TRANSFORMING THE ASIAN MOTORCYCLE CITY? EVALUATING THE TRAVEL AND URBAN DEVELOPMENT EFFECTS OF THE MASS RAPID TRANSIT IN TAIPEI, TAIWAN

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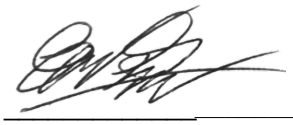

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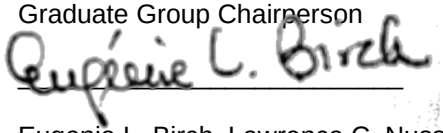

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TRANSFORMING THE ASIAN MOTORCYCLE CITY? EVALUATING THE TRAVEL AND URBAN DEVELOPMENT EFFECTS OF THE MASS RAPID TRANSIT IN TAIPEI, TAIWAN

To my father, mother, and brother

ACKNOWLEDGMENT

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ABSTRACT

TRANSFORMING THE ASIAN MOTORCYCLE CITY? EVALUATING THE TRAVEL AND URBAN DEVELOPMENT EFFECTS OF THE MASS RAPID TRANSIT IN TAIPEI, TAIWAN

Bing-yu Chiu

Erick Guerra

Motorcycles bring environmental and health harm. Many cities with high motorcycle ownership rates have been establishing or expanding mass rapid transit. Whether the metro system can lure existing motorcyclists is of great policy concern, and a common goal in metro investments besides traffic congestion alleviation is to stimulate the economy through reshaping urban development patterns. Literature suggests that motorcycle ownership is associated with socioeconomic conditions and the built environment and that increased transit presence is linked to reduced motorcycle ownership and use, but scholars disagree on transit's ability to shift activities toward stations. This dissertation explores the relationship between the built environment and motorcycle travel and the metro effects on motorcycle travel and urban development between 2000 and 2009 in Taipei, Taiwan, one the earliest motorcycle-stressed cities to have adopted mass rapid transit. Regression analysis and an econometric method of causal inference are employed on data from the two most recent large-scale household travel surveys. Findings on the relationship between motorcycle travel and the built environment suggest: being farther from the central business district and from metro stations were correlated with higher household motorcycle ownership levels, likelihood of motorcycle mode choice, and household motorcycle vehicle kilometers traveled (VKT); higher population density is correlated with higher likelihood of motorcycle mode choice and household motorcycle VKT; and lower job density was correlated with higher household motorcycle ownership levels and household motorcycle VKT. Findings on the metro effects on motorcycle travel suggest that both new and older stations are effective in reducing the motorcycle mode choice odds relative to that of the metro for trips originating and motorcycle VKT of households located in their proximity. Lastly, findings on the metro effects on urban development suggest that neither new stations nor older ones affect population or job densities in their proximity. This dissertation argues for transit-oriented development and by-hour pricing of motorcycle parking. It fills gaps in knowledge by rejecting

hypotheses about how the built environment and income are related to motorcycle travel, advancing transit-motorcycle research frontiers by examining a metro system, and contributing to a currently small literature on transit effects on employment.

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CHAPTER 1: INTRODUCTION

1.1. Introduction

Motorcycles are widely and increasingly used for utilitarian passenger transportation worldwide. Motorcycles bring environmental and public health harms to users and the general public. Many cities that have high motorcycle ownership rates have been establishing or expanding mass transit systems. Whether mass transit can lure existing motorcycle users is of great policy concern. In addition, a common policy goal in transit investments besides traffic congestion alleviation is to stimulate the economy through affecting urban development patterns. Taiwan has the world's highest motorcycle ownership rate, and its capital Taipei is one the earliest cities to have adopted a mass rapid transit system while having high motorcycle ownership rates. Travel data are available from the most recent large-scale household travel surveys in the Taipei Metropolitan Area during periods of expansions of the metro network, offering the opportunity to understand how transit supply affects motorcycle travel and urban development.

Literature suggests that motorcycle ownership is associated with socioeconomic conditions and the built environment and that increased presence of transit is linked to reduced motorcycle ownership and use, but scholars disagree on transit's ability to shift activities toward the proximity of stations.

1.2. Motivation

Motorcycles are widely and increasingly used for utilitarian passenger transportation worldwide, especially in Asia. Research based on earlier WHO-collected data estimated that around 79% of the world's motorcycles are in Asia, followed by Europe 9%, South America 5%, the Middle East 3%, North America 3%, and Africa 2% (Nguyen, 2013). The growth in motorcycle ownership is fast in middle-income Asian countries. In China, motorcycles grew from 23% of all registered motor vehicles in 1987 to 63% in 2001 (Wen et al., 2012). Vietnam has experienced a dramatic growth in motorbike ownership both nationwide and in its largest cities. Motorbike ownership in Vietnam at large grew from 4 million to 43 million between 1996 and 2014 (Hansen, 2017), and in Ho Chi Minh City alone it increased from 2 million to almost 7 million between 2002 and 2015 (Chu et al., 2019; Hoang & Okamura, 2020) which equals an average annual growth rate of 10%. In Indonesia, localities also reported sharp average annual growth rates in motorcycle ownership, ranging from 11% in the province of Bali (Wedagama, 2009) and 19% in the city of Solo/Surakarta between 2009 and 2013 (Guerra, 2017) to an astonishing 68% in the city of Palembang between 2015 and 2016 (Rosa et al., 2019). In Bangladesh, the average annual growth rate of motorcycles was also higher than 10% (Zafri et al., 2021). The increase in the number of motorcycles in middle-income Asian countries is much faster than that of cars. In Vietnam, the latest average annual growth rates for motorcycles and cars were 7.3% and 6.3% respectively (Huu & Ngoc, 2021). In Indonesia, nationwide, the number of motorcycles grew from 23 million to 60 million between 2003 and 2009, much faster than the increase of cars from 5 million to 12 million over the same period (Wandani et al., 2018). Also in Indonesia, locally, in the capital Jakarta the growth rate of motorcycles is 10.5% per year, while that of passenger cars is 8.8% per year (Suatmadi et al., 2019), and in Bali almost 85% of the annually registered vehicles were motorcycles (Wedagama, 2009). In India, the average

annual sales growth of motorized two-wheelers was 12% between 2009 and 2015 while that of cars was 7% (Shirgaokar, 2016).

Countries of lower average income, higher population density, and higher level of urbanization tend to have higher motorcycle ownership levels. An inverse U-shape relationship, or a "motorcycle Kuznets curve", exists between motorcycle ownership and a nation's average income, suggesting that the number of motorcycles per thousand population first increased then decreased as GDP per capita rose, and the motorcycle Kuznets curve was more pronounced in densely populated countries, indicating that high population density could keep motorcycle ownership high and population density seemed to be the key mediating variable explaining the cross-country difference in motorcycle-income relationships (Nishitateno & Burke, 2014; Law et al, 2015; Chu et al, 2021). A similarly inverse U-shape or convex relationship exists between motorcycle ownership and a nation's level of urbanization, potentially because the motorcycle's popularity over the car first decreased as long-distance travel demand grew while urban population density and urban areas increased, and then decreased as traffic congestion worsened and competition for parking spaces intensified (Law et al, 2015).

Motorcycles bring both harm and benefits to users and the general public. The harms have environmental and public health natures, are diverse and comprehensive, and affect every urban resident whether they drive or not, while the benefits are primarily economic and are limited to road users. On the negative side, motorcycles cause harm through degrading motorcyclist and pedestrian safety and the quality of public space and producing local pollution. For the users, motorcycles have higher fatality rates compared to automobiles (Nugroho et al., 2011). For the general public, motorcycles adversely impact the quality of public spaces due to the proliferation of their operation and parking in the pedestrian realm (Cervero et al., 2017). For example, sidewalks are limited and are often

occupied by motorcycles and fast-moving three-wheel vehicles in cities like Ahmedabad, India (Cervero et al., 2017). Finally, fossil-fuelled motorcycles produce high levels of concentrated local air pollution and greenhouse gas (GHG) emissions (Leong et al., 2002; Guerra, 2017). The per vehicle-mile travelled emission of CO, CH4, NOx, HC and particulate matter of motorcycles is higher than that of automobiles (Hernandez et al., 2019). Motorcycles also produce substantial noise pollution (Cervero et al., 2017). On the positive side, motorcycles enable affordable commuting trips and efficient use of road space. For the users, often from lower income households, the small size of motorcycles allows low fuel consumption, high maneuverability on congested roads, and easy parking, which are conditions that save time and money while providing access to jobs (Chiu & Tseng, 1999; Law et al., 2015; Guerra, 2017). For the general public, a high share of the vehicle fleet being motorcycles instead of automobiles can mean efficient use of road space and substantially less congestion than may have been caused by car traffic.

Many cities that have high motorcycle ownership rates have been establishing or expanding mass transit systems. While motorcycle use has proliferated in Asia in the recent decades, countries in the region have been aggressively establishing high-capacity transit systems in their largest cities since around the turn of the 21st century. Malaysia, Taiwan, and Thailand opened their first metro systems in the late 1990s. Eight out of the 9 Indian cities and 35 out of the 39 Chinese cities that have had metro systems up to 2020 joined the lists only after the millennium. Indonesia put bus rapid transit (BRT) systems to 13 of its cities since 2004 until its first metro system opened in Jakarta in 2019. Currently, more than thirty metro systems under construction are planned for opening by 2030 around the world, some of which are in countries with high motorcycle ownership rates such as Colombia, India, Iran, and Vietnam. In the meantime, a common policy goal in transit investments, besides traffic congestion alleviation, is to stimulate the economy. Transit investments may affect urban development patterns and thus affect the urban economy. The perceived positive impact of transportation investments on

economic development is an important consideration to transportation decision makers, and it is a subject of much research.

Taiwan has the world's highest motorcycle ownership rate. With those available data on either motorized two-wheelers only (JAMA, 2020) or motorized two- and three-wheelers combined (WHO, 2018) between 2014 and 2018, it is possible to see the relative motorcycle dependence between the world's regions from a country-based motorcycle-to-population-ratio perspective (see Figure 1.1). Asia is indisputably the most motorcycle-dependent region and is home to the world's highest motorcycle-to-population ratios: Taiwan with 587 motorcycles per thousand population, followed by Vietnam (498), Indonesia (446), and Malaysia (406); they have close followers including Thailand (298), Sri Lanka (232), Laos (211), Cambodia (172), and India (117). Latin America, particularly South America, comes as the world's second motorcycle dependent region with the highest ratios from Uruguay (364), Argentina (161), Colombia (154), and Brazil (122). This is followed by Europe, with the highest ratios located in Southern Europe including Greece (266), Italy (157), and Spain (110) as well as Central Europe including the Czech Republic (97), Austria (94), Switzerland (86), and Germany (76). The Middle East comes next as a region with most ratios such as Egypt (52) and Turkey (38) lower than that of European countries, except for Iran (144). Then come Oceania and North America with ratios of Australia (34), the US (27), and Canada (20) resembling that of Britain (21), their Anglo-Saxon-majority cultural relative in Europe. Sub-Saharan Africa ranks the lowest as a region with ratios generally low such as Tanzania (23) and Uganda (23), except for Mauritius (158).

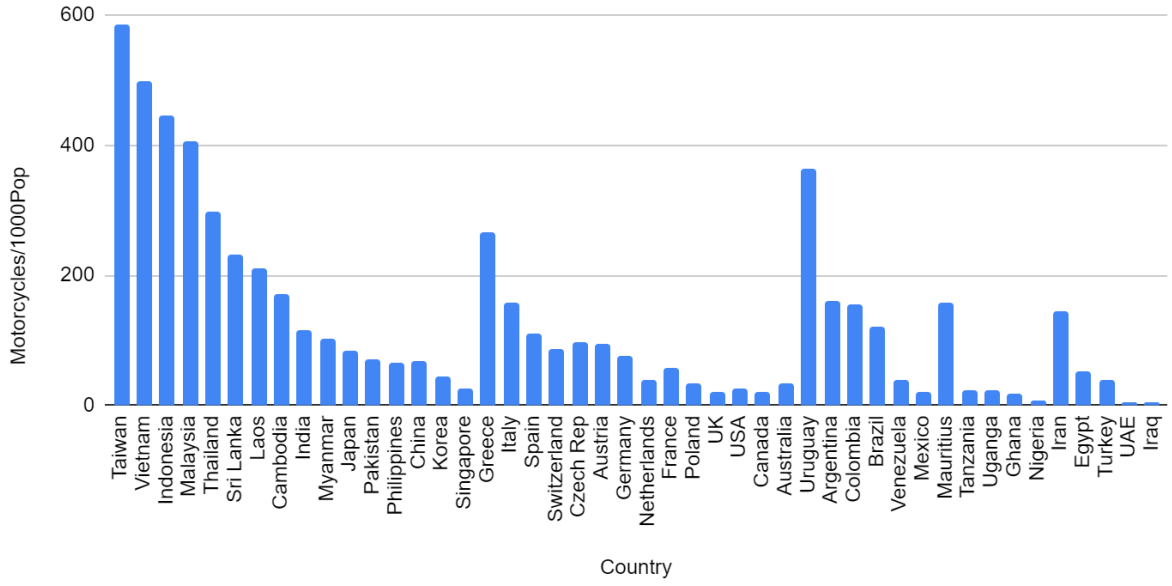


Figure 1.1: Motorized two- and three-wheelers per thousand population by country, 2014-2018

Taipei, the capital and the largest city of Taiwan, is one the earliest cities to have adopted a mass rapid transit system while having high motorcycle ownership rates. Currently, the world's highest motorcycles-to-population ratios are in Taiwan, Vietnam, Indonesia, Malaysia, Thailand, Sri Lanka, Laos, Greece, and Uruguay, all being higher than 200 motorcycles per thousand population. Greece opened its first metro system in Athens in 1904, long before motorcycles became widely used. In the late 1990s, motorcycle-stressed Malaysia, Taiwan, and Thailand opened their first metro systems with the 1995 launch of the Rapid KL, the 1996 launch of the Taipei Metro, and the 1999 launch of the BTS Skytrain. Indonesia and Vietnam did not have metro systems until around 2020. To date, Sri Lanka, Laos, and Uruguay do not have metro systems. Travel data are available from the most recent household travel surveys in the Taipei Metropolitan Area during periods of expansions of the metro network, offering the opportunity of understanding how transit supply affects motorcycle travel and urban development. The

most recent household travel surveys in the Taipei Metropolitan Area were conducted in 2000 and 2009, between which the metro system in Taipei considerably expanded. The surveys offer the opportunity of understanding how travel behavior changed as the metro system expands and modal split shifts at the metropolitan scale. The first survey was conducted immediately after the Taipei Metro first formed a connected network in December 1999. The second survey was conducted immediately after the metro system reached a suburban district Neihu with the most rapid job growth in the metropolitan area.

