-source software BIOGEME 2.0 (Bierlaire, M., 2010)
2) *** ($p = 0.00$), ** ($0.00 < p \leq 0.05$), * ($0.05 < p \leq 0.1$)

When comparing the sequential results for the nests in levels A, B and C, there are some interesting findings. Consistently, the prevalence of the young (up to 24 years) and the middle aged individuals (between 45 and 64 years) predicts preference for owning vehicles. Similarly, the larger a housing unit is, the more is the preference to vehicle ownership; however, this variable may be a proxy for income level. Per capita income is a consistent predictor of vehicle ownership at all levels. Therefore, the models suggest that if a middle-class Mumbai household has younger, more middle aged individuals in the household, larger housing unit, and higher incomes, it will likely own vehicles.

However, from a technical logit modeling perspective, the results shown in table 2.3 illustrate why nesting the households in this manner is not robust. The nests at level B (only TW/s owned or at least one car owned) and level A (vehicle owned or not owned) were run with the logsums computed using all the variables that had been used to calculate the systematic component of the utility equation. Table 2.3 shows the output of this additional analysis. Note that the logsum check for the variables used in models 2, 3 and 4, came out insignificant; the p-values are highlighted in red. This illustrated that the households in the nests at these levels are not distinctly different given the variables used in the utility equation. Hence, nesting in this manner does not help highlight clear differences between households who make the choice between the kind and number of vehicles they own.

TABLE 2.3 Sequential Binomial Models for Level B and Level A for Checking Nests

Variable Category	Variable	Model 5 - Level B - Households own only TW/s or at least one car (with possible TW/s)			Model 6 - Level A - Households own or do not own a motorized vehicle		
		Estimates for households owning at least one car (with possible TW/s)	Std Err	t-value	Estimates for households owning a motorized vehicle	Std Err	t-value
	Constant	-11.70***	0.87	-13.33	-9.69***	0.45	-21.52
Life cycle	Persons in household up to (and including) 24 years	0.14***	0.04	3.22	0.21***	0.02	12.85
	Persons in household from 25 to 44 years	-0.13	0.11	-1.16	0.19***	0.02	8.39
	Persons in household from 45 to 64 years	0.21*	0.12	1.81	0.12***	0.03	3.62
Socio-demographic	Educational attainment of primary wage earner (college education/technical diploma=1, other=0)	0.69***	0.08	8.83	0.57***	0.04	13.73
	Type of residence (apartment/independent house=1, other=0)	1.04***	0.10	10.65	0.52***	0.04	12.18
	Number of rooms	0.37***	0.05	7.67	0.41***	0.02	18.14
Policy	Dummy for housing location (RoR=1, Greater Mumbai=0)	-1.47***	0.14	-10.30	-0.46***	0.07	-6.19
	Dummy for housing location (Suburban Mumbai=1, Island Mumbai and RoR=0)	-0.39***	0.13	-3.12	-0.44***	0.06	-7.36
	CBD dummy for primary wage earner's work location (Island Mumbai=1, Suburban Mumbai and RoR=0)	0.30**	0.11	2.72	-0.26***	0.05	-5.63
	CBD dummy for primary wage earner's work location (RoR=1, Greater Mumbai=0)	0.42***	0.11	3.66	0.58***	0.05	12.11
	Natural log of TAZ area as a proxy for population density at housing location in km^2	-0.09***	0.03	-3.04	-0.09***	0.01	-6.69
	Natural log of Euclidean distance to nearest rail station (in km) from home location	0.16***	0.05	2.92	0.28***	0.02	11.68
	Natural log of per capita annual household income	0.82***	0.07	10.93	0.62***	0.04	14.93
	Usual trip start time for work of primary wage earner between 8.31am and 11.30am (yes=1, no=0)	0.30***	0.08	3.65	0.25***	0.03	7.49
Logsum checks	Logsum of variables in model 3 - level C - Households own single or multiple TWs (but no car/s)	-0.41	0.82	-0.50 (p-value = 0.62)	n.a.	n.a.	n.a.
	Logsum of variables in model 4 – level C - Households own single or multiple cars (with possible TW/s)	1.50	2.60	0.58 (p-value = 0.56)	n.a.	n.a.	n.a.

	Logsum of variables in Model 2 - Level B - Households own only TW/s or at least one car (with possible TW/s)	n.a.	n.a.	n.a.	-0.13	0.11	-1.21 (p-value = 0.23)
Model Overview	Number of observations:	5,690			29,481		
	Null log-likelihood:	-3,944.01			-20,434.67		
	Final log-likelihood:	-2,597.75			-12,808.63		
	Likelihood ratio test:	2,692.52			15,252.09		
	Adjusted rho-square:	0.337			0.372		

Notes: 1) Estimated using the open-source software BIOGEME 2.0 (Bierlaire, M., 2010)
2) *** ($p = 0.00$), ** ($0.00 < p \leq 0.05$), * ($0.05 < p \leq 0.1$)

In summation, the sequential modeling indicated which variables were the most consistent predictors for kinds and numbers of vehicles in middle-class Mumbai households. However, the exercise also revealed that the households that are within the lowest level nests in figure 2.1 are not so different, for the variables going into the utility equation, to reliably predict ownership by kind and numbers. Consequently, a simpler multinomial logit structure was used to predict vehicle ownership in middle-class Mumbai households (see chapter 4).

Appendix 3

Output for the Multinomial Logit Model for Vehicle Ownership

3.1 MODEL SPECIFICATION (MOD FILE)

[Model Description]
"Estimating vehicle ownership in a middle-class GMR household"
"Dependent Variable - CHOICE3 where no vehicle owned in household (fixed) = 1, only two-wheeler/s owned in household = 2, at least one car with possible two-wheeler/s owned in household = 3"
"Multinomial logistic model"
"Unit of analysis is household"
“Estimated using the open-source software BIOGEME 2.0 (Bierlaire, M., 2010)”

[Choice]
CHOICE3

[Beta]
// Name Value Lower Bound Upper Bound status (0=variable, 1=fixed)
ASC_NOVEH   0   -10000   10000   1
ASC_ONLYTW   0   -10000   10000   0
ASC_ATLEASTONECAR   0   -10000   10000   0
B_PRCPTHHINCLN_TW   0   -10000   10000   0
B_PRCPTHHINCLN_CAR   0   -10000   10000   0
B_RESTYPDM_TW   0   -10000   10000   0
B_RESTYPDM_CAR   0   -10000   10000   0
B_RROMS_TW   0   -10000   10000   0
B_RROMS_CAR   0   -10000   10000   0
B_EDUCDM_TW   0   -10000   10000   0
B_EDUCDM_CAR   0   -10000   10000   0
B_HHEUDISTSTATLN_TW   0   -10000   10000   0
B_HHEUDISTSTATLN_CAR   0   -10000   10000   0
B_PERHH_TW   0   -10000   10000   0
B_PERHH_CAR   0   -10000   10000   0
B_HHISMUMDM_TW   0   -10000   10000   0
B_HHISMUMDM_CAR   0   -10000   10000   0
B_HHRORMUMDM_TW   0   -10000   10000   0
B_HHRORMUMDM_CAR   0   -10000   10000   0
B_WKRORMUMDM_TW   0   -10000   10000   0
B_WKRORMUMDM_CAR   0   -10000   10000   0
B_HHPRKM2LN_TW   0   -10000   10000   0
B_HHPRKM2LN_CAR   0   -10000   10000   0

B_JOBPRKM2LN_TW 0 -10000 10000 0
B_JOBPRKM2LN_CAR 0 -10000 10000 0
B_AGE_TW 0 -10000 10000 0
B_AGE_CAR 0 -10000 10000 0
B_TM2WK910DM_TW 0 -10000 10000 0
B_TM4RMWK1719DM_TW 0 -10000 10000 0
B_TM4RMWK2022DM_TW 0 -10000 10000 0
B_TM2WK910DM_CAR 0 -10000 10000 0
B_TM4RMWK1719DM_CAR 0 -10000 10000 0
B_TM4RMWK2022DM_CAR 0 -10000 10000 0
B_DISTNTADJKMLN_TW 0 -10000 10000 0
B_DISTNTADJKMLN_CAR 0 -10000 10000 0
B_OCCUPDM_TW 0 -10000 10000 0
B_OCCUPDM_CAR 0 -10000 10000 0
B_MARITALDM_TW 0 -10000 10000 0
B_MARITALDM_CAR 0 -10000 10000 0
B_SEXDM_TW 0 -10000 10000 0
B_SEXDM_CAR 0 -10000 10000 0
B_NTRIPS_TW 0 -10000 10000 0
B_NTRIPS_CAR 0 -10000 10000 0
B_KIDS00TO05_TW 0 -10000 10000 0
B_KIDS00TO05_CAR 0 -10000 10000 0
// B_ONE 0 -10000 10000 1

[Utilities]
// Id Name Avail linear-in-parameter expression (beta1*x1 + beta2*x2 + ...)

1 NOVEH ONE ASC_NOVEH * ONE

2 ONLYTW ONE ASC_ONLYTW * ONE + B_PRCPTHHINCLN_TW * PRCPTHHINCLN + B_RESTYPDM_TW * RESTYPDM + B_RROMS_TW * RROMS + B_EDUCDM_TW * EDUCDM + B_HHEUDISTSTATLN_TW * HHEUDISTSTATLN + B_PERHH_TW * PERHH + B_HHISMUMDM_TW * HHISMUMDM + B_HHRORMUMDM_TW * HHRORMUMDM + B_WKRORMUMDM_TW * WKRORMUMDM + B_HHPRKM2LN_TW * HHPRKM2LN + B_JOBPRKM2LN_TW * JOBPRKM2LN + B_AGE_TW * AGE + B_TM2WK910DM_TW * TM2WK910DM + B_TM4RMWK1719DM_TW * TM4RMWK1719DM + B_TM4RMWK2022DM_TW * TM4RMWK2022DM + B_DISTNTADJKMLN_TW * DISTNTADJKMLN + B_OCCUPDM_TW * OCCUPDM + B_MARITALDM_TW * MARITALDM + B_SEXDM_TW * SEXDM + B_NTRIPS_TW * NTRIPS + B_KIDS00TO05_TW * KIDS00TO05

3 ATLEASTONECAR ONE ASC_ATLEASTONECAR * ONE + B_PRCPTHHINCLN_CAR * PRCPTHHINCLN + B_RESTYPDM_CAR * RESTYPDM + B_RROMS_CAR * RROMS + B_EDUCDM_CAR * EDUCDM + B_HHEUDISTSTATLN_CAR * HHEUDISTSTATLN + B_PERHH_CAR * PERHH +

B_HHISMUMDM_CAR * HHISMUMDM + B_HHRORMUMDM_CAR * HHRORMUMDM + B_WKRORMUMDM_CAR * WKRORMUMDM + B_HHPRKM2LN_CAR * HHPRKM2LN + B_JOBPRKM2LN_CAR * JOBPRKM2LN + B_AGE_CAR * AGE + B_TM2WK910DM_CAR * TM2WK910DM + B_TM4RMWK1719DM_CAR * TM4RMWK1719DM + B_TM4RMWK2022DM_CAR * TM4RMWK2022DM + B_DISTNTADJKMLN_CAR * DISTNTADJKMLN + B_OCCUPDM_CAR * OCCUPDM + B_MARITALDM_CAR * MARITALDM + B_SEXDM_CAR * SEXDM + B_NTRIPS_CAR * NTRIPS + B_KIDS00TO05_CAR * KIDS00TO05

[Expressions]
ONE = 1

[Model]
$MNL

[Exclude]
(CHOICE3 == -999999) || (PRCPTHHINCLN == -999999) || (RESTYPDM == -999999) || (RROMS == -999999) || (EDUCDM == -999999) || (HHEUDISTSTATLN == -999999) || (PERHH == -999999) || (HHISMUMDM == -999999) || (HHRORMUMDM == -999999) || (WKRORMUMDM == -999999) || (HHPRKM2LN == -999999) || (JOBPRKM2LN == -999999) || (AGE == -999999) || (DISTNTADJKMLN == -999999) || (TM2WK910DM == -999999) || (TM4RMWK1719DM == -999999) || (TM4RMWK2022DM == -999999) || (OCCUPDM == -999999) || (MARITALDM == -999999) || (SEXDM == -999999)|| (NTRIPS == -999999) || (KIDS00TO05 == -999999)

3.2 MODEL OUTPUT

Model: Multinomial Logit
Number of estimated parameters: 44
Number of observations: 20,513
Number of individuals: 20,513
Null log-likelihood: -22,535.834
Cte log-likelihood: -12,651.307
Init log-likelihood: -22,535.834
Final log-likelihood: -10,704.317
Likelihood ratio test: 23,663.033
Rho-square: 0.525
Adjusted rho-square: 0.523
Final gradient norm: +7.660e-002
Diagnostic: Convergence reached...
Iterations: 25
Smallest singular value of the hessian: 0.789491

3.2.1 Utility Parameters

Name	Value	Std err	t-test	p-value		Robust Std err	Robust t-test	p-value	
ASC_ATLEASTONECAR	-25.6	1.08	-23.76	0.00		1.09	-23.50	0.00	
ASC_NOVEH	0.00	fixed							
ASC_ONLYTW	-9.82	0.630	-15.59	0.00		0.627	-15.65	0.00	
B_AGE_CAR	0.0190	0.00367	5.19	0.00		0.00360	5.28	0.00	
B_AGE_TW	-0.00945	0.00234	-4.04	0.00		0.00231	-4.08	0.00	
B_DISTNTADJKMLN_CAR	-0.225	0.0326	-6.89	0.00		0.0312	-7.22	0.00	
B_DISTNTADJKMLN_TW	-0.271	0.0198	-13.72	0.00		0.0194	-13.94	0.00	
B_EDUCDM_CAR	1.10	0.0777	14.19	0.00		0.0787	14.01	0.00	
B_EDUCDM_TW	0.416	0.0480	8.67	0.00		0.0486	8.57	0.00	
B_HHEUDISTSTATLN_CAR	0.209	0.0513	4.07	0.00		0.0537	3.90	0.00	
B_HHEUDISTSTATLN_TW	0.117	0.0309	3.78	0.00		0.0313	3.73	0.00	
B_HHISMUMDM_CAR	0.550	0.104	5.28	0.00		0.107	5.14	0.00	
B_HHISMUMDM_TW	0.0355	0.0737	0.48	0.63	*	0.0742	0.48	0.63	*
B_HHPRKM2LN_CAR	0.00660	0.0288	0.23	0.82	*	0.0298	0.22	0.82	*
B_HHPRKM2LN_TW	-0.0555	0.0160	-3.47	0.00		0.0163	-3.41	0.00	
B_HHRORMUMDM_CAR	-0.441	0.0990	-4.45	0.00		0.0993	-4.44	0.00	
B_HHRORMUMDM_TW	0.395	0.0618	6.39	0.00		0.0613	6.44	0.00	
B_JOBPRKM2LN_CAR	-0.0598	0.0229	-2.61	0.01		0.0230	-2.60	0.01	
B_JOBPRKM2LN_TW	-0.0717	0.0133	-5.38	0.00		0.0134	-5.36	0.00	
B_KIDS00TO05_CAR	0.358	0.117	3.07	0.00		0.117	3.05	0.00	
B_KIDS00TO05_TW	0.228	0.0643	3.55	0.00		0.0645	3.54	0.00	
B_MARITALDM_CAR	0.421	0.179	2.35	0.02		0.184	2.29	0.02	
B_MARITALDM_TW	0.157	0.0990	1.58	0.11	*	0.0988	1.58	0.11	*
B_NTRIPS_CAR	0.133	0.0621	2.15	0.03		0.0607	2.20	0.03	
B_NTRIPS_TW	0.215	0.0337	6.38	0.00		0.0341	6.30	0.00	
B_OCCUPDM_CAR	0.798	0.533	1.50	0.13	*	0.504	1.59	0.11	*
B_OCCUPDM_TW	0.597	0.205	2.92	0.00		0.207	2.89	0.00	
B_PERHH_CAR	0.346	0.0257	13.46	0.00		0.0248	13.92	0.00	
B_PERHH_TW	0.176	0.0164	10.71	0.00		0.0163	10.77	0.00	
B_PRCPTHHINCLN_CAR	1.54	0.0723	21.25	0.00		0.0753	20.39	0.00	
B_PRCPTHHINCLN_TW	0.602	0.0482	12.47	0.00		0.0484	12.43	0.00	
B_RESTYPDM_CAR	1.47	0.108	13.59	0.00		0.107	13.69	0.00	
B_RESTYPDM_TW	0.327	0.0495	6.61	0.00		0.0497	6.59	0.00	
B_RROMS_CAR	0.502	0.0374	13.42	0.00		0.0391	12.84	0.00	
B_RROMS_TW	0.274	0.0257	10.64	0.00		0.0259	10.57	0.00	
B_SEXDM_CAR	0.723	0.284	2.54	0.01		0.283	2.55	0.01	
B_SEXDM_TW	0.895	0.183	4.89	0.00		0.181	4.93	0.00	
B_TM2WK910DM_CAR	0.225	0.0723	3.10	0.00		0.0744	3.02	0.00	
B_TM2WK910DM_TW	0.108	0.0440	2.46	0.01		0.0439	2.46	0.01	
B_TM4RMWK1719DM_CAR	0.217	0.120	1.80	0.07	*	0.121	1.79	0.07	*
B_TM4RMWK1719DM_TW	-0.124	0.0612	-2.03	0.04		0.0609	-2.04	0.04	
B_TM4RMWK2022DM_CAR	0.495	0.120	4.13	0.00		0.121	4.09	0.00	
B_TM4RMWK2022DM_TW	-0.0502	0.0613	-0.82	0.41	*	0.0609	-0.82	0.41	*
B_WKRORMUMDM_CAR	0.432	0.111	3.88	0.00		0.111	3.88	0.00	
B_WKRORMUMDM_TW	0.158	0.0666	2.37	0.02		0.0671	2.35	0.02	

Appendix 4

Regression Model Outputs for Vehicle Use

Notes:
VKT = Vehicle Kilometers Traveled
PKT = Person Kilometers Traveled
TW = Motorized Two-Wheeler
All reduced models have been run without the speed variable
These outputs are based on work done with SPSS (v 13), 2004.

4.1 CAR VKT (FULL MODEL)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	TM2WK8102D, HHPERJOBSLN, EMPHHLN, OCCUP2DP3, MNMODEP22D, PRCPTHHINCLN, HHPRKM2LN, SPEEDREDLN, HHSUBMUMDM, JOBSPERINDIVLN, WKNTDISTSTATLN, PRCPTTBUDGTLN, UPWKISMUMDM, JOBPRKM2LN	.	Enter

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	VKTCR2DRI = 1 (Selected)	VKTCR2DRI ~= 1 (Unselected)			
1	.804		.647	.641	.72646

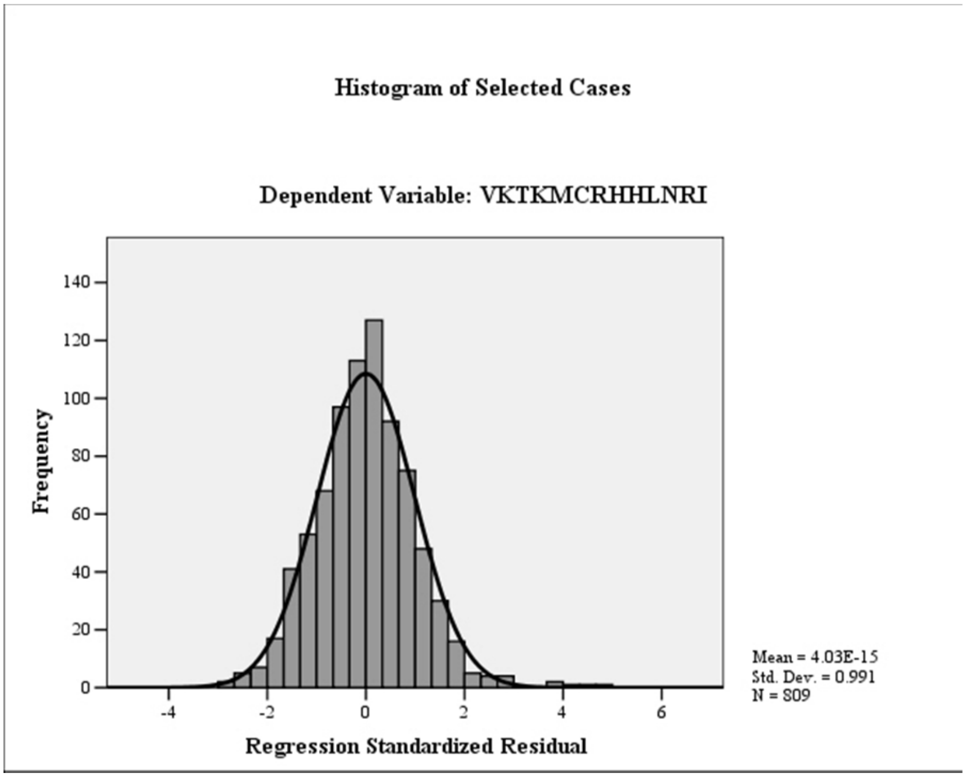
ANOVA

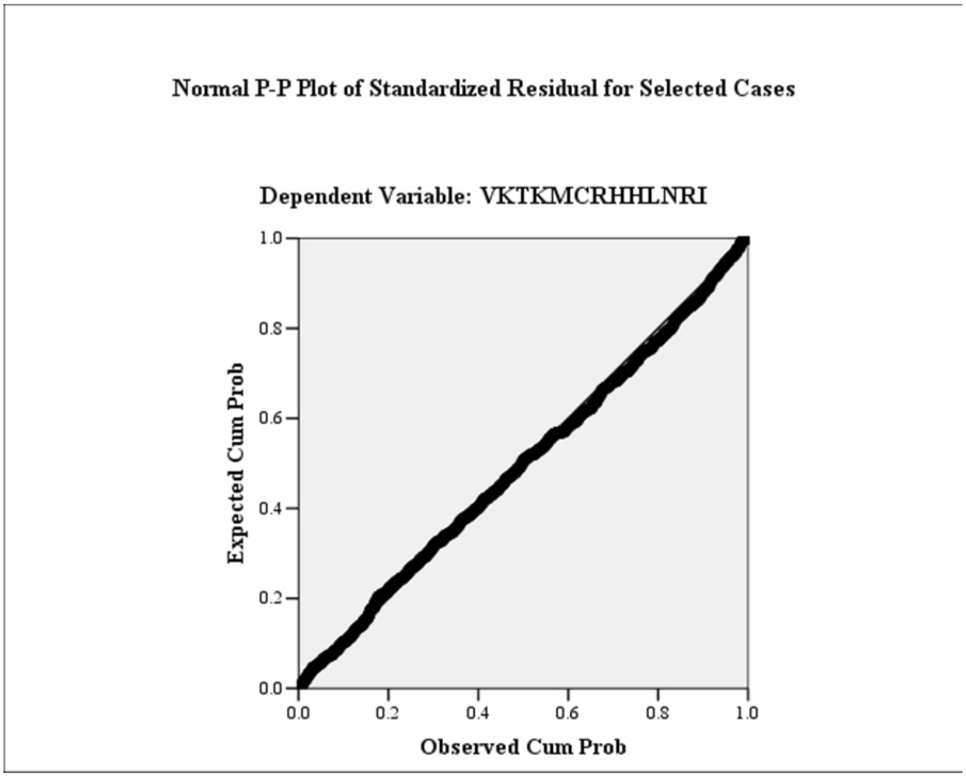
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	768.507	14	54.893	104.016	.000
	Residual	419.024	794	.528		
	Total	1187.532	808			