1.3. Overview and outline

This dissertation explores the relationship between motorcycle travel and the built environment, the mass transit effects on motorcycle travel and urban development between 2000 and 2009 in the Taipei Metropolitan Area, also known as Greater Taipei. The main datasets used in this dissertation were pooled travel data from the 2000 and 2009 household travel surveys in Greater Taipei, the most recent two household travel surveys in the metropolis; data of all kinds of trips were used, regardless of the type of origins, destinations and purposes. Publicly available population and employment statistics were also used to generate data for the variables needed in the models. Methods by which the relationship between the built environment and motorcycle travel was examined include multinomial logistic regression and tobit regression. To examine the mass transit effects on motorcycle travel and urban development, difference-in-differences, an econometric technique of causal inference, was applied within binomial logistic, tobit, and ordinary least squares regression models. Key findings include: (1) Higher population density, being farther from the central business district and from metro

stations were correlated with higher household motorcycle ownership levels, higher likelihood of motorcycle mode choice, and higher household motorcycle vehicle kilometers traveled (VKT); (2) Lower job density was correlated with higher household motorcycle ownership levels and higher household motorcycle VKT; (3) Lower income is correlated with higher likelihood of owning motorcycles but no cars, higher motorcycle mode choice likelihood, and lower household motorcycle VKT; (4) Both newly introduced metro stations and older pre-existing ones were effective in reducing the motorcycle mode choice odds relative to that of the metro for trips originating in their proximity; (5) Both new and older metro stations were effective in reducing household motorcycle VKT in their proximity; and (6) Neither newly introduced metro stations nor older pre-existing ones were effective in affecting the population density or the job density of traffic analysis zones in their close proximity.

This dissertation consists of an introduction chapter, a background chapter on land use and transportation in the Taipei Metropolitan Area, three research chapters on the relationship between the built environment and motorcycle travel, the mass transit effects on motorcycle travel, and the mass transit effects on urban development, as well as a conclusions chapter.

1.4. Research contributions

In examining the relationship between the built environment and motorcycle travel, the findings of this dissertation fill two gaps in knowledge and sheds light on the relationship between income and motorcycle travel. While much has been found about the socioeconomic predictors of a household's motorcycle ownership level, only population and road densities have been identified as influential built environment predictors, and this dissertation adds job density, distance to the central business district

(CBD), and distance to metro stations to that list. Previously, built environment characteristics have not been identified as predictors of motorcycle mode choice, and this dissertation identifies population density, job density, distance to the CBD, and distance to metro stations as such predictors. Although the literature suggests that income is negatively correlated with motorcycle ownership, mode choice, and use, this dissertation points out that income is, in fact, positively correlated with household motorcycle VKT.

In examining the effects of metro stations on motorcycle travel in their proximity, the findings of this dissertation fill two gaps in knowledge. First, it pioneers research on the relationship between transit investments and motorcycle travel to explore that for mass rapid transit systems. Second, it is perhaps the first study on mode choice involving the motorcycle to take the influence of the built environment into account.

Lastly, in examining the effects of metro stations on urban development in their proximity, this dissertation contributes to a currently small literature on transit effects on employment by using the destinations of work trips in household travel surveys as proxies of the locations of jobs.

CHAPTER 2: TAIPEI METROPOLITAN AREA

2.1. Introduction

What factors drive changes in travel behavior in a metropolitan area? Transit investments are only one such factor. Other factors include the geography and history of the metropolitan area and changes in the population, housing, employment, and transportation infrastructure. Household travel surveys contribute to the understanding of changes in travel behavior.

This chapter summarizes the geographic and historic background and the changes in these characteristics of the Taipei Metropolitan Area, as well as household travel surveys that have been conducted based on whose data this dissertation research unfolds.

Three general trends provide important clues on how travel behavior may change in the Taipei Metropolitan Area: the opposite directions of the suburbanization of population and employment; a disconnect between the strongest population and employment growth and the geographic priorities of the expansion of the metro system; and a possible substitution between motorcycle trips and metro rides.

2.2. The Taipei Metropolitan Area

The economic and political center of Taiwan, the 7-million-people Taipei Metropolitan Area (or Greater Taipei, interchangeably) spans across an area twice that of New York City. The Taipei Metro mass rapid transit system opened in 1996 and connected the downtown and all the inner suburbs by 2013. Large business parks that opened in the inner suburbs during the 1990s and 2000s have become new employment centers, while new town developments in the outer suburbs have struggled to lure residents until recently.

Scope and size

The interchangeable terms “Taipei Metropolitan Area” and “Greater Taipei” in this dissertation, unless otherwise specified, refer to Taipei City, New Taipei City, Keelung City, plus the Guishan district of Taoyuan City. (See Figure 2.1)

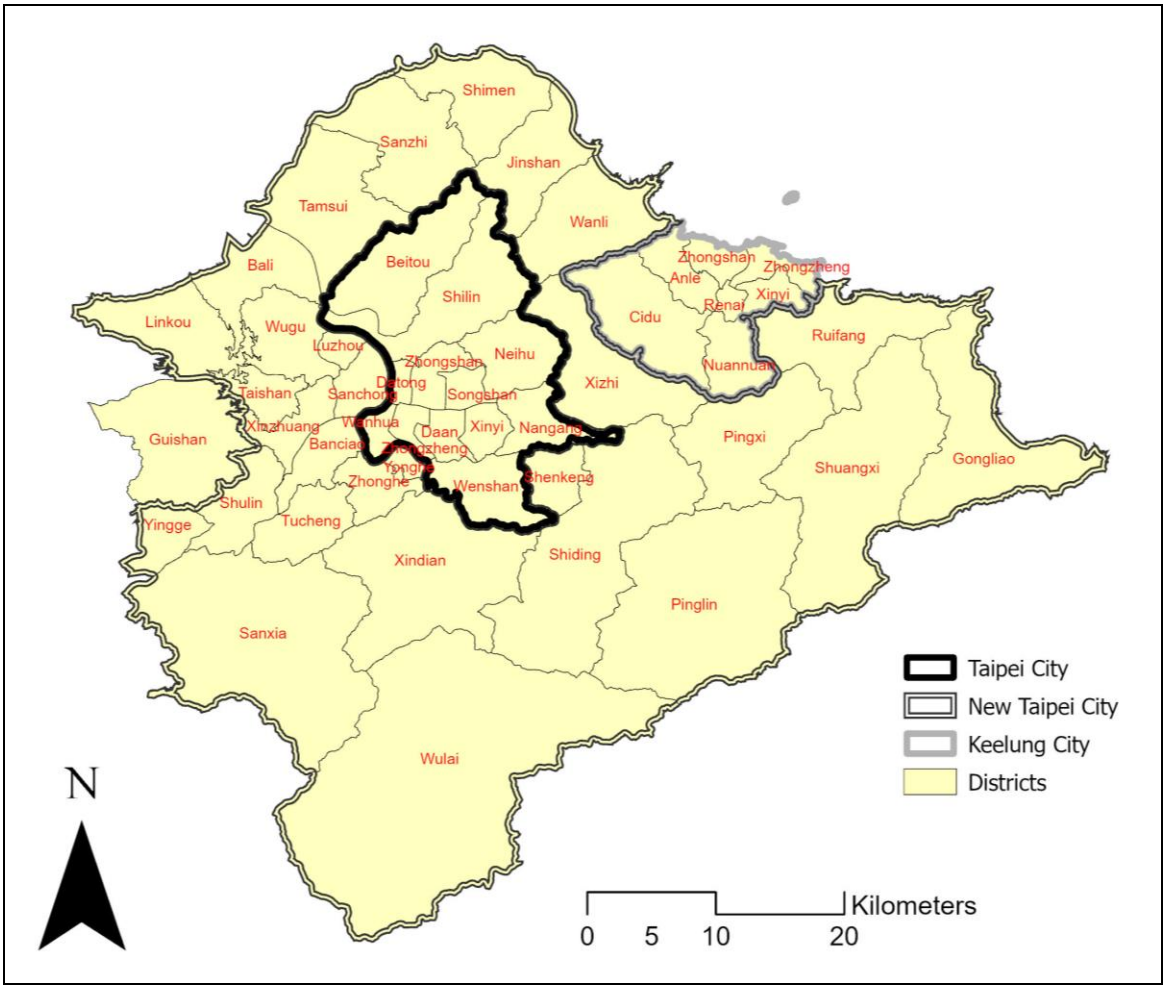


Figure 2.1: Cities and districts of the Taipei Metropolitan Area defined in transportation studies

The Taipei Metropolitan Area is commonly defined as consisting of Taipei City, New Taipei City, and Keelung City with a total area of 2,436 km2. Such a total area is approximately twice the total land and water area of New York City. Although there are currently no official definitions of a metropolitan area that covers Taipei City and its environs (for example, in the National Spatial Plan that came into effect in 2018), there used to be two. The 1983 Northern Taiwan Regional Plan issued by the Ministry of the Interior defined a “Taipei Metropolitan Area” as covering Taipei City, most of Taipei County (later renamed New Taipei City) and a township of Taoyuan County (later renamed Taoyuan City) (MOI, 1983). Then, in 1985, the Ministry of Budget, Accounting and Statistics (later reorganized as the current Directorate-General of Budget, Accounting and Statistics), which performs the role of census bureau of Taiwan, issued the first standard classification of statistical areas, in which six metropolitan areas were defined, including a “Taipei-Keelung Metropolitan Area” that covers Taipei City, the entire Taipei County, and Keelung City (DGBAS, 2010). Although the latter and wider definition (as well as the entire standard classification of statistical areas) was announced to cease to take effect in 2010, such a general definition of a Taipei Metropolitan Area has long been used in policy and research, including large-scale household travel surveys (see Section 2.8).

In transportation studies, the Taipei Metropolitan Area often refers to Taipei City, New Taipei City, Keelung City, plus the Guishan District of Taoyuan City. The Guishan District of Taoyuan City (or the Guishan Township of Taoyuan County before 2015) has close ties with the Linkou District of New Taipei City (or the Linkou Township of Taipei County before 2011) because a major public-led new town project, the Linkou New Town, spans across the two districts. The total population of the Guishan District was nearly 167,000 in 2021.

Terrains

The terrain of Greater Taipei is characterized by a large Taipei Basin in its center, surrounded by over-thrust fault ridges in the east and south, a mesa in the west, and volcanoes in the north. Major rivers that snake across the basin include the Dahan and Xindian Rivers which converge and form the Tamsui River, as well as the Keelung River.

Administrative geographies

The administrative geographies of Greater Taipei consist of three cities (Taipei, New Taipei, and Keelung), 48 districts (or 49 if including Guishan District of Taoyuan City), and more than a thousand villages. The three cities have a total of 1,645 villages as of early 2021. The current hierarchical order of administrative geographies with democratically elected leaders, from high to low, is three-level: cities/counties; districts/townships; villages. Currently, Taipei City, New Taipei City, and Keelung City have 12, 29, and 7 districts, respectively. Each district consists of dozens of villages. In large-scale household travel surveys, villages were consolidated into traffic analysis zones (TAZs) for research purposes (see Section 2.8).

Metropolitan structure

The metropolitan structure of Greater Taipei is circular, consisting of a downtown, four quarters of inner suburbs, and outer suburbs. Likewise, there are currently no official definitions of the metropolitan structure. However, the planning history provides clues of how to draw lines between the downtown, the inner suburbs, and the outer suburbs. Therefore, this dissertation defines the downtown as the seven districts that composed Taipei City prior to the 1968 expansion of city limits, the inner suburbs as the five districts annexed by Taipei City in 1968 plus the 11 districts designated as two metropolitan centers in the

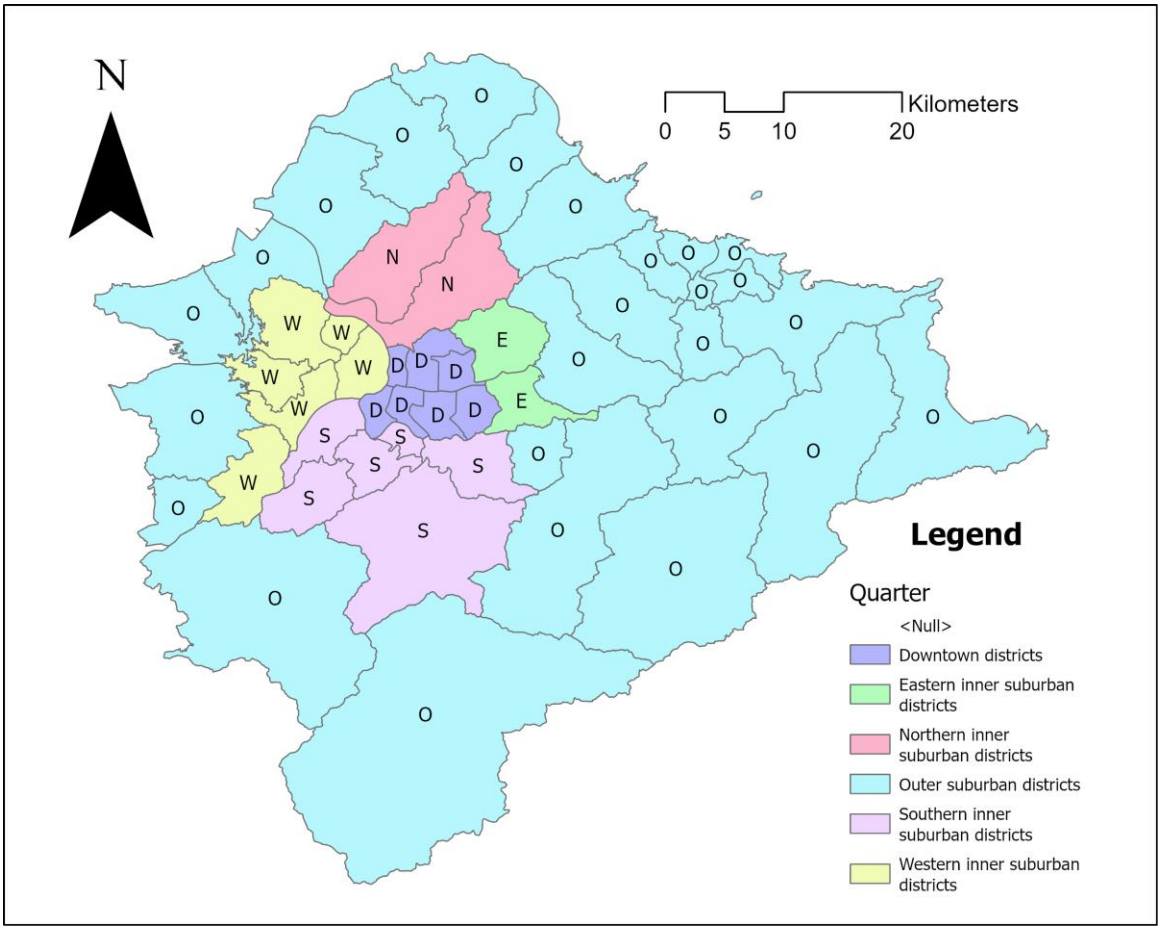
2017 Regional Plan of New Taipei City (NTCG, 2022a), and the outer suburbs as the remaining 25 districts plus Guishan District of Taoyuan City that was included in the large-scale household travel surveys (see Section 2.8). For the inner suburbs, this dissertation further classifies them into four quarters (northern, eastern, southern, and western inner suburbs) based on their distinct trajectories of planning history in administrative, transit, land use, and strategic terms. Table 2.1 and Figure 2.2 provide an overview of the characteristics as well as the locations of the quarters of Greater Taipei to which the districts are assigned.