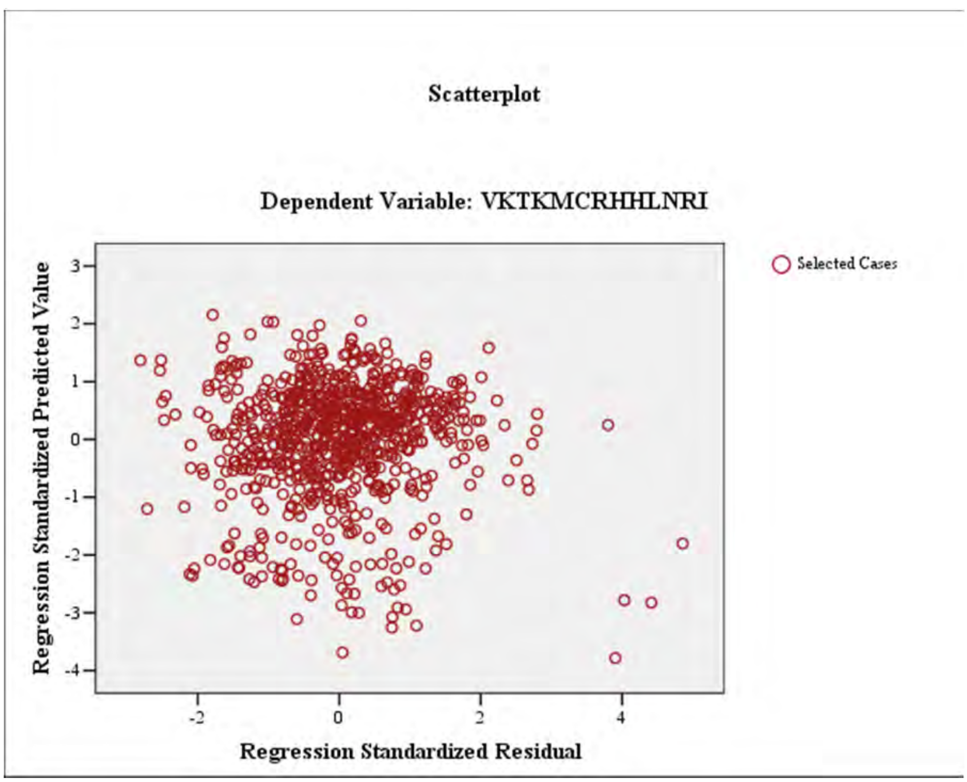
Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.175	.604		-1.945	.052
	HHPRKM2LN	-.068	.021	-.074	-3.238	.001
	JOBSPERINDIVLN	-.071	.029	-.055	-2.473	.014
	HHSUBMUMDM	.217	.056	.088	3.879	.000
	WKNTDISTSTATLN	.061	.036	.043	1.703	.089
	HHPERJOBSLN	-.104	.024	-.109	-4.281	.000
	JOBPRKM2LN	-.056	.020	-.082	-2.808	.005
	UPWKISMUMDM	.213	.072	.084	2.959	.003
	EMPHHLN	.281	.057	.105	4.894	.000
	OCCUP2DP3	.653	.301	.046	2.174	.030
	PRCPTHHINCLN	.042	.048	.021	.875	.382
	MNMODEP22D	.145	.069	.046	2.116	.035
	PRCPTTBUDGTLN	.073	.047	.037	1.552	.121
	SPEEDREDLN	.928	.027	.745	34.316	.000
	TM2WK8102D	.143	.070	.044	2.054	.040

Residuals Statistics										
	VKTCR2DRI = 1 (Selected)					VKTCR2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.3009	4.4910	2.3885	.97526	809	.	.	.	.	0
Residual	-2.04341	3.52839	.00000	.72013	809	.	.	.	.	0
Std. Predicted Value	-3.783	2.156	.000	1.000	809	.	.	.	.	0
Std. Residual	-2.813	4.857	.000	.991	809	.	.	.	.	0




Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: VKTKMCRHHLNRI
Expected Cum Prob
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0


Scatterplot
Dependent Variable: VKTKMCRHHLNRI
Selected Cases
Regression Standardized Predicted Value
Regression Standardized Residual
3
2
1
0
-1
-2
-3
-4
-2
0
2
4

4.2 CAR VKT (REDUCED MODEL)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	TM2WK8102D, HHPERJOBSLN, EMPHHLN, OCCUP2DP3, MNMODEP22D, PRCPTHHINCLN, HHPRKM2LN, HHSUBMUMDM, JOBSPERINDIVLN, WKNTDISTSTATLN, PRCPTTBUDGTLN, UPWKISMUMDM, JOBPRKM2LN	.	Enter

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	VKTCR2DRI = 1 (Selected)	VKTCR2DRI ~= 1 (Unselected)			
1	.352		.124	.109	1.14403

ANOVA

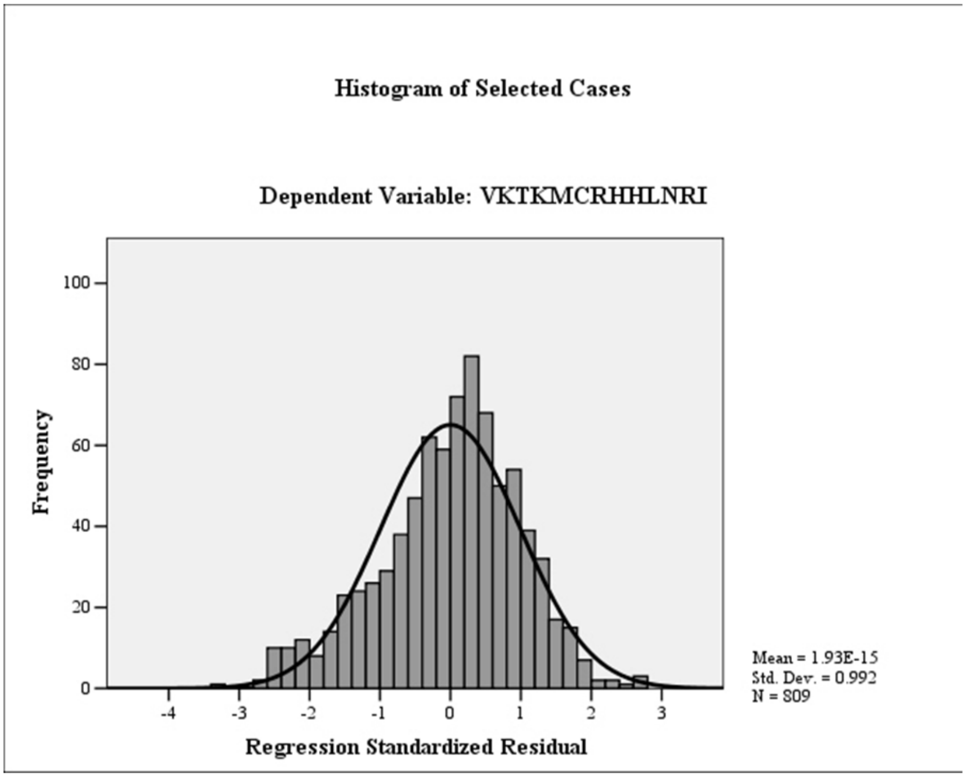
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	147.039	13	11.311	8.642	.000
	Residual	1040.493	795	1.309		
	Total	1187.532	808			

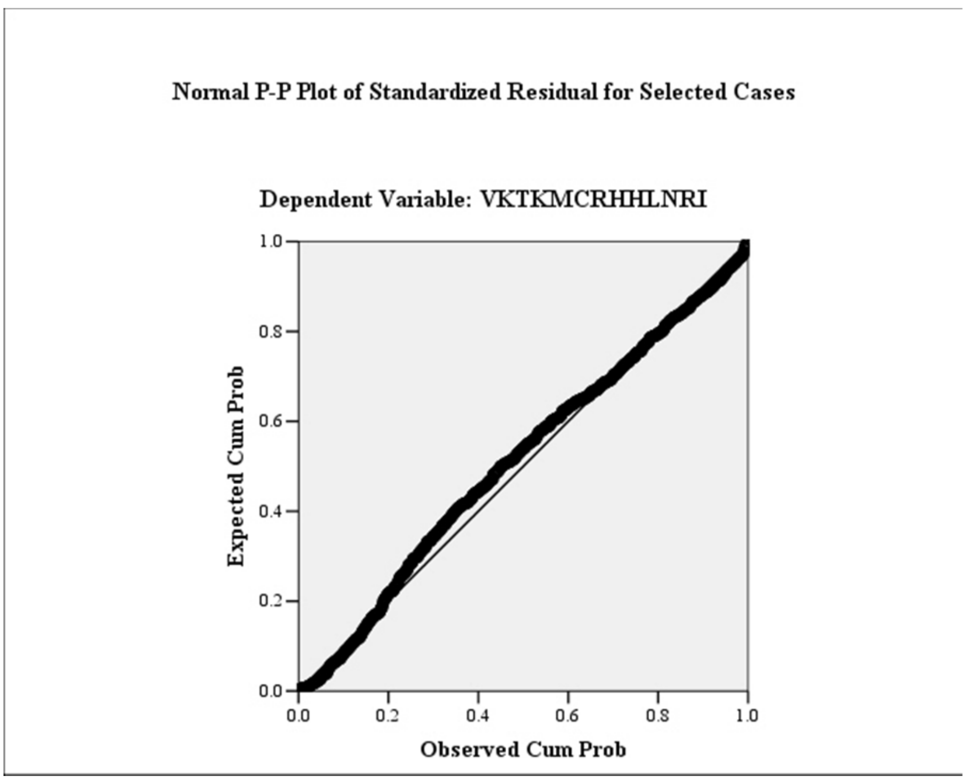
Coefficients

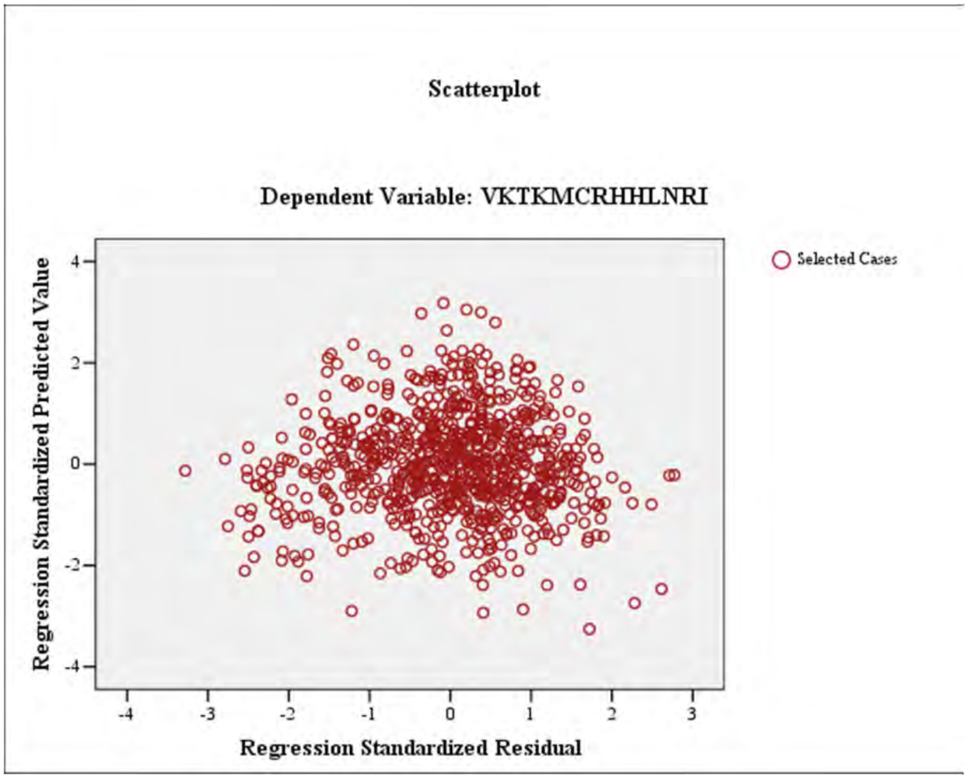
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.367	.944		1.448	.148
	HHPRKM2LN	-.106	.033	-.115	-3.209	.001
	JOBSPERINDIVLN	-.214	.045	-.166	-4.779	.000
	HHSUBMUMDM	.364	.088	.147	4.150	.000
	WKNTDISTSTATLN	.010	.057	.007	.177	.860
	HHPERJOBSLN	-.232	.038	-.244	-6.155	.000
	JOBPRKM2LN	-.119	.031	-.173	-3.798	.000
	UPWKISMUMDM	.320	.114	.126	2.821	.005
	EMPHHLN	.176	.090	.066	1.946	.052
	OCCUP2DP3	.279	.473	.020	.589	.556
	PRCPTHHINCLN	.049	.075	.024	.644	.520
	MNMODEP22D	.143	.108	.046	1.326	.185
	PRCPTTBUDGTLN	.130	.074	.067	1.759	.079
	TM2WK8102D	.202	.110	.062	1.840	.066