Table 2.1: Overview of the characteristics of the quarters of Greater Taipei

Quarter (code)	*No. of Dist.*	*Range of population densities by district in 2009 (per./km²)*	*Range of job densities by district in 2009 (per./km²)*	*Range of jobs-to-population ratios by district in 2009 (jobs/per.)*	*Rationale for classification based on planning history: administrative, transit, land use, and strategic*
Downtown (D)	7	15545 - 27497	7178 - 24615	0.28 - 1.49	Taipei City prior to 1968
Northern inner suburbs (N)	2	4296 - 4577	1073 - 1220	0.25 - 0.27	Annexed by Taipei City in 1968; earlier completion of metro connections with the downtown (1997); later launch of a large-scale business park (2019)
Eastern inner suburbs (E)	2	5166 - 8365	2899 - 6576	0.56 - 0.79	Annexed by Taipei City in 1968; later completion of metro connections with the downtown (2009); earlier launch of large-scale business parks (around 2000)
Southern inner suburbs (S)	6	2431 - 38450	821 - 7964	0.14 - 0.37	Annexed by Taipei City in 1968 (Wenshan District); Designated as a strategic metropolitan center in the 2017 New Taipei City Regional Plan and placed under a consolidated South-of-the-Dahan Urban Plan in 2020 (the other 5

					districts)
Western inner suburbs (W)	6	2305 - 25533	1167 - 6885	0.18 - 0.69	Designated as a strategic metropolitan center in the 2017 New Taipei City Regional Plan 2017 and placed under a consolidated North-of-the-Dahan Urban Plan in 2020
Outer suburbs (O)	26	17 - 11064	2 - 3822	0.06 - 0.76	--

Figure 2.2: Six quarters of Greater Taipei to which the districts are assigned in this dissertation



History

Brief economic and political history

Taipei has been the economic and political center of Taiwan since the late 19th century. The Taipei basin was historically inhabited by Austronesian peoples, primarily the Ketagalans, who lived by hunting, gathering, and small-scale farming. The Spanish and Dutch established coastal settlements around Taipei in the early 17th century, but their activities within the Taipei Basin were limited to explorations and missions. The Manchu-led Empire of Qing, which ruled China proper since 1644, annexed the western part of the island of Formosa (how Taiwan was then called internationally) in 1683, and settlers from modern-day southern China introduced large-scale agriculture to Taipei in 1709. Towns gradually formed and developed. As Taiwan began camphor and tea exports in 1860, the island's relative wealth was rapidly shifted from Tainan in the southwest to Taipei in the north where these products are grown. The Qing Empire officially made Taipei the capital of Taiwan in 1894, and the two subsequent governing authorities of Taiwan, the Empire of Japan (1895-1945) and the Republic of China (ROC) (1945-present), followed suit.

Planning history

The origin of the name Taipei traces back to the late 19th century. Qing granted prefectural status to northern Taiwan (an area larger than the current Greater Taipei) in 1876 and named it as Taipeh, literally "the north of Taiwan". As Japan and ROC took over Taiwan, they converted the name Taipeh into Taihoku and Taipei, both being merely different pronunciations of the same Chinese characters.
The foundation was laid for Taipei's modern city planning and the boundaries of its downtown during the early 20th century. Japan initiated modern city planning in Taihoku around 1900 by improving or establishing road, water, and sewage networks, and flood walls in the historic core of the region. In 1921,

Japan granted city status to the historic core of Taihoku and its environs (that is, approximately, the five western districts in the current downtown). The 1932 Taihoku Urban Plan envisioned a 600,000 population and designated sites for roads, parks, parkways, and industrial and military land uses further east (Watanabe, 2008). In 1938, Taihoku City formally annexed the planned areas to its east (that is, approximately, the two eastern districts in the current downtown). Such city limits, which defined the current downtown, were inherited by the ROC authorities, and remained unchanged for 30 years until Taipei City took its current shape by further annexing areas to its north, east, and south in 1968.

The opening of the Taipei Metro mass rapid transit system in 1996 and its expansions by 2013 have connected the downtown with all the inner suburbs. Initially, the urban rail transit network connected the downtown with the northern and southern inner suburbs. Then, the connection between the downtown and the eastern inner suburbs was completed in 2009 and that between the downtown and the western inner suburbs completed in 2013. From then up to 2020, newly opened metro light rail transit (LRT) lines strengthened the connections between the downtown and the southern and western inner suburbs, as well as linking the downtown with Greater Taipei's primary international airport Taoyuan located beyond the western outer suburbs (see Section 2.6) and linking the downtown and inner suburbs to the developing new towns in the outer suburbs.

Land use planning has aimed at directing population growth to the outer suburbs and job growth to the inner suburbs. Three public-led new town development projects – Linkou since 1979, Danhai since 1994, and Sanxia since 1997 – have been incrementally carried out in the western (on top of the mesa), northern (by the sea), and southern (in a river valley) outer suburbs (See Figure 2.7 in Section 2.3), but all three have been subject to skepticism and pressure to halt due to the gap between expected mass migration into the new towns and the reality, partly because the metro expansion or LRT connection did not reach these places until rather recently (Linkou in 2017, Danhai in 2018). On the contrary, several private-led or public-led large business park development projects, the majority of which are in the inner suburbs and opened in the 1990s and 2000s, have been rather successful in becoming new employment centers (See Figure 2.10 in Section 2.5).

Strategic planning has designated the southern and western inner suburbs as metropolitan centers in addition to the downtown. The current planning system of Taiwan is decentralized, in which the power of drafting spatial plans is delegated to county/city governments. New Taipei City issued its regional plan in 2017, in which it designated its five districts within the southern inner suburbs as a new metropolitan center and its six districts within the western inner suburbs as another, both adding to the existing metropolitan center, the downtown of Greater Taipei (NTCG, 2022a). To reflect such a vision, in 2022, New Taipei City consolidated its several urban plans for these areas into a North-of-the-Dahan Urban Plan covering the western inner suburban districts and a South-of-the-Dahan Urban Plan covering the southern inner suburban ones (NTCG, 2022b).

2.3. Population

Population trends from 1981 to 2020 show signs of suburbanization. The downtown lost residents, while the southern and western inner suburbs as well as some of the outer suburbs had generally strong population gains. Over time, fewer people lived in an average household, and one-person households became more common.

Total population growth

The total population has grown steadily over the past four decades. Population in Greater Taipei increased from 5,048,448 in 1981 to 7,165,347 in 2020. On average, the metropolitan area gained 54,279 people per year over this period; the average annual growth rate (AAGR) was 0.9%. (MOI, 2022a)

Population growth by area

Population growth during this period has been driven primarily by increases in the southern and western inner suburbs and the outer suburbs. In the meantime, the downtown has generally lost population steadily, and growth in the northern and eastern inner suburbs was rather modest (See Figure 2.3). A closer look at the districts suggests that the strongest population growth occurred in peripheral parts of the southern and western inner suburbs as well as three outer suburbs in the west, north, and east (See Figure 2.4). (MOI, 2022a)

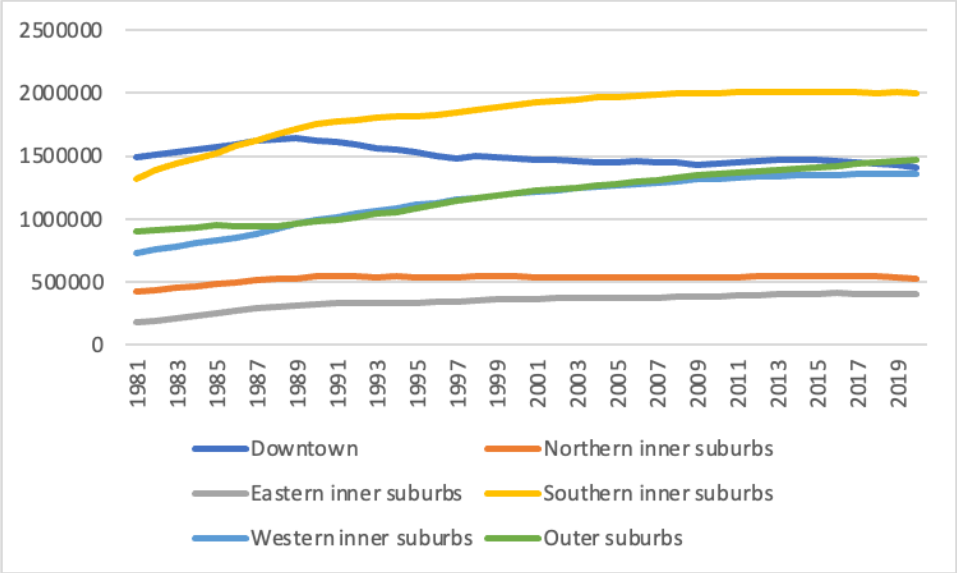


Figure 2.3: Population changes in Greater Taipei by quarter, 1981-2020

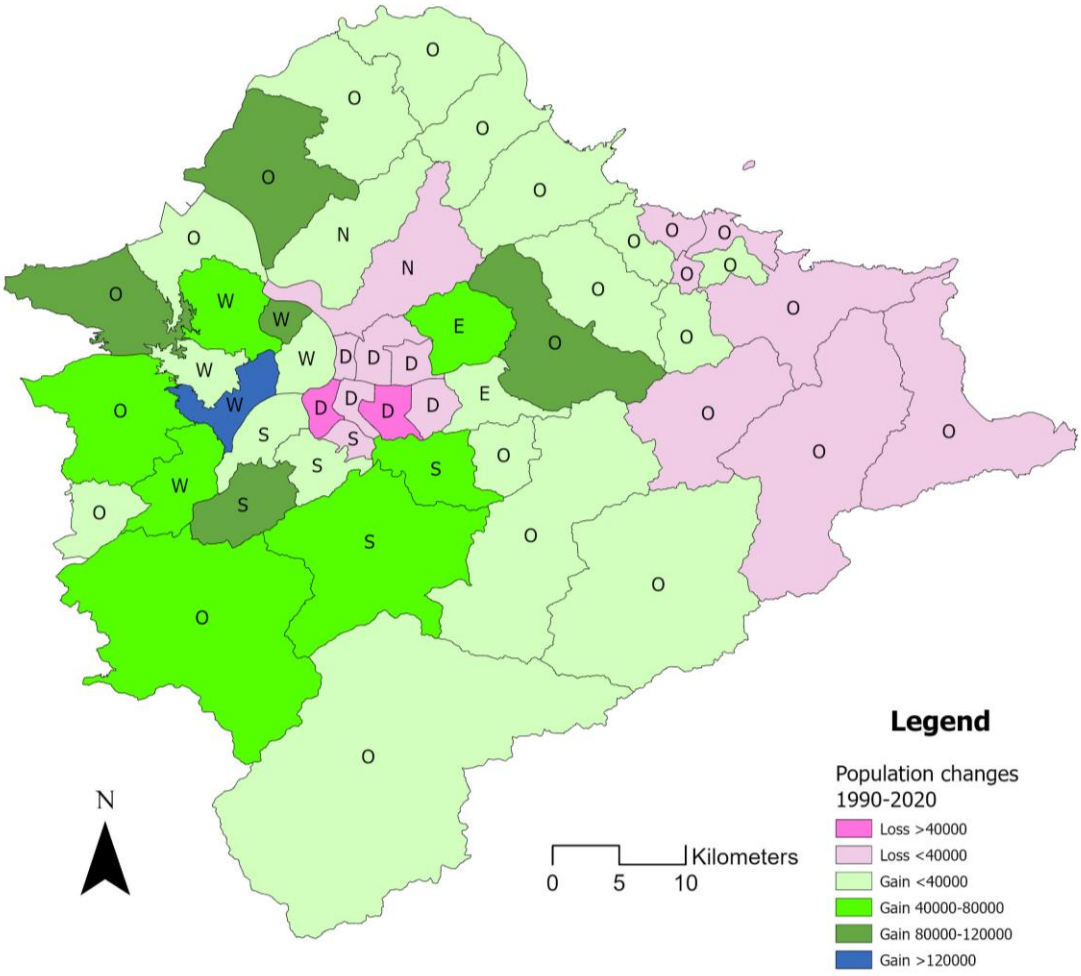


Figure 2.4: Population changes in Greater Taipei by district, 1990-2020

Household size

The number of people living in an average housing unit has been shrinking, and the share of one-person households has increased. A decennial Population and Housing Census has been conducted in Taiwan. Among the census-defined ordinary households in Taipei, New Taipei, and Keelung Cities combined, which are almost all households (over 99%), there were on average 3.72 persons per housing

unit in 1990, 3.09 in 2000, 2.87 in 2010, and 2.75 in 2020. Among all households, 15% were households that consisted of only one person in 1990, and the share rose to 24% in 2000 and 27% in 2020. (DGBAS, 2022a)

2.4. Housing

Housing trends show that, over time, housing ownership has become more common. Increasing throughout the metropolitan area, housing prices particularly in the central city are much higher than in its environs, but those in the suburbs have been catching up quickly.