Residuals Statistics

	VKTCR2DRI = 1 (Selected)					VKTCR2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.0004	3.7449	2.3885	.42659	809	.	.	.	.	0
Residual	-3.75345	3.17095	.00000	1.13479	809	.	.	.	.	0
Std. Predicted Value	-3.254	3.180	.000	1.000	809	.	.	.	.	0
Std. Residual	-3.281	2.772	.000	.992	809	.	.	.	.	0


Histogram of Selected Cases
Dependent Variable: VKTKMCRHHLNRI
Frequency
Regression Standardized Residual
Mean = 1.93E-15
Std. Dev. = 0.992
N = 809


Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: VKTKMCRHHLNRI
Expected Cum Prob
Observed Cum Prob



4.3 CAR PKT (FULL MODEL)

Variables Entered/Removed			
Model	Variables Entered	Variables Removed	Method
1	TM2WK8102D, WKNTDISTSTATLN, SPEEDREDLN, MNMODEP22D, OCCUP2DP3, EMPHHLN, PRCPTHHINCLN, HHSUBMUMDM, JOBSPERINDIVLN, HHPRKM2LN, HHPERJOBSLN, PRCPTTBUDGTLN, UPWKISMUMDM, JOBPRKM2LN	.	Enter

Model Summary					
Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	PKTCR2DRI = 1 (Selected)	PKTCR2DRI ~= 1 (Unselected)			
1	.798		.637	.632	.74724

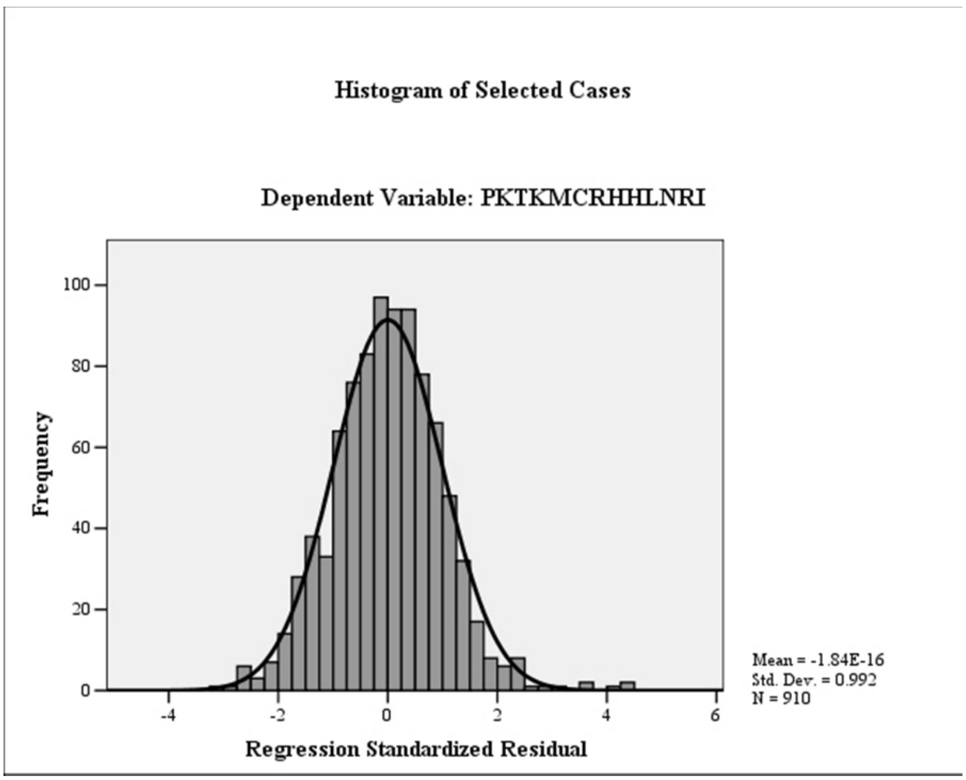
ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	878.695	14	62.764	112.405	.000
	Residual	499.744	895	.558		
	Total	1378.439	909			

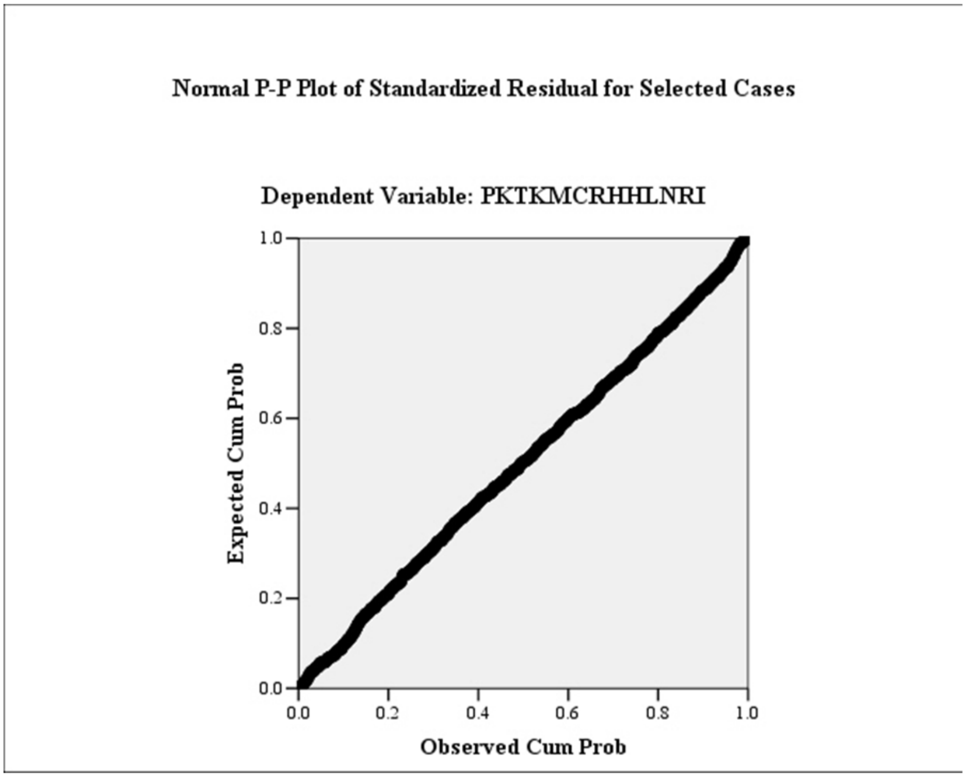
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.995	.591		-1.685	.092
	HHPRKM2LN	-.069	.020	-.075	-3.410	.001
	JOBSPERINDIVLN	-.057	.028	-.043	-2.027	.043
	HHSUBMUMDM	.178	.054	.071	3.306	.001
	WKNTDISTSTATLN	.066	.035	.046	1.870	.062
	HHPERJOBSLN	-.100	.024	-.104	-4.263	.000
	JOBPRKM2LN	-.051	.019	-.074	-2.648	.008
	UPWKISMUMDM	.235	.070	.091	3.343	.001
	EMPHHLN	.557	.056	.205	10.027	.000
	OCCUP2DP3	.576	.308	.038	1.867	.062
	PRCPTHHINCLN	.028	.046	.014	.607	.544
	MNMODEP22D	.211	.065	.068	3.271	.001
	PRCPTTBUDGTLN	.083	.043	.044	1.916	.056
	SPEEDREDLN	.922	.026	.727	35.087	.000
	TM2WK8102D	.065	.066	.020	.978	.328

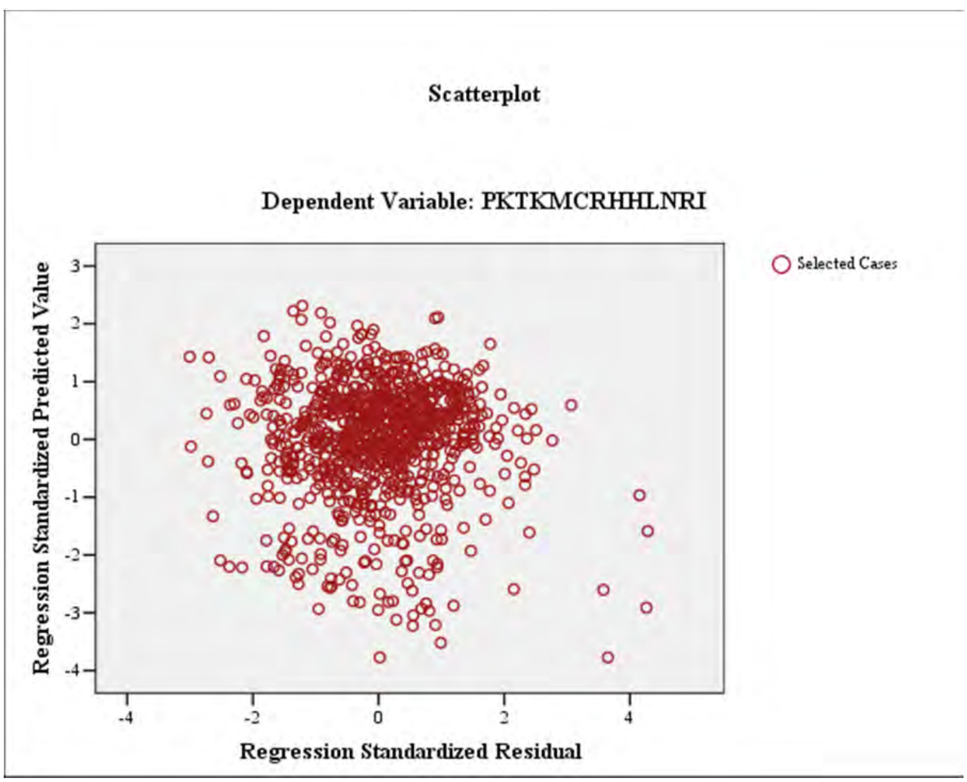
Coefficients

	PKTCR2DRI = 1 (Selected)					PKTCR2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.1913	4.7908	2.5189	.98319	910	.	.	.	.	0
Residual	-2.24487	3.20107	.00000	.74147	910	.	.	.	.	0
Std. Predicted Value	-3.774	2.311	.000	1.000	910	.	.	.	.	0
Std. Residual	-3.004	4.284	.000	.992	910	.	.	.	.	0

Residuals Statistics




Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: PKTKMCRHHLNRI
Expected Cum Prob
Observed Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0


Scatterplot
Dependent Variable: PKTKMCRHHLNRI
Selected Cases
Regression Standardized Predicted Value
Regression Standardized Residual
3
2
1
0
-1
-2
-3
-4
-4
-2
0
2
4

4.4 CAR PKT (REDUCED MODEL)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	TM2WK8102D, WKNTDISTSTATLN, EMPHHLN, PRCPTHHINCLN, OCCUP2DP3, MNMODEP22D, JOBSPERINDIVLN, HHSUBMUMDM, HHPRKM2LN, HHPERJOBSLN, PRCPTTBUDGTLN, UPWKISMUMDM, JOBPRKM2LN	.	Enter

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	PKTCR2DRI = 1 (Selected)	PKTCR2DRI ~= 1 (Unselected)			
1	.373		.139	.126	1.15107