Housing ownership

The housing ownership rate has continued to increase. Among the ordinary households, 73% lived in housing units owned either by themselves or by immediate or extended family members in 1990. This ownership rate rose to 80% in 2000 and 2010 and to 81% in 2020. (DGBAS, 2022a)

Housing vacancy

The housing vacancy rate has generally remained stable. Among all housing units, 81% were regularly occupied in 1990, and the rate decreased to 80% in 2000, 76% in 2010, and 78% in 2020. (DGBAS, 2022a)

Housing prices

Housing prices are much higher in the central city than in the suburbs. In Greater Taipei, longitudinal records of absolute housing prices by district are unavailable because the Ministry of the Interior did not require the reporting of real estate transaction prices until 2012, has only kept records at the city/county level since 2012, and has kept track of the median price instead of the average price, which is susceptible to outliers, since 2016. Quarterly records of median transaction prices per unit floor area of housing units in multistory buildings (the dominant housing type in Greater Taipei) between the third quarter of 2017 and the first quarter of 2022 show that, on a quarterly average, median housing prices in New Taipei City were 45-59% and those in Keelung City 23-31% that in Taipei City (see Table 2.2). (MOI, 2022b)

Table 2.2: Quarterly average of median housing prices per unit area in multistory buildings in Greater Taipei, 2017-2022, comparison between cities

Stories	5 or less	5 or less	10 or less	10 or less	11 or more	11 or more
Elevators	No	No	Yes	Yes	Yes	Yes
Parking	No	Yes	No	Yes	No	Yes
Taipei City	100%	100%	100%	100%	100%	100%
New Taipei City	59%	53%	49%	50%	52%	45%
Keelung City	23%	28%	28%	31%	30%	23%

Overall housing prices in Greater Taipei rose rapidly during the past decade, and housing prices in the suburbs, despite being much lower than in the central city, have increased twice as rapidly as those in the central city. In Greater Taipei, longitudinal records of relative housing prices (housing price index) by city and by district have been available since 2012. City-wide housing price indices show that, between

August 2012 and December 2021, the monthly average housing price index in Taipei City rose by 22% (from 91.69 in August 2012 to 112.02 in December 2021, using 2018 as the base year), and the AAGR is 2.3%; the monthly average housing price index in New Taipei City rose by 48% (from 81.12 in August 2012 to 119.68 in December 2021, using 2018 as the base year), and the AAGR is 4.4%. (TCG, 2022a; NTCG, 2022c)

Social housing

Social housing rental programs that target the general public did not exist in Taiwan until very recently. Prior to 2017, state-supplied housing, mostly for-sale, was concentrated in Taipei City and, while not small in quantity, was only available to specific groups. National Housing was constructed between 1950 and 2006, whose priority of purchase or rental was given to public servants and their families, most of whom were Chinese immigrants who moved to Taiwan between the ROC takeover of Taiwan in 1945 and the establishment of the People's Republic of China in 1949; there were a total of 133,169 housing units within Taipei City by 2006. Other types of state-supplied housing targeted mostly lower-income groups and groups displaced by urban renewal projects, and 10,415 such housing units were constructed within Taipei City in the 1960s and 1970s. Besides, there are a small number of Military Housing units. In 2017, the central government initiated the Social Housing Construction Program which aimed at providing 280,000 housing units all over Taiwan by 2024; however, by April 2022, there were only 19,593 social housing units in Taipei City and 15,018 units in New Taipei City that were either in operation, completed, under construction, or commissioned for construction. (TCG, 2022b)

2.5. Employment

Employment trends from 1991 to 2016 show signs of suburbanization, like that of its population. The downtown lost jobs, while the southern and eastern inner suburbs as well as some of the outer suburbs had generally strong job gains. Wage growth in real terms has been slow.

Total job growth

The total number of jobs has grown slightly more rapidly than population over the past three decades. A quinquennial Industry and Service Census has been conducted in Taiwan. Jobs in Greater Taipei increased from 2,388,078 in 1991 to 3,308,442 in 2016. On average, the three cities altogether gained 36,815 jobs per year over this period; the AAGR was 1.3%. (DGBAS, 2022b)

Job growth by area

Job growth during this period has been driven primarily by growth in the southern and eastern inner suburbs as well as the outer suburbs. In the meantime, the downtown has generally lost jobs, and growth in the northern and western inner suburbs was rather modest (See Figure 2.5). A closer look at the districts suggests that the strongest job growth occurred in an eastern inner suburb, Neihu. The next strongest job growth occurred in its immediate proximity - one downtown district, Xinyi, where the central business district (CBD) Xinyi Special District is located and one outer suburb neighboring it in the east – as well as one southern inner suburb and one peripheral outer suburb in the west. All these districts that had strong job growth are either home to the CBD or business parks (See Figure 2.6). (DGBAS, 2022b)

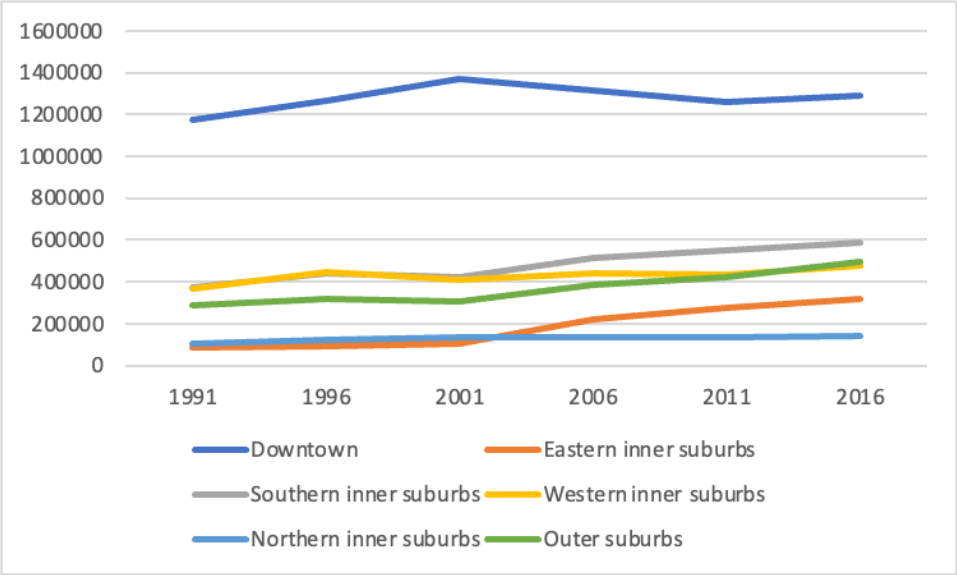


Figure 2.5: Job changes in Greater Taipei by quarter, 1991-2016

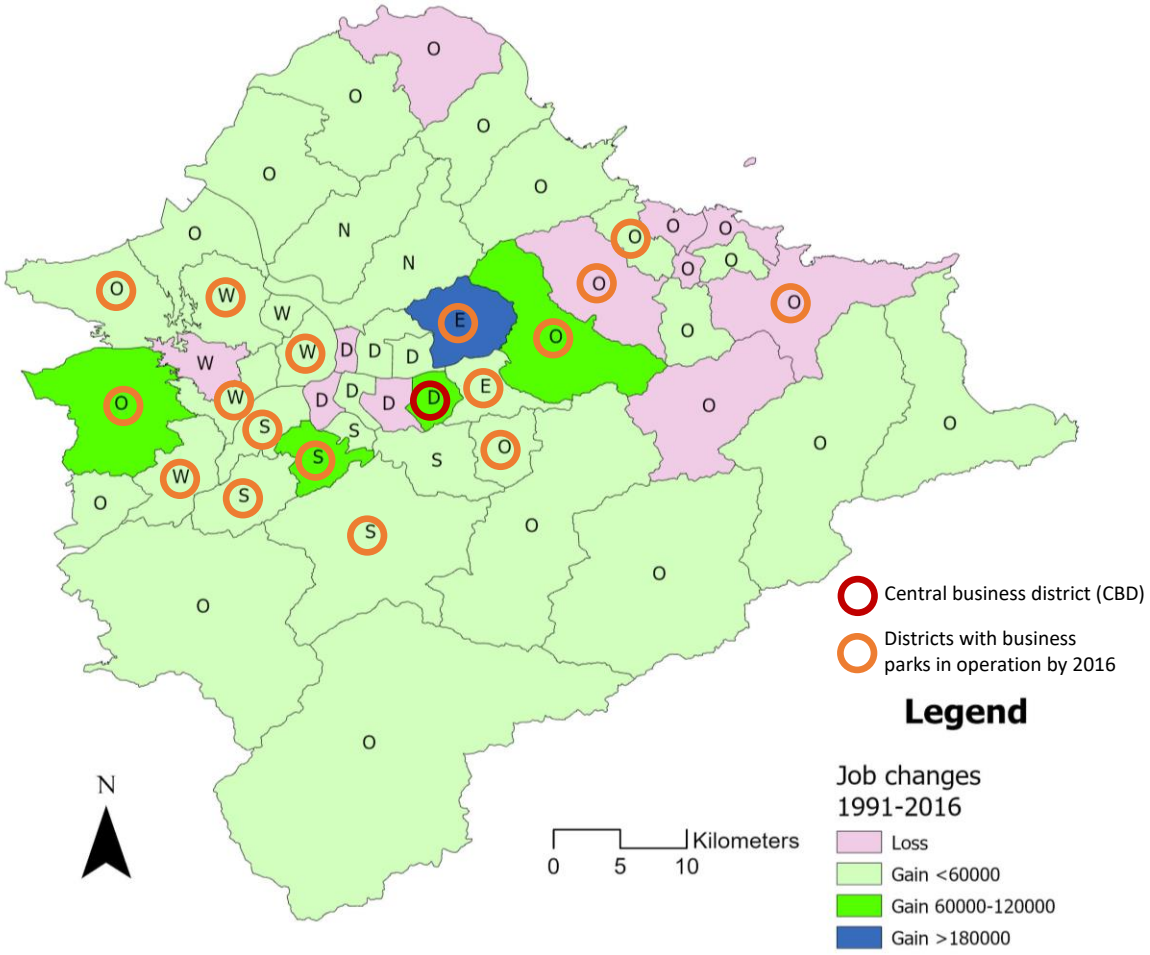


Figure 2.6: Job changes in Greater Taipei by district, 1991-2016

Wage growth

The average wage per worker grew slowly in real terms during the past two decades. The average year-round payrolls per worker in Taipei, New Taipei, and Keelung Cities grew from TW$412,223 in 1996 to TW$603,000 in 2016 in nominal terms, and the AAGR of nominal average year-round payrolls per worker was 1.9%. However, if wages are adjusted by consumer price index (CPI) changes using

1996 as the base year, the amount only grew to TW$495,183 in 2016 in real terms; therefore, the AAGR of real average year-round payrolls per worker was 0.9%. (DGBAS, 2022b)

2.6. Transportation infrastructure

The supply of roads and parking spaces grew rapidly. The conventional railway network has not been expanding. Bus supply expanded significantly. The metro network initially linked the downtown only with the northern and southern inner suburbs, leaving the eastern and western inner suburbs unserved until a decade later. Cycle lanes expanded, and public bikeshare supply grew significantly.

Roads and parking spaces

The supply of roads including highways grew rapidly in length and area during the past two decades. The total length of roads in Taipei, New Taipei, and Keelung Cities combined increased from 3,856 kilometers in 1998 to 5,535 in 2020. On average, the three cities altogether gained 76 kilometers of additional road length per year over this period; the AAGR was 1.7%. Similarly, the total area of road space in Taipei, New Taipei, and Keelung Cities combined increased from 48 square kilometers in 1998 to 71 in 2020. On average, the three cities altogether gained about 1 square kilometers of additional road space per year over this period; the AAGR was 1.8%. (MOTC, 2022)

The supply of automobile and motorcycle parking spaces grew even more rapidly during the past decade. The total number of automobile parking spaces in Taipei, New Taipei, and Keelung Cities combined increased from 1,222,707 in 2009 to 1,737,424 in 2020. On average, the three cities altogether gained 46,792 additional automobile parking spaces per year over this period; the AAGR was 3.2%. Similarly, the total number of motorcycle parking spaces in Taipei and New Taipei Cities combined increased from 778,178 in 2012 to 1,091,072 in 2020; counts of motorcycle parking spaces in Keelung City are unavailable. On average, the two cities altogether gained 39,112 additional motorcycle parking spaces per year over this period; the AAGR was 4.3%. (MOTC, 2022; TCG, 2022c; NTCG, 2022c)

Railway, buses, and the metro

The conventional railway network within Greater Taipei did not expand during the past two decades. The earliest section of the conventional railway system in Taiwan was launched in 1891, connecting downtown Taipei and Keelung. The 20th century saw the Taiwan Railway flourished and, as more advanced rail transportation technologies were adopted, declined. The railway line that linked downtown Taipei with the northern suburbs was demolished in 1988, giving way to a metro line using the same corridor that would begin operation in 1997. No length changes have since occurred to the railway network in Greater Taipei. Nevertheless, most of the railway sections within Greater Taipei had been put underground by 2008. In addition, 5 new stations were added to the existing network in Greater Taipei between 2003 and 2015, three of which are in the eastern outer suburbs (among which one, Xike, serving several small business parks) and two in the western inner suburbs. Longitudinal data of station-level ridership is not publicly available from the Taiwan Railway Administration.