ANOVA

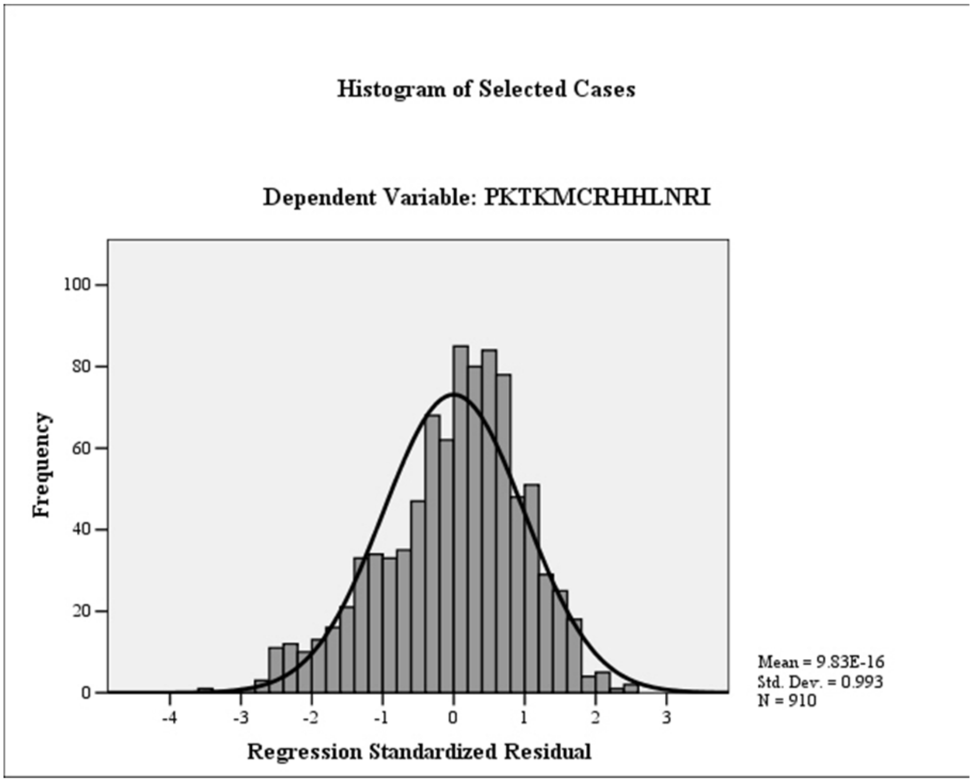
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	191.282	13	14.714	11.105	.000
	Residual	1187.157	896	1.325		
	Total	1378.439	909			

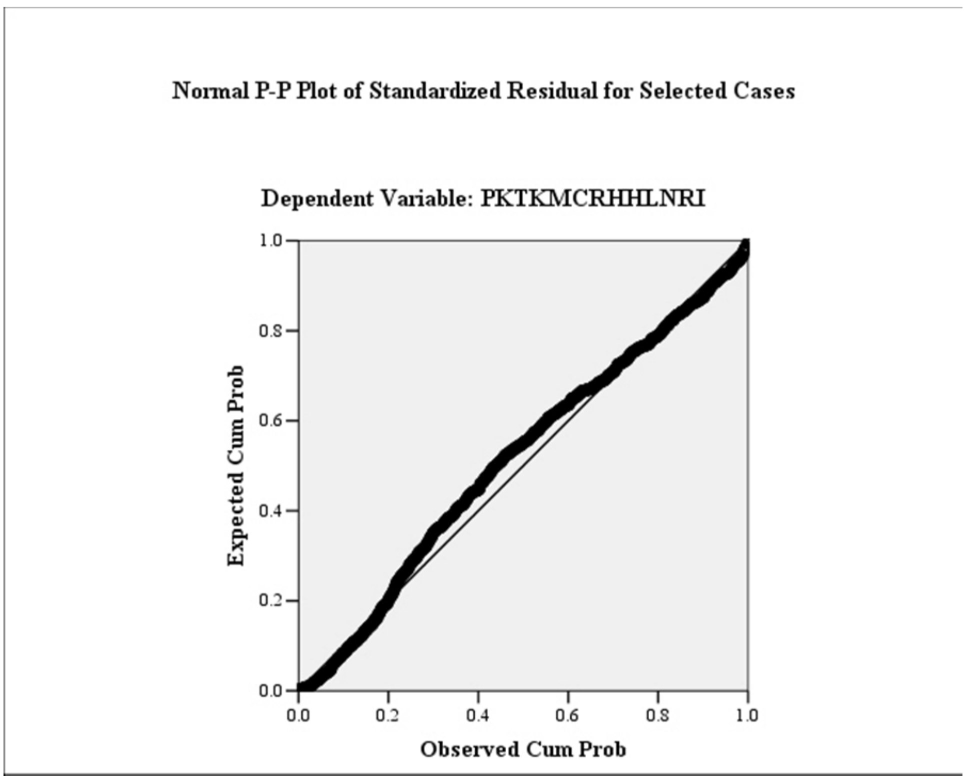
Coefficients

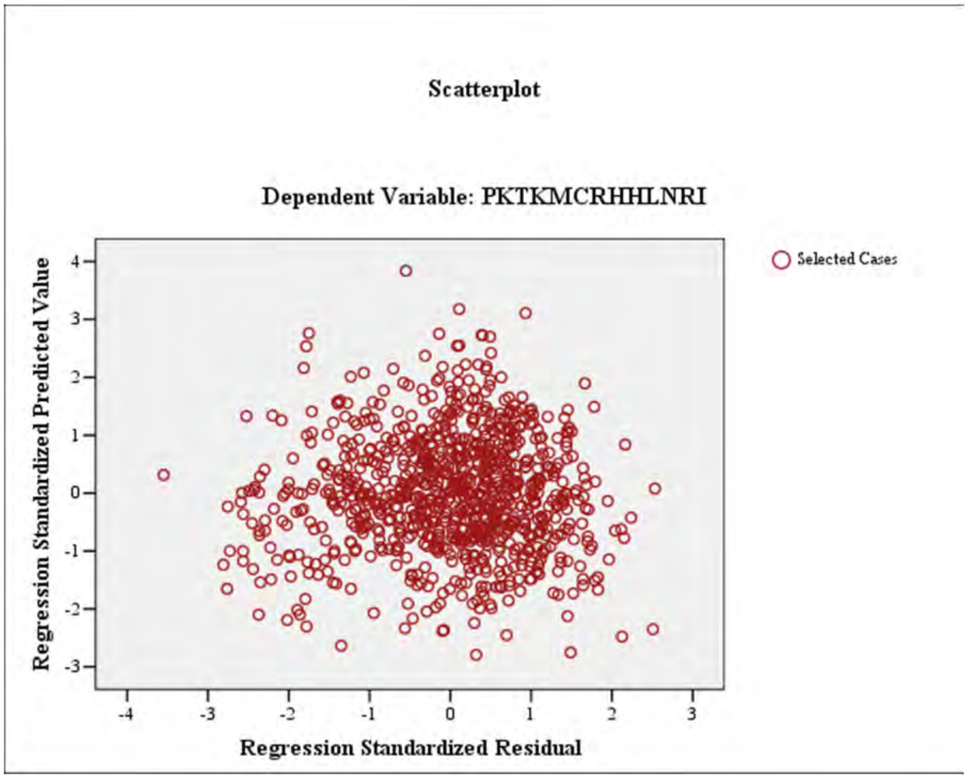
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.872	.901		2.077	.038
	HHPRKM2LN	-.106	.031	-.115	-3.389	.001
	JOBSPERINDIVLN	-.190	.043	-.145	-4.459	.000
	HHSUBMUMDM	.290	.083	.115	3.494	.000
	WKNTDISTSTATLN	.002	.054	.001	.032	.974
	HHPERJOBSLN	-.236	.036	-.243	-6.592	.000
	JOBPRKM2LN	-.120	.030	-.174	-4.062	.000
	UPWKISMUMDM	.288	.108	.111	2.657	.008
	EMPHHLN	.487	.085	.179	5.698	.000
	OCCUP2DP3	.243	.475	.016	.511	.609
	PRCPTHHINCLN	.031	.071	.016	.444	.657
	MNMODEP22D	.251	.099	.081	2.522	.012
	PRCPTTBUDGTLN	.107	.067	.056	1.594	.111
	TM2WK8102D	.112	.102	.035	1.102	.271

Residuals Statistics

	PKTCR2DRI = 1 (Selected)					PKTCR2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.2372	4.2803	2.5189	.45873	910	.	.	.	.	0
Residual	-4.08399	2.91393	.00000	1.14280	910	.	.	.	.	0
Std. Predicted Value	-2.794	3.840	.000	1.000	910	.	.	.	.	0
Std. Residual	-3.548	2.532	.000	.993	910	.	.	.	.	0


Histogram of Selected Cases
Dependent Variable: PKTKMCRHHLNRI
Frequency
100
80
60
40
20
0
-4
-3
-2
-1
0
1
2
3
Regression Standardized Residual
Mean = 9.83E-16
Std. Dev. = 0.993
N = 910


Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: PKTKMCRHHLNRI
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob



4.5 TWO-WHEELER VKT (FULL MODEL)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	TM4RMWK17192D, HHISMUMDM, PRCPTTBUDGTLN, MNMODEP22D, NTRIPSLN, SPEEDREDLN, EMPHHLN, UPWKSUBMUMDM, JOBSPERINDIVLN, HHNTDISTSTATLN, HHPERJOBSLN, JOBPRKM2LN, PRCPTHHINCLN, HHPRKM2LN	.	Enter

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	VKTTW2DRI = 1 (Selected)	VKTTW2DRI ~= 1 (Unselected)			
1	.773		.598	.596	.75288

ANOVA

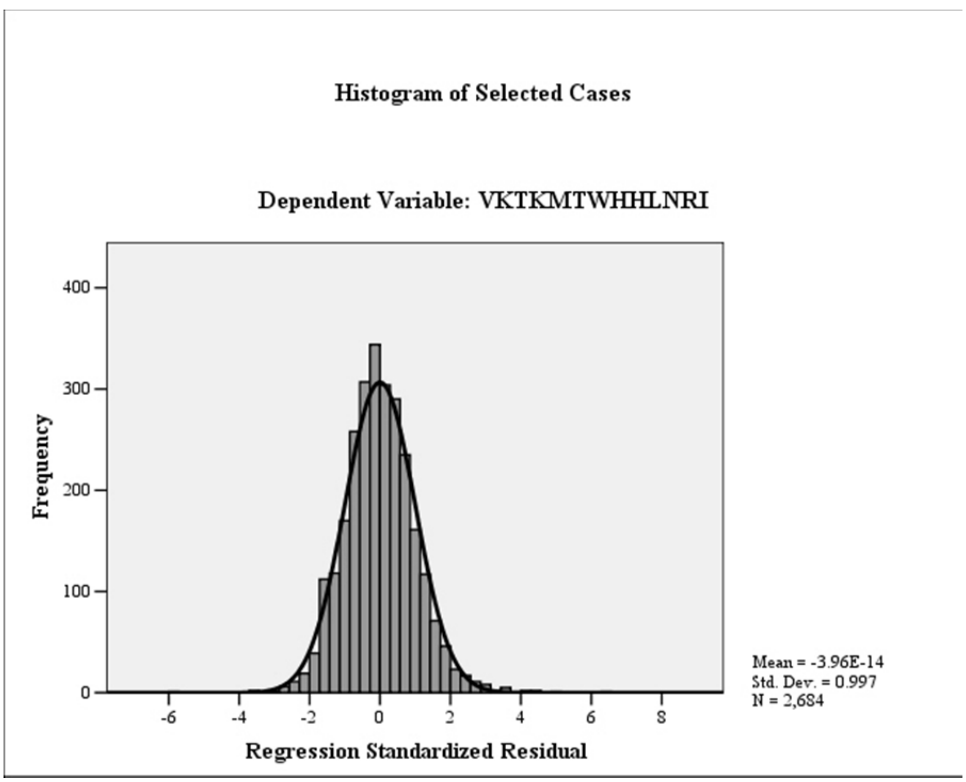
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2248.636	14	160.617	283.359	.000
	Residual	1512.873	2669	.567		
	Total	3761.509	2683			