Public transportation supply has expanded significantly. Bus supply expanded significantly during the past decade. The metro network initially linked the downtown only with the northern and southern inner suburbs, leaving the eastern and western inner suburbs unserved until a decade later. Details of the supply and ridership of both the bus and the metro systems are given as contextual information in the three research chapters (See sections 3.3, 4.3, and 5.3).

Cycling infrastructure

Cycle lanes expanded but have remained unprotected, and public bikeshare supply grew significantly for the past 15 years. Public bikeshare systems were introduced to Taipei City in 2007 and New Taipei City in 2009, both underwent a few initial tests years before the expansion of facilities took off. In the meantime, the supply of cycle lanes increased, although they remained mere unprotected marked

cycle lanes. In 2010, Taipei and New Taipei Cities had 538 kilometers of cycle lanes (only marked, not protected), 36 bikeshare stations with multiple docks at each, and 3,170 shared bicycles for hire. By 2020, these had grown into 1,156 kilometers of cycle lanes, 1,047 bikeshare stations, and 35,717 shared bicycles for hire. (TCG, 2022c; NTCG, 2022c)

2.7. Travel behavior

The motorcycle as the dominant primary mode in trips slightly lost popularity, while that of the metro has been on the rise.

Bus and metro ridership

Bus ridership declined in the central city but grew fast in the suburbs at least during the past decade, while metro ridership grew continuously and rapidly ever since the opening of the system. Details of bus and metro ridership are given as contextual information in the first two of the three research chapters (See Sections 3.3 and 4.3).

Cycling

Bikeshare use grew explosively during the past decade as cycling infrastructure increased, although cycling remained a non-primary mode in trips. Annual bikeshare rentals in Taipei and New Taipei Cities combined grew from 470,685 in 2010 to 64,211,519 in 2019 (TCG, 2022c; NTCG, 2022c). Despite the very rapid growth in bikeshare use, the modal share of cycling as a primary mode in trips in Taipei, New Taipei, and Keelung Cities remained small since 2010.

2.8. Household travel surveys

The importance of household travel surveys in Greater Taipei is that they provide a more fine-grained view of travel behavior at the level of the traffic analysis zone (TAZ). All the above-mentioned transportation statistics are available only at the city level. Household travel surveys are conducted for the purpose of transportation planning, especially transit planning. TAZs are usually drawn in household travel surveys for the purpose of studying travel behavior. Except for larger TAZs drawn for geographies outside of the study area, the regular TAZ within the study area of Greater Taipei is a geographic unit smaller than the city and the district and is usually an aggregate of some or all the villages within one district; in other words, a district within the study area in a survey can be divided into one or more regular TAZs (see Figure 2.8). Boundaries of the TAZs can change from survey to survey at the discretion of the designers of each survey. (ATCI, 2001; THI, 2012)

Figure 2.8: Districts (left), traffic analysis zones (center), and villages (right) within Taipei City in the 2009 household travel survey

To date, four large-scale household travel surveys have been conducted in Greater Taipei. The survey years were 1980, 1991, 2000, and 2009. The first large-scale household travel survey was conducted in 1980, based on which the earliest travel demand model for the Taipei Metropolitan Area, the TRTS-I model, was established in 1981 with the technical assistance of British mass transit consultants as part of a preliminary study for the Taipei Metro system. The model was revised into a TRTS-II model

by American transit consultants in 1987. Another large-scale household travel survey was conducted in 1991, based on which the Department of Rapid Transit Systems of the Taipei City Government revised the previous model into a TRTS-III model in 1994. Major changes in land use and transportation had occurred since, such as new towns, business parks, construction of the high-speed rail, opening of the metro system, expansions of highway networks, and dedicated bus lanes. Thus, in 1997, 2001, and 2009, local Taiwanese consultants were commissioned to update the previous model into the DOTS-I, DOTS-II, and TRTS-IV models, of which the latter two were based on large-scale household travel surveys conducted in 2000 and 2009. (ATCI, 2001; THI, 2012)

Data from the latest two large-scale household travel surveys, conducted in 2000 and 2009, were obtained for this dissertation. Datasets and reports of the last two surveys were obtained from the Departments of Rapid Transit Systems and Transportation of the Taipei City Government. Despite the changes in the boundaries of the TAZs between the two surveys, this dissertation was able to generate transportation and land use data with exact precision for any TAZ from either survey by using the TAZ-village matching tables from both surveys. Details of the two household travel surveys are provided as contextual information in the three research chapters (see Sections 3.3, 4.3, and 5.3)

The major differences between the 2000 and 2009 household travel surveys can be summarized as the following. Firstly, in terms of geographical sampling, the 2000 survey included Keelung City while the 2009 one excluded it, and the latter demarcated TAZs in a more fine-grained way, almost double the number of those drawn by the former. Secondly, in terms of survey methods, the 2000 survey excluded trips on foot while the 2009 one included such trips. Thirdly, in terms of modal split, if excluding the trips on foot in the 2000 survey, the modal share of the motorcycle, the most popular mode in both surveys, is larger in the 2009 survey (53%) than in the 2000 one (42%), mainly because of a drop in the modal share of the car.

2.9. Summary of metropolitan changes

The planning history of the Taipei Metropolitan Area since the 1990s is characterized by a rapid expansion of the metro system and the fast growth of inner-suburban business parks. Population declined in the downtown and increased in the southern and western inner suburbs. Housing ownership has become more common, and as housing prices are growing everywhere, central-city housing prices are much higher than suburban ones, but the latter have been catching up quickly. Employment opportunities also declined in the downtown and increased in the southern and eastern inner suburbs. Transportation infrastructure for private vehicles, bus, metro, and cycling all grew, although expansion of the metro prioritized the northern and southern inner suburbs over the eastern and western ones. Travel behavior trends show that the popularity of the metro has risen. Household travel surveys in Greater Taipei provide a more fine-grained view on travel behavior, and data from the latest two large-scale household travel surveys conducted in 2000 and 2009 were obtained for this dissertation research.

Three trends deserve particular attention, and together they provide important clues on how travel behavior may change in Greater Taipei. First, the opposite directions of the suburbanization of population and employment. As both residents and jobs gravitated from the downtown to the inner suburbs, although both increased in the south, population grew the most strongly in the west while employment did in the east. Second, a disconnect between the strongest population and employment growth and the geographic priorities of the expansion of the metro system. The initial metro expansions only reached the north and the south, leaving the fast growth of jobs in the east and residents in the west uncaptured by mass transit for several years. Third, a possible overall substitution between motorcycle trips and metro rides. Evidence includes, since around 2010, declining modal share and ownership rate (despite growing household ownership) of the motorcycle, growing modal share and ridership of the metro, little change in the modal share and ridership of the buses, and little change in the modal share and ownership rate of the cars.

CHAPTER 3: RELATIONSHIP BETWEEN MOTORCYCLE TRAVEL AND THE BUILT ENVIRONMENT

3.1. Introduction

Although motorcycles are often considered having advantages of time and cost savings compared with other travel modes, these advantages should be subject to characteristics of the built environment, such as population density. It should be no coincidence that Asia, the most densely populated world region, is home to the world's most intense motorcycles-to-population ratios led by Taiwan with 587 motorcycles per thousand population, followed by Vietnam (498), Indonesia (446), and Malaysia (406) (WHO, 2018; JAMA, 2020). While the built environment effects on the ownership and use of cars and motorcycles are different, the former has been much more studied, for example in the meta-analysis conducted by Ewing & Cervero (2010), than the latter. The existing literature on motorcycle travel leaves two gaps in knowledge. First, the current understanding of the built environment effects on motorcycle ownership remains limited. Second, no built environment characteristics have been identified as predictors of motorcycle mode choice likelihood. The objective of this chapter is to fill these gaps in knowledge by examining the relationship between motorcycle travel and the built environment using the largest metropolis of Taiwan, home to the world's highest motorcycle ownership rate, as the study context.

Is there a relationship between the built environment and motorcycle travel in Taipei? This chapter examines the relationship between the built environment including the presence of metro stations on household vehicle ownership, mode choice in a trip, and household motorcycle vehicle kilometers traveled (VKT) by specifying multinomial logistic and tobit regression models, controlling for socioeconomic predictors of motorcycle travel. It uses trip and household datasets from both the 2000 and 2009 large-scale household travel surveys in the Taipei Metropolitan Area, the most recent two in the metropolis, with a total 93,230 trips not limited to any specific type of origins, destinations, and purposes as well as 27,754 households being used for analysis.

This chapter makes several academic and policy contributions to existing knowledge on the relationships between motorcycle travel and the built environment. This chapter verifies literature-based hypotheses including that motorcycle ownership is positively correlated with population density, motorcycle mode choice likelihood is correlated with built environment variables, household motorcycle VKT is negatively correlated with population density and land use diversity, and income is negatively correlated with motorcycle ownership, mode choice, and VKT. This chapter also makes policy recommendations on how transportation and land use should be coordinated to influence motorcycle travel for any cities in the world that have high rates of motorcycle ownership and motorcycle-predominant traffic.

3.2. Literature review

Based on the existing empirical literature on travel and the built environment, the differences between built environment effects on the ownership and use of cars and motorcycles can be summarized as the following: the ownerships of cars and motorcycles are associated with population and road densities in ways opposite to each other, and the use of cars and motorcycles are associated with different built environment variables. Motorcycle ownership is associated with higher population and road densities, and motorcycle use is associated with a higher population density and perhaps a lower degree of land use diversity. Nevertheless, the current understanding of the built environment effects of built environment on motorcycle ownership remains limited, and although motorcycles are often considered having advantages of time and cost savings compared with other modes, these advantages should be subject to the built environment characteristics, which have not been identified as predictors of motorcycle mode choice. To sum up, new research that comprehensively includes built environment variables is needed for understanding the built environment characteristics associated with motorcycle travel.

Built environment effects on vehicle ownership and use

Car ownership is associated with lower population and employment densities, less dense street network design, lower presence of transit, and a longer distance from downtown. Recent empirical studies on car ownership and the built environment in Canada, China, Finland, India, and the US suggest that population and employment densities, pedestrian-friendly street network design (such as smaller average block size, higher densities of roads or intersections), and the presence of public transit are negatively correlated with car ownership in most urban contexts across developed and developing countries; also consistent among most research contexts regardless national income levels is the positive association between car ownership and the distance from the central business district (CBD) of a city; however, the relationship between land use diversity and car ownership remain disputed among studies not only on different countries but even on the very same city such as Changchun, China. (Ao et al, 2019; Ding et al, 2018; Ding et al, 2017; Ding & Cao, 2019; Doddamani & Manoj, 2021; Laviolette et al, 2022; Li & Zhao, 2017; Ramezani et al, 2021; Wang et al, 2018; Yin et al, 2018; Yin & Sun, 2018; Zhang et al, 2018)

Car use is strongly associated with a higher accessibility to destinations and a less dense street network design, while its relationship with densities is weak. Perhaps the most comprehensive summary of the relationship between the built environment and car use to date is provided by Ewing & Cervero (2010) in their meta-analysis of the built environment-travel literature up to the end of 2009. Their findings confirmed earlier propositions that built environment measures including densities, land use diversity, street network design, accessibility to destinations, and distance to transit are all explanatory to car vehicle miles traveled (VMT). Collectively, these built environmental measures are dubbed the “D variables”. The signs and magnitudes of the associations between the D variables and car VMT differ. Job density is positively correlated with car use, while what is negatively correlated with car use includes population density, land use diversity, the design metrics (intersection density and street connectivity), destination accessibility, and distance to the nearest transit stop. Car VMT is most strongly related to destination accessibility; next, to distance to downtown which is a proxy of many of the D variables such as density, diversity, and destination accessibility; and next, to street network design. The association

between population and job densities and car use are weak once the above other built environmental variables are controlled.

Motorcycle ownership is associated with higher population and road densities. The population density at a household's residential location is positively correlated with its motorcycle ownership level, agreed by most relevant research (Kepaptsoglou et al, 2011; Wong, 2013; Yamamoto, 2009). However, in highly motorcycle-dependent contexts like Jakarta, Indonesia, population density can be uncorrelated with private motorcycle ownership, as motorcycles had diffused so widely all over the metropolitan area regardless of whether the place was urban or not (Yagi et al, 2014). The road density at a household's residential location is positively correlated with its motorcycle ownership level, also agreed by all relevant research (Chiou et al, 2009; Doddamani & Manoj, 2021; Putranto et al, 2007).

Motorcycle use is associated with a lower population density and perhaps a lower degree of land use diversity. Population density is negatively correlated with the amount of motorcycle use, suggested by studies on motorcycle use in Mumbai, India (Shirgaokar, 2016) and across cities of Indonesia (Wandani et al, 2018). Land use diversity, although only identified by one single study on motorcycle use, can have a notably large negative impact on motorcycle VKT, a measure of the amount of a household's daily motorcycle use, as Shirgaokar (2016) found in Mumbai that a one-unit increase in land use diversity index resulted in a 40% decrease in motorized two-wheeler use; he called for more studies to verify such a finding, especially in the motorcycle-stressed South Asian and Southeast Asian context.

In comparison, car ownership and motorcycle ownership are associated with population and road densities in ways opposite to each other, and the use of cars and motorcycles are associated with different built environment variables. While car ownership is associated with a lower population density and a less dense street network design, motorcycle ownership is associated with higher population and road densities. Destination accessibility and the design of street networks are associated with car use; however, population density and perhaps land use diversity are associated with motorcycle use.

Transit effects on motorcycle ownership and use

Increased presence of transit is linked to reduced motorcycle ownership, mode choice, and amount of use. Within a city, the supply of public transportation, both rail and bus transit, had a negative effect on motorcycle ownership. Two studies support this finding. Nagai et al (2003) examined Thailand's seven major cities to study vehicle ownership, and they found that the presence of public transportation measured by the number of registered buses suppressed motorcycle ownership in Bangkok and Chiang Mai; but in other cities motorcycle ownership tended to increase as the local economic conditions improved regardless of public transportation provision. Yamamoto (2009) found that public transit accessibility, calculated by the cumulative opportunities accessible from the residence weighted by public transit (both train and bus) travel time, had a negative effect on motorcycle ownership in both Osaka, Japan and Kuala Lumpur, Malaysia, consistent with expectations about motorcycle ownership.

Also, within a city, the distance to certain forms of high-capacity transit was correlated with motorcycle travel, as a longer distance to railway or bus rapid transit (BRT) from the residential location was correlated with a higher likelihood of motorcycle mode choice or higher motorcycle VKT, but such relationships did not exist if the transit station concerned was a bus stop. Three studies support these findings. Shirgaokar (2016) in his Mumbai study found that a 10% increase in the distance between the home and railway station would result in a 0.6% increase in motorized two-wheeler VKT. Satiennam et al (2016) studied Khon Kaen, Thailand to assess the potential of BRT for attracting travelers from passenger cars and motorcycles and found that motorcycle users whose residential location was within 400 meters from the station were more likely to switch to BRT than those whose residential location was farther away. Herwangi et al (2018) studied Yogyakarta, Indonesia and found that the distance to a bus stop had no effect on motorcycle dependence, as those who owned a motorcycle would prefer to use it even if they were close to a bus stop.

Residential location choice and vehicle use

Residential self-selection complicates the relationship between the built environment and vehicle use. Residential location can be a choice that people make based on their preference of certain travel modes over others, which informs their residential selection of locations with built environment characteristics that allow such travel options, such as homes close to transit or highways, thus their vehicle ownership and use levels are so shaped (Cervero, 2007; Brownstone, 2008; Ewing & Hamidi, 2014; Houston et al., 2015; Weinberger & Goetzke 2010). In research, the failure to account for residential self-selection can cause overestimates or underestimates of the relationship between the built environment and travel, which is the so-called self-selection bias (Cao et al., 2009; Chatman, 2009; Mokhtarian & Cao, 2008). While including sociodemographic control variables in statistical models can account for some residential self-selection (Bhat & Guo, 2007; Brownstone & Golob, 2009; Guerra, 2014), self-selection bias can also be corrected via being computed and used as a covariate in models (Houston et al., 2015; Shirgaokar, 2016; Zegras, 2010).

Cross-context differences can exist in terms of residential location choice and vehicle use. For example, the downtown/suburban distinction can be relevant or irrelevant in predicting vehicle use. While in North America it is the households who choose to live in suburbs have higher car use than those who choose to live downtown (Zhou & Kockelman, 2008), in Asian cities such as Mumbai, downtown households have higher car use and peripheral ones have higher motorized two-wheeler use (Shirgaokar, 2016). As another example, distance to transit may or may not matter in vehicle use. In some cities, transit stations can become centers of clusters of employment and entertainment, thus attracting households who are of higher income who can afford the resulting heightened housing prices and who tend to own and use vehicles more, and households who cannot afford to live close to transit stations may also own and use vehicles to access transit, employment, and entertainment (Bhat & Guo, 2007; Guerra, 2015; Shirgaokar, 2016).

Socioeconomic effects on motorcycle ownership and use

Motorcycle ownership level of a household is associated with socioeconomic variables including the numbers of adults and workers, car ownership level, and income of a household. Both the number of adults and that of workers in a household are positively correlated with its motorcycle ownership level (Chiou et al, 2009; Hai & Susilo, 2009; Lai & Lu, 2007; Tuan & Shimizu, 2005; Wedagama, 2009; Wong, 2013; Yamamoto, 2009). The car ownership level of a household is negatively correlated with its motorcycle ownership level (Chiou et al, 2009; Hai & Susilo, 2009; Hsu et al, 2007; Kepaptsoglou et al, 2011; Leong & Sadullah, 2007; Wen et al, 2012). The income of a household is negatively correlated with its motorcycle ownership level (Doddamani & Manoj, 2021; Hai & Susilo, 2009; Hsu et al, 2007; Joewono et al, 2013; Kepaptsoglou et al, 2011; Putranto et al, 2015; Tuan & Shimizu, 2005), while some studies suggest a positive correlation (Rose & Delbosc, 2016; Doddamani & Manoj, 2021; Leong & Sadullah, 2007; Wong, 2013; Yagi et al, 2014) or no correlation (Yamamoto, 2009). The disagreement within countries over the role of household income on motorcycle ownership occurs between cities: Dharwad and Hubli in India; Bandung and Jakarta in Indonesia; and Kuala Lumpur and Penang in Malaysia.

Mode choice between motorcycle and other modes of travel is associated with socioeconomic variables including the income and age of a trip maker. Income is negatively correlated with the mode choice likelihood of motorcycles (Chang & Wu, 2008; Chen & Lai, 2011; Irza et al, 2021). Likewise, age is negatively correlated with the mode choice likelihood of motorcycles (Chang & Wu, 2008; Irza et al, 2021; Satiennam et al, 2016).

Motorcycle VKT of a household is associated with socioeconomic variables including household size, car ownership level, the age of the principal user, and income. However, the role played by income remains in disagreement. The number of household members, or household size, is positively correlated with the amount of motorcycle use (Shirgaokar, 2016; Thu Huyen & Tu, 2019). Car ownership level is negatively correlated with the amount of motorcycle use (Chiou et al, 2009; Kepaptsoglou et al, 2011). The age of the principal user is negatively correlated with the amount of motorcycle use (Chiou et al, 2009; Lai & Lu, 2007). Income can be negatively correlated (Chiou et al, 2009; Kepaptsoglou et al, 2011;

Wen et al, 2012), positively correlated (Shirgaokar, 2016), or uncorrelated (Lai & Lu, 2007) with the amount of motorcycle use in different contexts; disagreement remains between studies on Taiwan over whether income negatively affects (Chiou et al, 2009; Wen et al, 2012) or does not affect (Lai & Lu, 2007) motorcycle use.

Gaps in knowledge on the built environment and motorcycle ownership and use

The current understanding of the built environment effects on motorcycle ownership remains limited. While much has been found about the socioeconomic predictors of a household's motorcycle ownership level, only population and road densities has been identified as influential built environment predictors. However, more aspects of the built environment can also affect decisions on vehicle travel, for example the above-mentioned D variables (Ewing & Cervero, 2010). So far, only two studies on motorcycle ownership included most of these predictors in their analyses (Doddamani & Manoj, 2021; Yamamoto, 2009). The small number of studies that included built environment predictors has resulted in a lack of agreement on the effect of these predictors on motorcycle ownership.

Although motorcycles are often considered having advantages of time and cost savings compared with other modes, these advantages should be subject to the built environment characteristics, which have not been identified as predictors of motorcycle mode choice. For example, seen from the mode share perspective, while in some contexts the motorcycles prove a time-saving mode compared to other surface modes such as cars and buses in times of traffic congestion, they are still less preferred than cars in low-density contexts including most parts of the US and less preferred than the public transport in contexts with extensive public transport networks such as Bogota, Colombia and Tokyo, Japan (LTA, 2011). The small number of studies on mode choice involving motorcycles that include built environment variables in their analyses (Herwangi et al, 2018; Jou & Chen, 2014; Satiennam et al, 2016; Yagi et al, 2014) may have prevented the forming of agreement on the effect of such variables on mode choice.

To sum up, new research that comprehensively includes built environment variables is needed for understanding the built environment characteristics associated with motorcycle travel. Households or individuals might have become motorcycle-dependent for a mix of reasons involving the built environment in addition to high population density and the resulting contested road space and parking spaces: low land use diversity and the resulting long travel distances between homes, jobs, and other daily activities; dense road networks with pedestrian-unfriendly design characteristics; and a lack of viable public transportation and other travel options other than private vehicles. Future studies that join existing ones to explore the relationship between the built environment and motorcycle travel will help form stronger academic agreements that can inform urban planning.

3.3. Context: Taipei Metropolitan Area

Household travel surveys in 2000 and 2009

The 2000 and 2009 household travel surveys in the Taipei Metropolitan Area, the largest metropolis of Taiwan, offer the opportunity to understand how trip-level travel behavior changed as the metro system expanded and modal split shifted at the metropolitan scale. The first survey “DOTS-II” was conducted immediately after the Taipei Metro first formed a connected network in December 1999. The second survey “TRTS-IV” was conducted immediately after the metro system reached Neihu, a suburban district to the northeast of downtown with the most rapid job growth in the metropolitan area.

The first of the two household travel surveys used in this chapter was conducted in 2000 and covered a total of 129,139 trips (not including trips on foot). The survey was conducted between April 1 and June 30, 2000. The survey was conducted by the Taipei-based Asian Technical Consultants, Inc., commissioned by the Department of Transportation of the Taipei City Government. The geographical scope of the study included Taipei City, Taipei County (today’s New Taipei City), Keelung City, plus Guishan Township of Taoyuan County (today’s Guishan District of Taoyuan City). The survey drew up

383 traffic analysis zones (TAZs) based on villages, including 376 within the study area and 7 outside of it. The survey covered socioeconomic and trip characteristics of 117,066 persons from 32,217 households (1.5% of all households in the study area) as an effective sample who reported trips. (ATCI, 2001)

The second of the two household travel surveys used in this chapter, being the most recent survey conducted in Greater Taipei, was conducted in 2009 and covered a total of 64,904 trips (including trips on foot). The survey was conducted partly (a minority of trips reported, about 10%) between May 1 and June 30, 2009, and mostly between September 1, 2009 and January 22, 2010. The survey was conducted by the Taipei-based THI Consultants Inc., commissioned by the Department of Rapid Transit Systems of the Taipei City Government. The geographical scope of the study was the same as that of the 2000 survey except that Keelung City was excluded. The survey drew up 601 TAZs, including 571 within the study area and 30 outside of it. The survey covered socioeconomic and trip characteristics of 32,136 persons from 9,000 households (0.39% of all households in the study area) as the sample, who reported trips. Note that only the approximately 10% earliest trips reported to the survey were made before the Taipei Metro extended further into the eastern inner suburbs, beginning to serve Taipei City's Neihu District, home to the strongest job growth in the metropolitan area between the two surveys. (THI, 2012)

The major differences between the 2000 and 2009 household travel surveys can be summarized as the following. Firstly, in terms of geographical sampling, the 2000 survey included Keelung City while the 2009 one excluded it, and the latter demarcated TAZs in a more fine-grained way, almost double the number of those drawn by the former. Secondly, in terms of survey methods, the 2000 survey excluded trips on foot while the 2009 one included such trips. Thirdly, in terms of modal split, if excluding the trips on foot in the 2000 survey, the modal share of the motorcycle, the most popular mode in both surveys, is larger in the 2009 survey (53%) than in the 2000 one (42%), mainly because of a drop in the modal share of the car (see Figure 3.7).

The estimation of the number of jobs at the TAZ level in this chapter relies partly on the household travel surveys. Unlike population, the number of jobs in a TAZ was not available in the household travel survey datasets, and the number of jobs in Taiwan is only counted at the district level,

not at the more fine-grained level of the village, every five years in the nationwide Industry and Service Censuses (ISCs). As a result, the approach to estimating TAZ-level jobs in this chapter was to use a TAZ's share in work trips that ended in a district in a household travel survey as the proxy of a TAZ's share in jobs located in a district (assumption: Total jobs in a TAZ / Total jobs in a district = Work trips to a TAZ / Work trips to a district), as well as to use the district-level job count in the closest ISC year to a household travel survey year as the proxy of the district-level job count in the household travel survey year; this chapter used two ISC years, 2001 and 2011, as proxies of the two household travel survey years, 2000 and 2009. Finally, the ArcGIS Pro software was used to calculate TAZ-level job density as the result of estimated TAZ-level jobs divided by TAZ total area.

Spatial distribution of population and jobs

The 2000-2009 period in Greater Taipei, which comes between the two household travel surveys from which trip and household data are available, was characterized by a dispersion of population and jobs from the downtown to the suburbs. Such a phenomenon can be seen at the TAZ level. Greater Taipei saw major growth in population in the western suburbs and major growth in jobs in an eastern suburb. Major suburban population growth occurred to the west of the downtown, while the downtown and the areas to the east of downtown experienced population losses. It is not surprising that the downtown lost population and many of the suburbs gained population, because housing prices are much higher in the central city than in the suburbs, pushing homebuyers to the peripheral areas. As for jobs, while the number of jobs grew throughout the region, the greatest job growth occurred in an eastern inner suburb, Neihu, with the presence of a fast-growing major business park. Figures 5.1 and 5.2 show increases in population and job densities in TAZs beyond the downtown between the 2000 and 2009 household travel surveys.