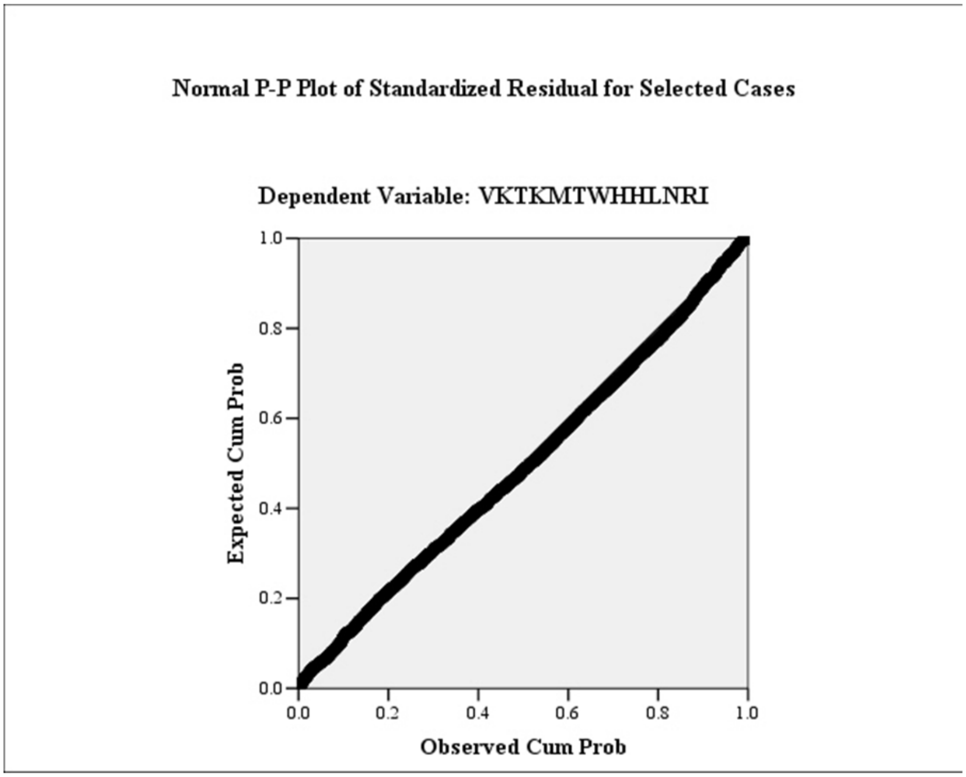
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.163	.307		-.529	.597
	HHNTDISTSTATLN	.065	.021	.043	3.100	.002
	HHPRKM2LN	-.076	.012	-.101	-6.556	.000
	JOBSPERINDIVLN	.024	.018	.017	1.289	.198
	HHISMUMDM	.081	.050	.023	1.626	.104
	HHPERJOBSLN	-.098	.015	-.089	-6.427	.000
	JOBPRKM2LN	-.051	.010	-.078	-5.073	.000
	UPWKSUBMUMDM	.275	.033	.111	8.352	.000
	EMPHHLN	.208	.033	.078	6.215	.000
	PRCPTHHINCLN	-.067	.030	-.031	-2.189	.029
	NTRIPSLN	.449	.061	.093	7.400	.000
	MNMODEP22D	.161	.032	.064	4.994	.000
	PRCPTTBUDGTLN	.174	.029	.086	6.052	.000
	SPEEDREDLN	.789	.014	.719	55.887	.000
	TM4RMWK17192D	.152	.030	.062	5.014	.000

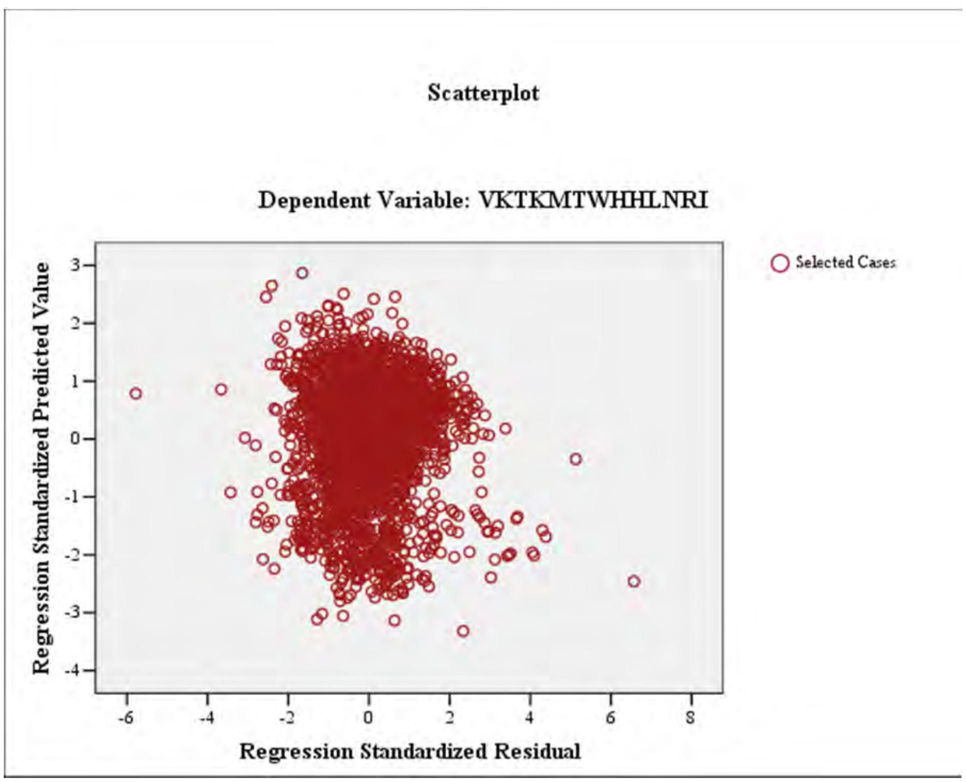
Coefficients

	VKTTW2DRI = 1 (Selected)					VKTTW2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.0301	4.6315	2.0071	.91548	2684	.	.	.	.	0
Residual	-4.35199	4.94671	.00000	.75092	2684	.	.	.	.	0
Std. Predicted Value	-3.318	2.867	.000	1.000	2684	.	.	.	.	0
Std. Residual	-5.780	6.570	.000	.997	2684	.	.	.	.	0

Residuals Statistics




Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: VKTKMTWHHLNRI
1.0
0.8
0.6
0.4
0.2
0.0
Expected Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob


Scatterplot
Dependent Variable: VKTKMTWHHLNRI
Selected Cases
3
2
1
0
-1
-2
-3
-4
Regression Standardized Predicted Value
-6
-4
-2
0
2
4
6
8
Regression Standardized Residual

4.6 TWO-WHEELER VKT (REDUCED MODEL)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	TM4RMWK17192D, HHISMUMDM, PRCPTTBUDGTLN, MNMODEP22D, NTRIPSLN, JOBSPERINDIVLN, EMPHHLN, UPWKSUBMUMDM, HHPERJOBSLN, HHNTDISTSTATLN, JOBPRKM2LN, PRCPTHHINCLN, HHPRKM2LN	.	Enter

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	VKTTW2DRI = 1 (Selected)	VKTTW2DRI ~= 1 (Unselected)			
1	.357		.127	.123	1.10892

ANOVA

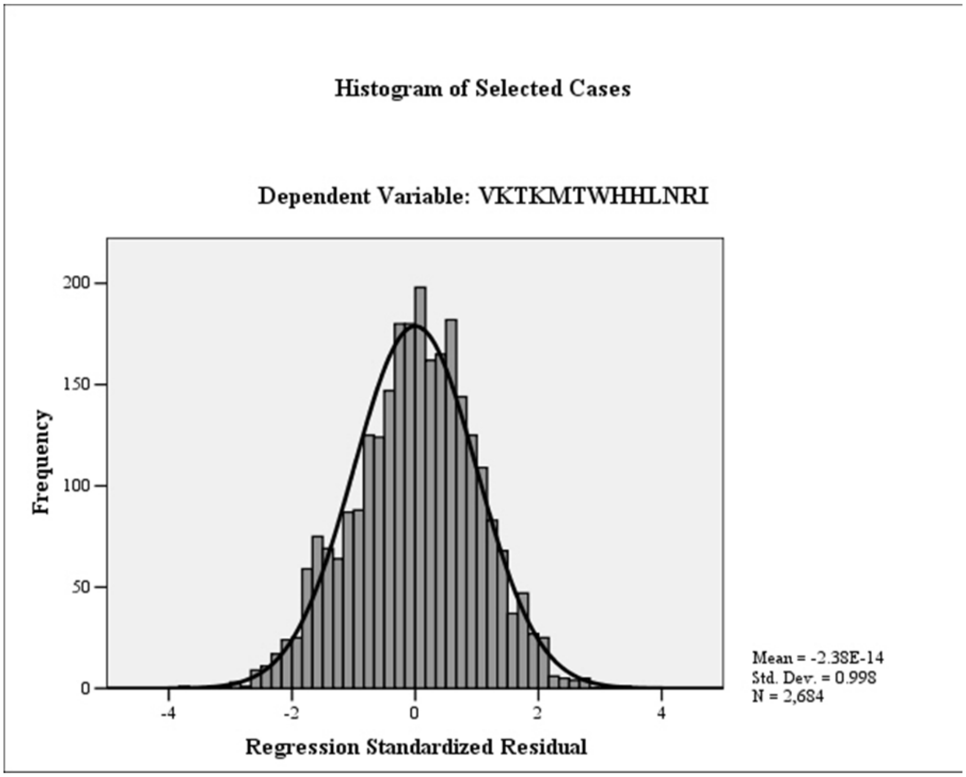
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	478.212	13	36.786	29.914	.000
	Residual	3283.297	2670	1.230		
	Total	3761.509	2683			

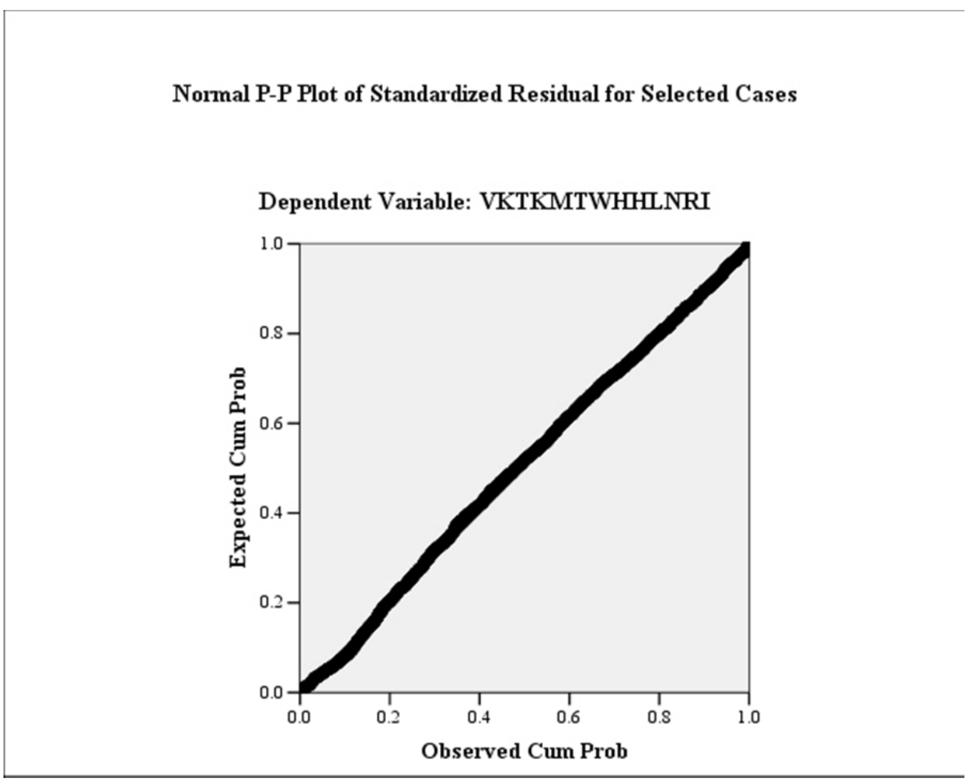
Coefficients

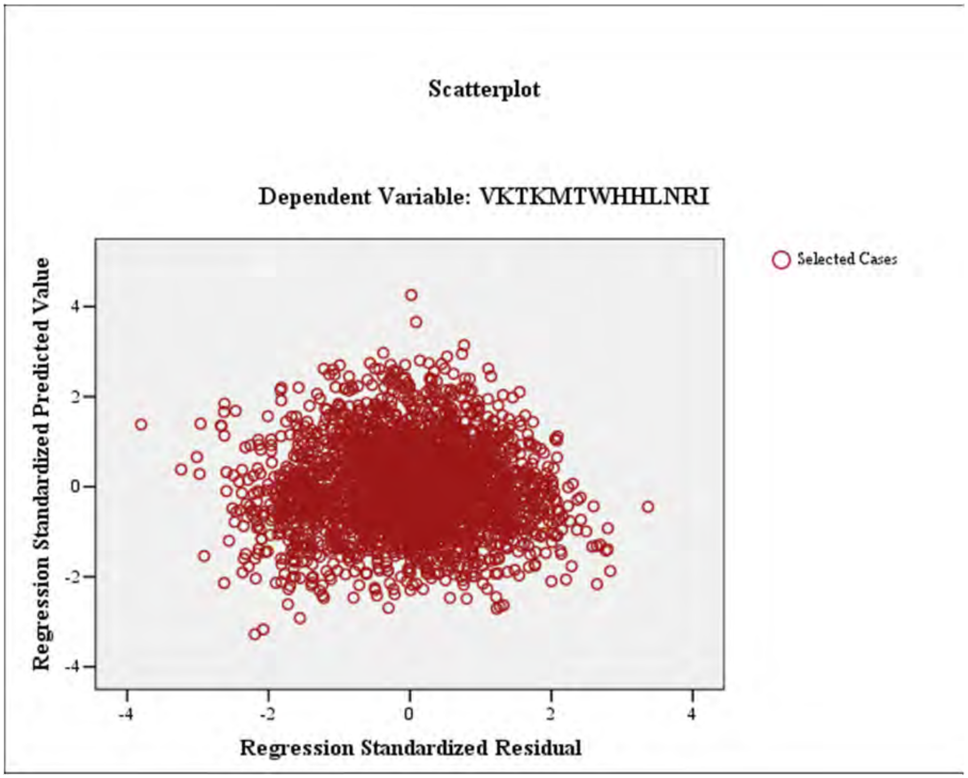
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.094	.452		2.422	.016
	HHNTDISTSTATLN	.036	.031	.024	1.165	.244
	HHPRKM2LN	-.102	.017	-.136	-5.986	.000
	JOBSPERINDIVLN	-.187	.026	-.133	-7.055	.000
	HHISMUMDM	.099	.074	.028	1.338	.181
	HHPERJOBSLN	-.258	.022	-.233	-11.670	.000
	JOBPRKM2LN	-.064	.015	-.098	-4.335	.000
	UPWKSUBMUMDM	.424	.048	.172	8.771	.000
	EMPHHLN	.180	.049	.068	3.651	.000
	PRCPTHHINCLN	-.097	.045	-.045	-2.174	.030
	NTRIPSLN	.294	.089	.061	3.294	.001
	MNMODEP22D	.069	.047	.027	1.455	.146
	PRCPTTBUDGTLN	.281	.042	.138	6.635	.000
	TM4RMWK17192D	.221	.045	.090	4.938	.000

Residuals Statistics

	VKTTW2DRI = 1 (Selected)					VKTTW2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.6238	3.8037	2.0071	.42218	2684	.	.	.	.	0
Residual	-4.21658	3.73314	.00000	1.10623	2684	.	.	.	.	0
Std. Predicted Value	-3.277	4.256	.000	1.000	2684	.	.	.	.	0
Std. Residual	-3.802	3.366	.000	.998	2684	.	.	.	.	0


Histogram of Selected Cases
Dependent Variable: VKTKMTWHHLNRI
Frequency
200
150
100
50
0
-4
-2
0
2
4
Regression Standardized Residual
Mean = -2.38E-14
Std. Dev. = 0.998
N = 2,684


Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: VKTKMTWHHLNRI
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob



4.7 TWO-WHEELER PKT (FULL MODEL)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	TM4RMWK17192D, HHISMUMDM, EMPHHLN, SPEEDREDLN, NTRIPSLN, PRCPTHHINCLN, MNMODEP22D, UPWKSUBMUMDM, JOBSPERINDIVLN, HHNTDISTSTATLN, HHPERJOBSLN, PRCPTTBUDGTLN, HHPRKM2LN, JOBPRKM2LN	.	Enter

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	PKTTW2DRI = 1 (Selected)	PKTTW2DRI ~= 1 (Unselected)			
1	.771		.594	.592	.76160

ANOVA

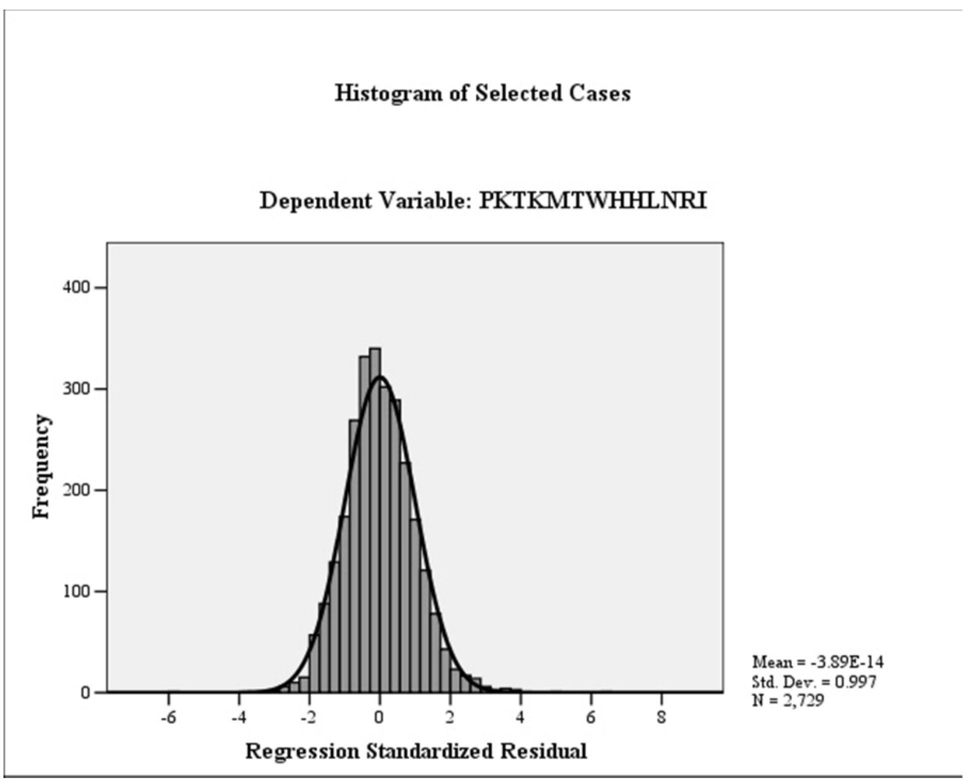
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2304.979	14	164.641	283.848	.000
	Residual	1574.212	2714	.580		
	Total	3879.192	2728			

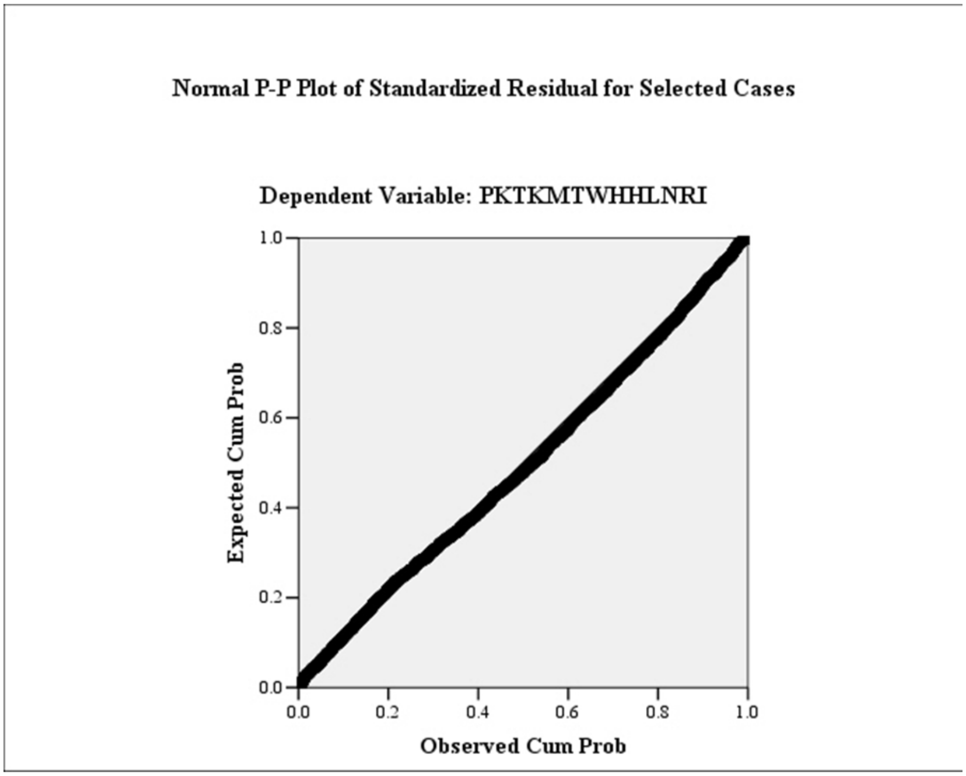
Coefficients

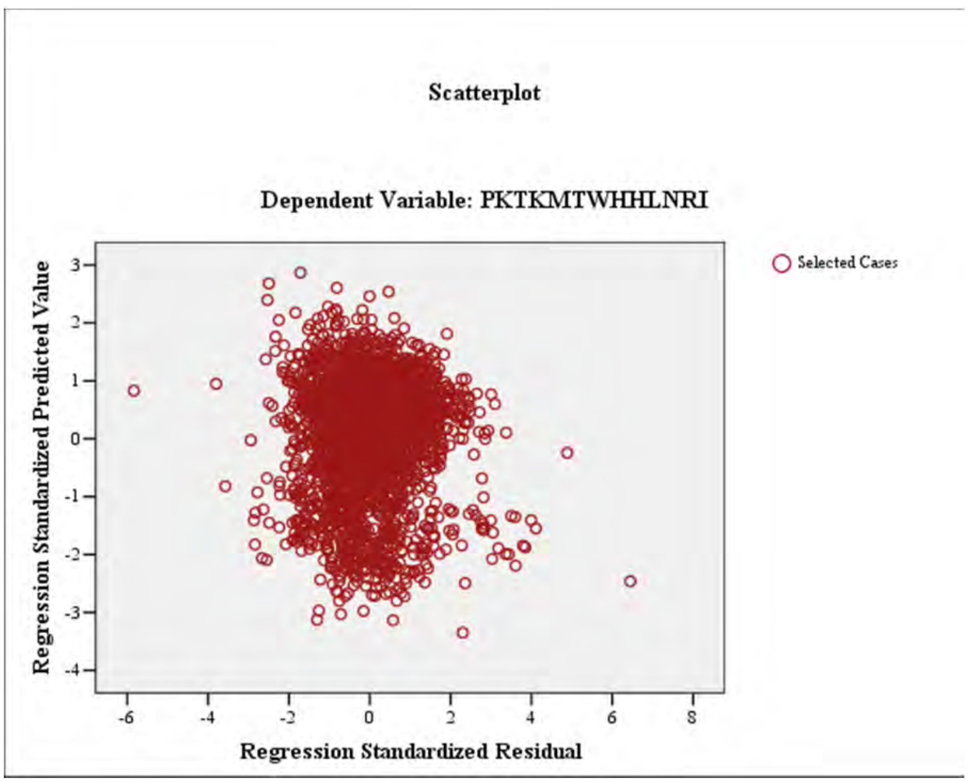
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-.076	.309		-.247	.805
	HHNTDISTSTATLN	.068	.021	.045	3.264	.001
	HHPRKM2LN	-.067	.012	-.088	-5.779	.000
	JOBSPERINDIVLN	.024	.018	.017	1.324	.186
	HHISMUMDM	.066	.050	.019	1.326	.185
	HHPERJOBSLN	-.095	.015	-.085	-6.192	.000
	JOBPRKM2LN	-.054	.010	-.082	-5.337	.000
	UPWKSUBMUMDM	.253	.033	.102	7.656	.000
	EMPHHLN	.331	.033	.124	9.900	.000
	PRCPTHHINCLN	-.079	.030	-.036	-2.592	.010
	NTRIPSLN	.432	.061	.088	7.073	.000
	MNMODEP22D	.236	.032	.093	7.294	.000
	PRCPTTBUDGTLN	.173	.029	.085	6.062	.000
	SPEEDREDLN	.790	.014	.716	55.790	.000
	TM4RMWK17192D	.122	.030	.050	4.019	.000