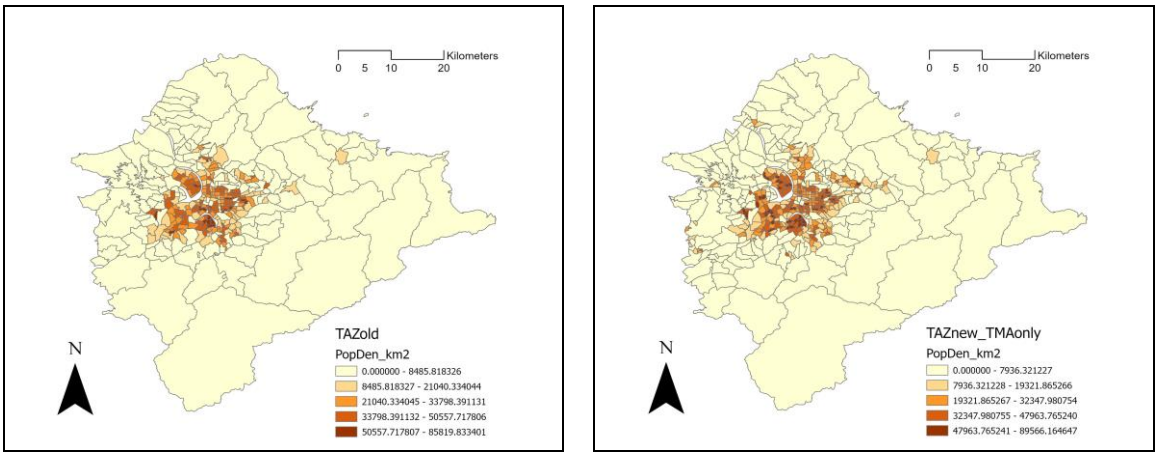


Figure 3.1: Population density (people/km^2) by TAZ during the 2000 (left) and 2009 (right) surveys

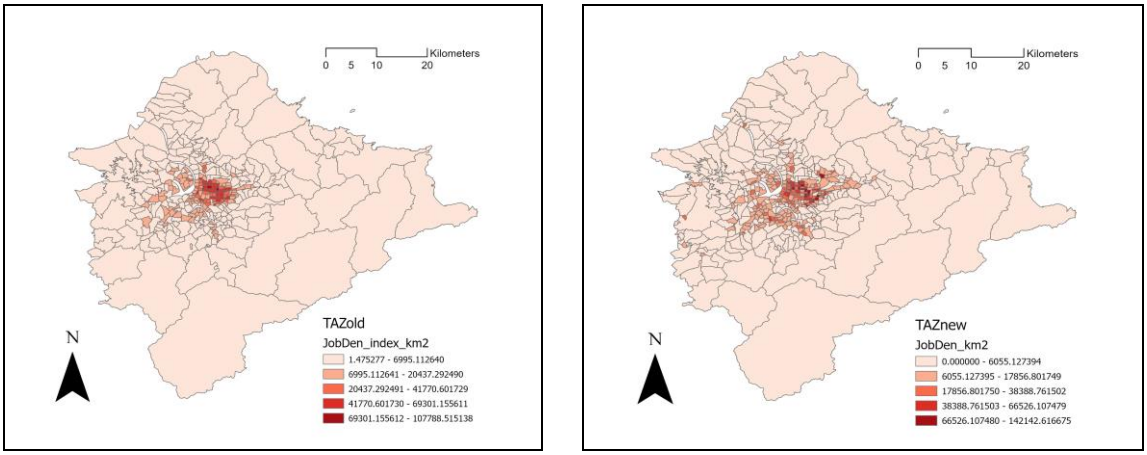


Figure 3.2: Job density (jobs/km^2) by TAZ during the 2000 (left) and 2009 (right) surveys

Metro expansion

The Taipei Metro system initially linked the downtown only with the northern and southern inner suburbs, leaving the eastern and western inner suburbs unserved until the late 2000s. The Taipei Metro expanded its network rapidly, from the initial 11 total revenue kilometers in 1996 to 146 in 2020 (see Figure 5.3). Initially, the system connected the downtown with the southern inner suburbs, the northern

inner suburbs, and a northern outer suburb; a connected network first formed by joining separate lines in December 1999, and the 2000 household travel survey used in this chapter was conducted with this scope of the metro network. Then, the network expanded and first reached an eastern inner suburb in late 2000, completed most of its eastern-suburb route in 2009 just before about 90% of the trips reported in the 2009 household travel survey occurred (in other words, the 2009 household travel survey used in this chapter was mostly conducted with this scope of the metro network), and finally all of it by 2011. The network first reached a western inner suburb in 2010, and it completed its western-suburb route in 2013. The first suburb-to-suburb connection was not launched between the southern and western inner suburbs until 2020. (MOTC, 2022)

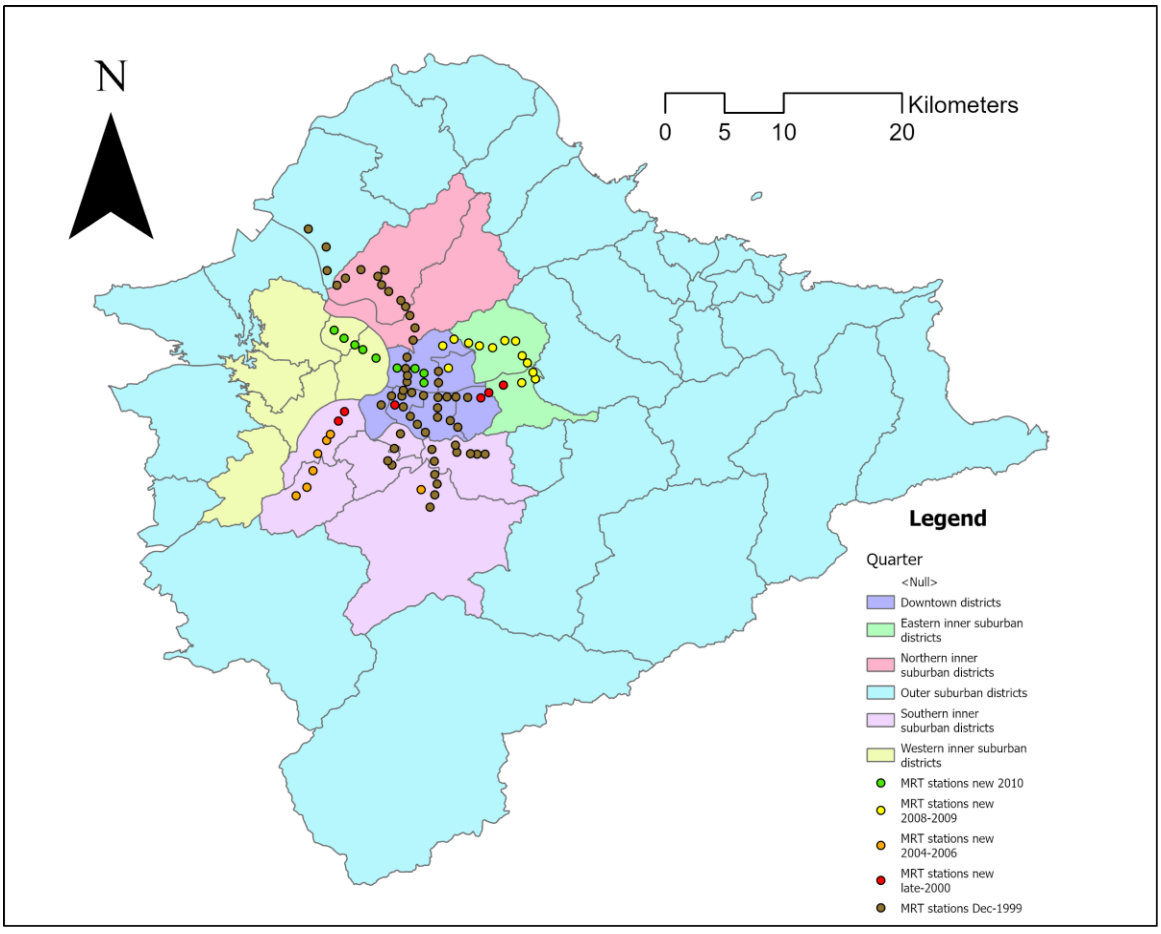


Figure 3.3: Incremental expansions of the Taipei Metro network up to November 2010 and their relationship with the quarters of Greater Taipei

Metro ridership

Metro ridership grew continuously and rapidly ever since the opening of the system in 1996. The Taipei Metro has spanned across Taipei and New Taipei Cities since the very first day of operation, so the system-wide ridership equals ridership in the two cities combined. The metro ridership grew from 31 million in 1997 to 790 million in 2019. On average, the entire metro system gained around 27 million additional passengers per year over between 2000 and 2019, excluding the extreme years such as the pre-2000 years when the network only had two disconnected separate lines and the post-2000 years when transit ridership was affected by the COVID-19 pandemic; the AAGR was 5.84% (MOTC, 2022). (See Figure 3.4)

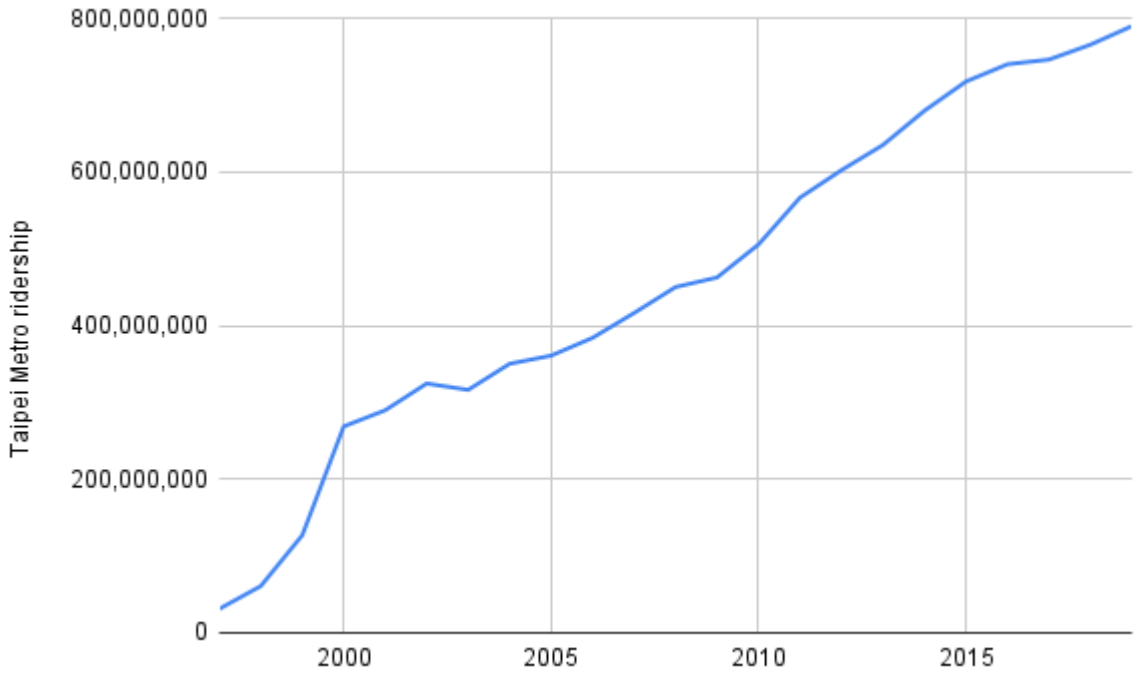


Figure 3.4: Taipei Metro ridership, 1997-2019

Motorcycle and car ownership

The motorcycle as the dominant type of private vehicles boasts a much larger fleet than the cars, but it has decreased in both total number and ownership rate since around 2011; nevertheless, from 2000 to 2009, household motorcycle ownership had grown, and the share of non-motorcycle-owning households had decreased across all income groups. The car, on the contrary, grew in number in a generally continuous fashion (See Figures 3.5 and 3.6). The motorcycle ownership rate has been high, but it peaked 15 years after the introduction of the metro system and declined steadily since. The total number of registered motorcycles in Taipei, New Taipei, and Keelung Cities combined was 2.2 million in 1996, peaked at 3.7 million in 2012, and declined steadily to 3.3 million in 2020. Taking population into consideration, the number of registered motorcycles per thousand people was 352 in 1996, peaked at 526 in 2011, and declined steadily to 478 in 2020 (MOTC, 2022). Household motorcycle ownership had grown across all income groups. Data from the 2000 and 2009 household travel surveys show that, between the two surveys, the share of households owning no motorcycles dropped both for the entire sample and across all income quintiles; there were considerable gains in the shares of households owning multiple (two or above) motorcycles. It is noteworthy that the lowest-quintile income group has had the largest share of non-motorcycle-owning households among all income groups. Car ownership rate has generally been growing. The total number of registered automobiles in Taipei, New Taipei, and Keelung Cities combined was 1.2 million in 1996 and grew to 1.7 million in 2020. Taking population into consideration, the number of registered automobiles per thousand people was 192 in 1996 and, despite slight fluctuations, grew to 247 in 2020. On average, the three cities altogether gained over 21,000 additional registered automobiles per year over this period; the AAGR was 1.48% (MOTC, 2022).

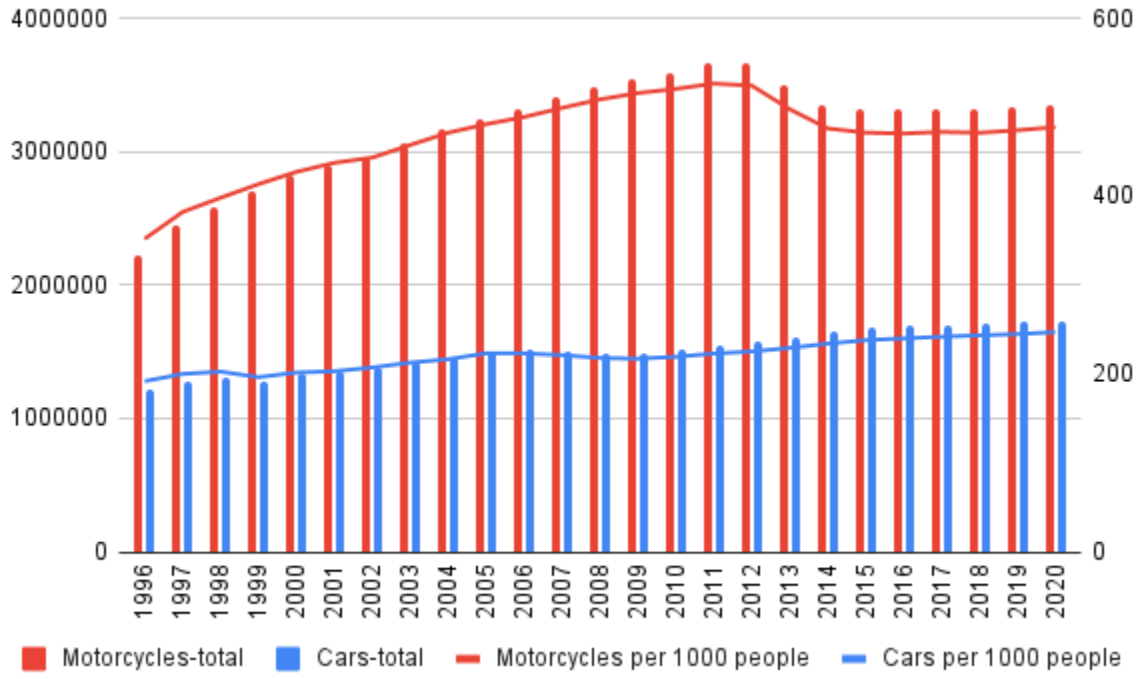
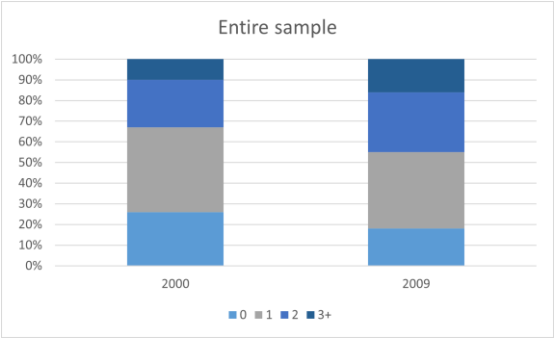
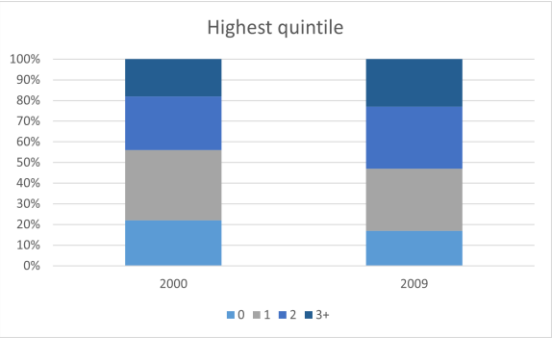