Residuals Statistics

	PKTTW2DRI = 1 (Selected)					PKTTW2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-1.0245	4.6914	2.0557	.91920	2729	.	.	.	.	0
Residual	-4.44447	4.90951	.00000	.75964	2729	.	.	.	.	0
Std. Predicted Value	-3.351	2.867	.000	1.000	2729	.	.	.	.	0
Std. Residual	-5.836	6.446	.000	.997	2729	.	.	.	.	0




Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: PKTKMTWHHLNRI
Expected Cum Prob
Observed Cum Prob
0.0
0.2
0.4
0.6
0.8
1.0


Scatterplot
Dependent Variable: PKTKMTWHHLNRI
Selected Cases
Regression Standardized Predicted Value
Regression Standardized Residual
-6
-4
-2
0
2
4
6
8
3
2
1
0
-1
-2
-3
-4

4.8 TWO-WHEELER PKT (REDUCED MODEL)

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	TM4RMWK17192D, HHISMUMDM, EMPHHLN, NTRIPSLN, PRCPTTBUDGTLN, JOBSPERINDIVLN, MNMODEP22D, UPWKSUBMUMDM, HHPERJOBSLN, HHNTDISTSTATLN, PRCPTHHINCLN, HHPRKM2LN, JOBPRKM2LN	.	Enter

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	PKTTW2DRI = 1 (Selected)	PKTTW2DRI ~= 1 (Unselected)			
1	.359		.129	.125	1.11569

ANOVA

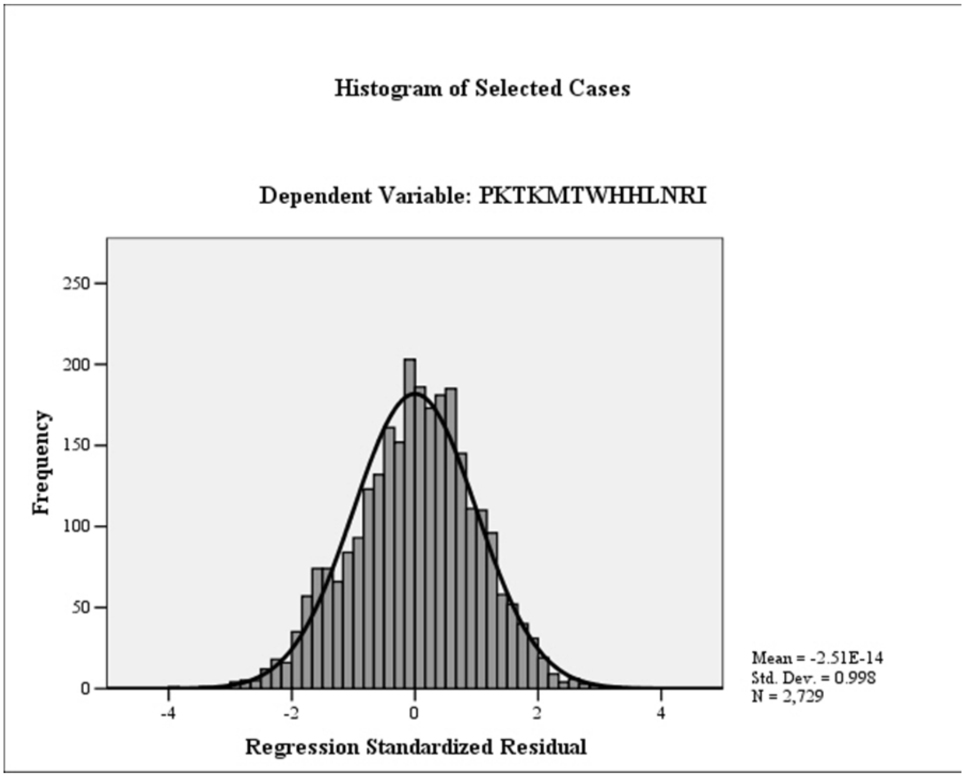
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	499.637	13	38.434	30.876	.000
	Residual	3379.555	2715	1.245		
	Total	3879.192	2728			

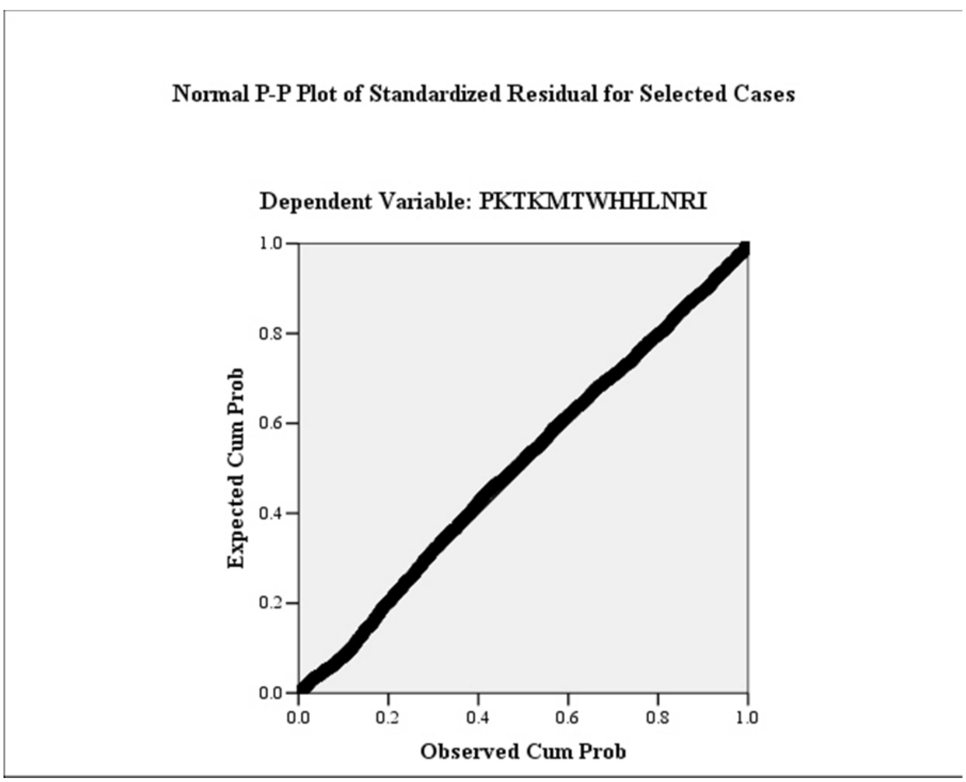
Coefficients

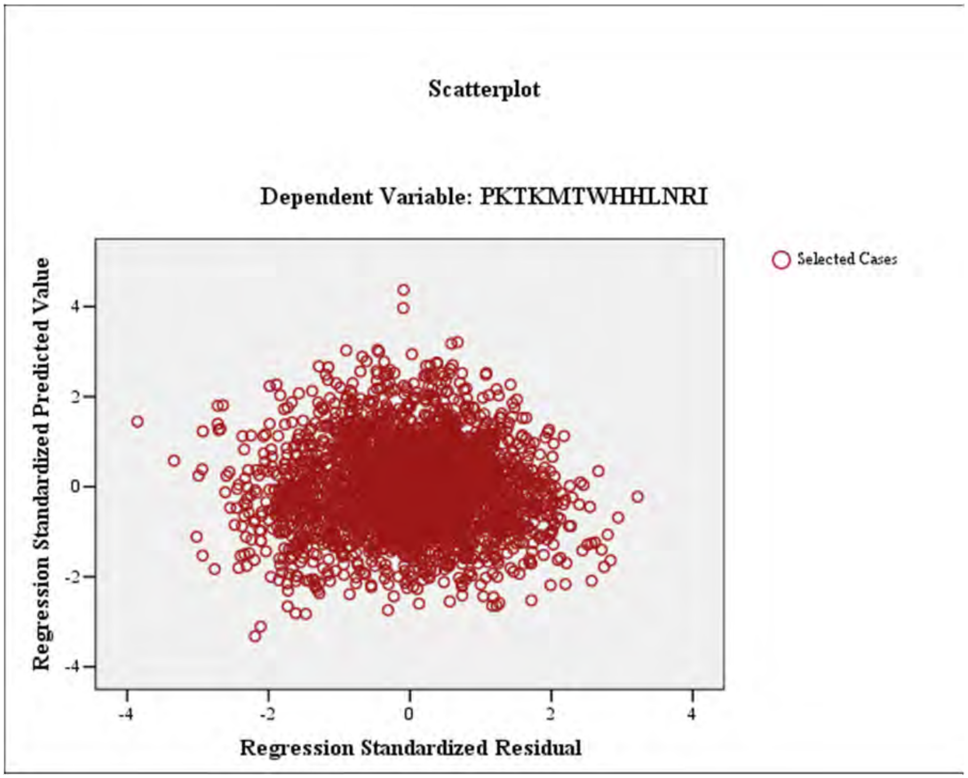
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.170	.451		2.593	.010
	HHNTDISTSTATLN	.037	.031	.024	1.205	.228
	HHPRKM2LN	-.094	.017	-.124	-5.544	.000
	JOBSPERINDIVLN	-.187	.026	-.133	-7.092	.000
	HHISMUMDM	.078	.073	.022	1.068	.286
	HHPERJOBSLN	-.256	.022	-.229	-11.563	.000
	JOBPRKM2LN	-.067	.015	-.102	-4.561	.000
	UPWKSUBMUMDM	.400	.048	.161	8.284	.000
	EMPHHLN	.295	.049	.111	6.024	.000
	PRCPTHHINCLN	-.119	.044	-.055	-2.684	.007
	NTRIPSLN	.278	.089	.057	3.113	.002
	MNMODEP22D	.143	.047	.056	3.030	.002
	PRCPTTBUDGTLN	.296	.042	.145	7.089	.000
	TM4RMWK17192D	.187	.045	.076	4.200	.000

Residuals Statistics

	PKTTW2DRI = 1 (Selected)					PKTTW2DRI ~= 1 (Unselected)				
	Minimum	Maximum	Mean	Std. Deviation	N	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.6346	3.9257	2.0557	.42796	2729	.	.	.	.	0
Residual	-4.30043	3.59177	.00000	1.11303	2729	.	.	.	.	0
Std. Predicted Value	-3.321	4.370	.000	1.000	2729	.	.	.	.	0
Std. Residual	-3.854	3.219	.000	.998	2729	.	.	.	.	0


Histogram of Selected Cases
Dependent Variable: PKTKMTWHHLNRI
Frequency
250
200
150
100
50
0
-4
-2
0
2
4
Regression Standardized Residual
Mean = -2.51E-14
Std. Dev. = 0.998
N = 2,729


Normal P-P Plot of Standardized Residual for Selected Cases
Dependent Variable: PKTKMTWHHLNRI
Expected Cum Prob
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
Observed Cum Prob


Scatterplot
Dependent Variable: PKTKMTWHHLNRI
Selected Cases
Regression Standardized Predicted Value
Regression Standardized Residual
4
2
0
-2
-4
-4
-2
0
2
4