Figure 3.5: Changes in total ownership and ownership per thousand people of registered cars and motorcycles in Taipei, New Taipei, and Keelung Cities combined, 1996-2020





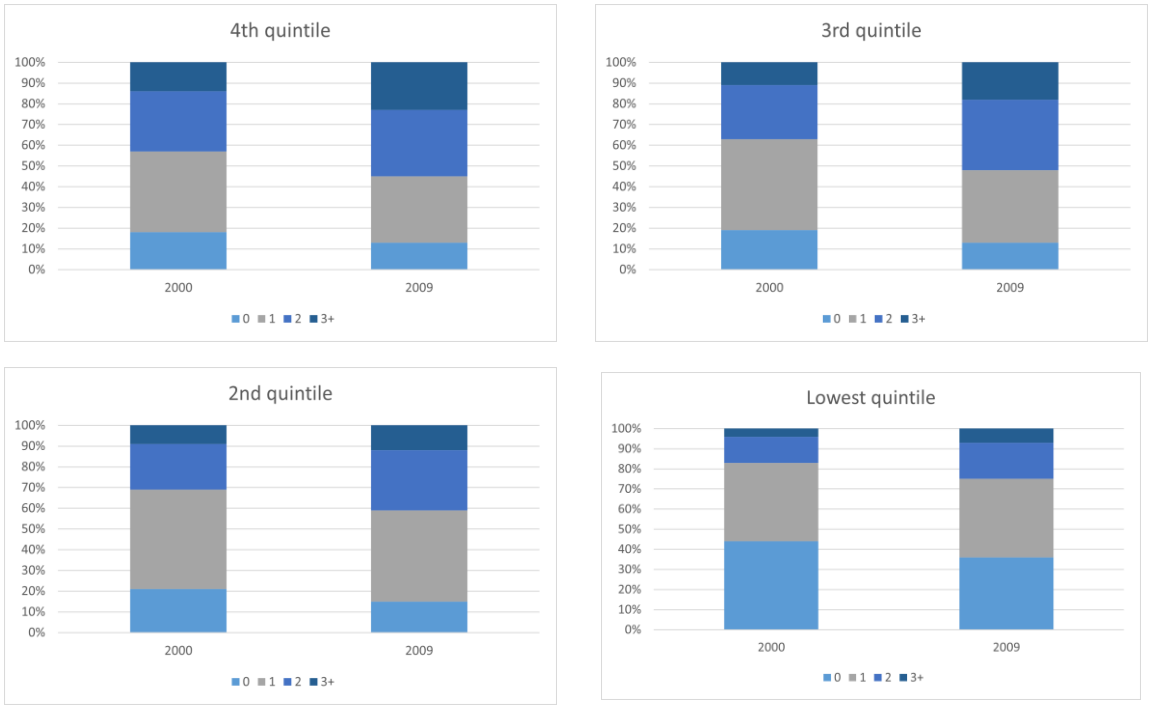


Figure 3.6: Changes in household motorcycle ownership by income quintile in the Taipei Metropolitan Area, 2000 and 2009

Modal split

The motorcycle as the dominant primary mode in all trips saw its popularity rising not only in all trips but also in trips to work in the office during the study period of this chapter. According to the trip datasets from the 2000 and 2009 household travel surveys before data-cleaning, the modal share of the motorcycle in all trips increased from 42% to 53% over the period (see Figure 3.7), and that of the motorcycles in commuting trips from 48% to 58% (see Figure 3.8), both calculated with walking (available only in the 2009 survey), other modes, and unidentifiable modes being excluded from the overall modal split. The modal share of the car shrank considerably, and that of the buses decreased while that of the metro increased.

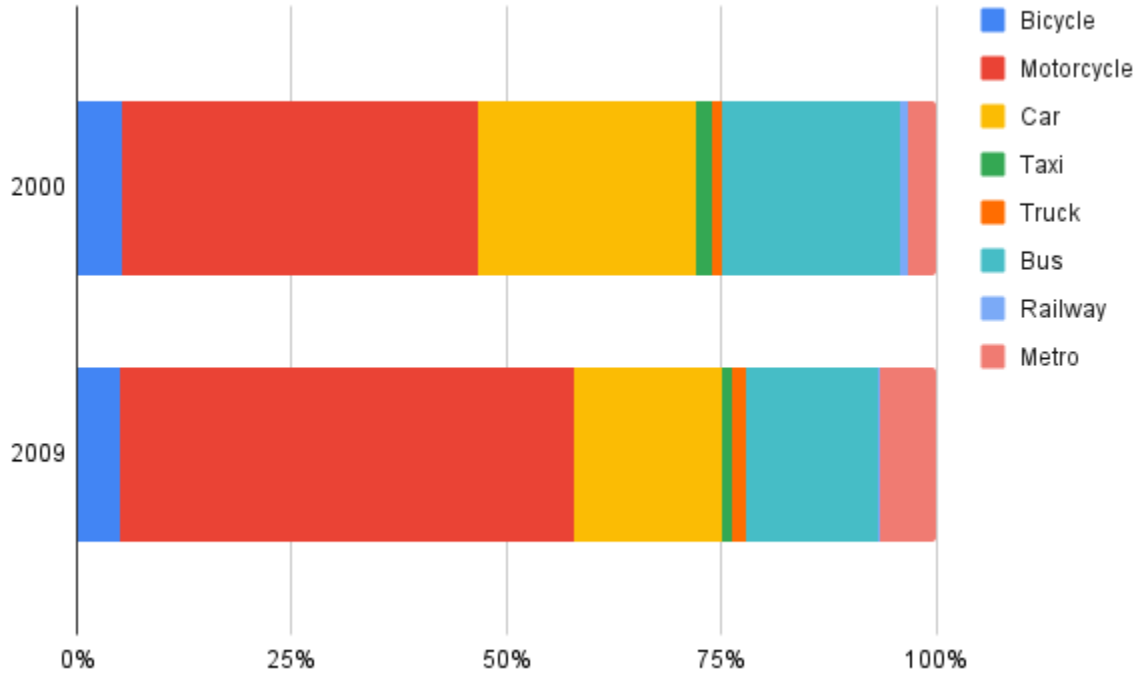


Figure 3.7: Changes in modal split of all trips in the Taipei Metropolitan Area, according to the 2000 and 2009 household travel surveys (before data-cleaning), excluding walking (available only in 2009 survey), other modes, and unidentifiable modes

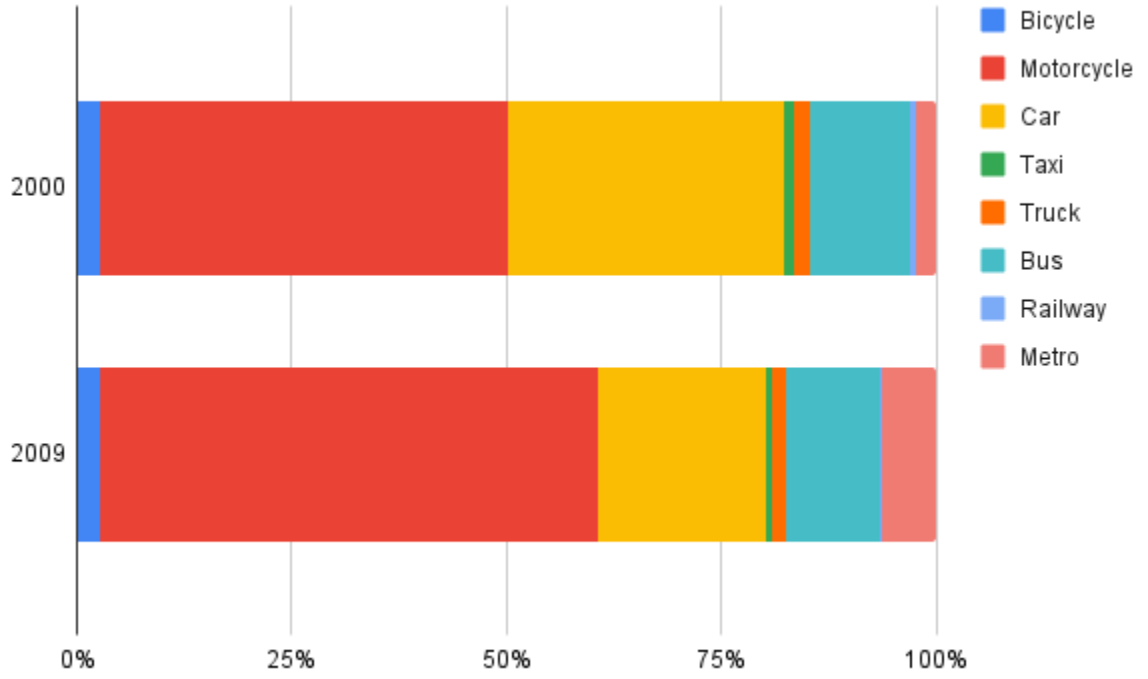


Figure 3.8: Changes in modal split of trips to work in the office in the Taipei Metropolitan Area, according to the 2000 and 2009 household travel surveys (before data-cleaning), excluding walking (available only in 2009 survey), other modes, and unidentifiable modes

3.4. Data

The data used in this chapter are separate household and trip datasets from the 2000 and 2009 household travel surveys in Greater Taipei, the most recent two in the metropolis; the chapter also uses population and employment statistics publicly available to generate data for the variables needed in the models. Trips used for analysis in this chapter are not limited to any specific type of origins, destinations, and purposes; a total of 93,230 trips remain after data cleaning (linking trips, trip makers, households, and TAZs) among all 203,175 trips from the two household travel surveys combined. Meanwhile, data cleaning leaves 27,754 households remaining among all 41,217 households from both surveys.

Potential built environment and socioeconomic predictors of motorcycle travel behavior are selected to be included in the models as control variables based on the literature review. These include the spatial relationship with metro stations, population density, land use diversity, the number of household members, the age of the trip maker, and household income; as for car ownership level, it is reflected in residential self-selection bias correction which is included as a control variable in the mode choice and household motorcycle VKT models. In addition, three other variables are added to the list of control variables, including job density, distance to the CBD, and the gender of the trip maker, among which the distance to the CBD can act as a proxy of densities, land use diversity, and destination accessibility (Ewing & Cervero, 2010). The design metrics of the built environment, such as intersection density and street connectivity, is also a commonly used control variable in built environment-travel research (Ewing & Cervero, 2010), but such variables are difficult to be calculated for Taipei due to the lack of available spatial data. The following paragraphs describe each of the variables, and Table 3.1 provides their descriptive statistics.

Dependent variables:

Household vehicle ownership. The number of motorcycles and cars that a household owns. Due to the fact that households may consider owning not only motorcycles but also cars as circumstances change, motorcycle ownership levels were incorporated into the level of combined ownership of motorcycles and cars for consideration in this chapter. There are five categories: zero motorcycles and zero or one or more cars (the base category – the non-vehicle owning group had a share less than 5% in both surveys and would cause overfitting in the model if being a separate group, thus it was pooled with the cars-only group); one motorcycle and zero cars; one motorcycle and one or more cars; two or more motorcycles and zero cars; and two or more motorcycles and one or more cars.

Likelihood of mode choice of motorcycle instead of bus/car/metro/bicycle. The likelihood that a trip maker chooses to use a motorcycle instead of an alternative mode to fulfill a trip.

Household motorcycle VKT. The sum of the distances, measured in kilometers, of all motorcycle trips made by members of the same household within a day.

Explanatory variables:

Population density. Number of persons, measured in 100,000, per square kilometers in a TAZ.

Job density. Number of jobs, measured in 100,000, per square kilometers in a TAZ.

Land use diversity index. A measure of land use diversity. A value that reflects the level of balance between different land uses of a TAZ. The highest possible value is 1 which indicates perfect balance, and the lowest value is 0 which indicates perfect imbalance (Rajamani et al, 2003; Zegras, 2010). Because direct data of land uses or zoning would not reflect the reality of the distribution of activities in high-density Greater Taipei where multistory buildings are the norm and mix of uses are common across all categories of zoning, this chapter used trip destinations as a proxy of the locations of activities (Guerra, 2014b; Shirgaokar, 2016) with one caveat: this chapter was only able to use three types of activities - homes, work, and school, because besides these three, all other trip purposes are categories that combine multiple kinds of activities. Equation 3.1 is the formula for calculating the land use diversity index.

$$DI = 1 - \frac{\sum_{i=1}^{3} \left| \frac{D_i}{D_t} - \frac{1}{3} \right|}{\frac{2}{1.5}}$$

(Equation 3.1.)

where DI is land use diversity index in a TAZ, D_i is the number of trip destinations of each of the three categories including homes, work, and school, and D_t is the total number of trip destinations of the three categories.

Distance to the CBD. Distance, measured in 100 kilometers, between the CBD of Greater Taipei, the Xinyi Special District located in the southeast of Taipei City, and the centroid of the TAZ. A measure of destination accessibility, because jobs or other attractions of trips tend to be the highest at central locations and lowest at peripheral ones (Ewing & Cervero, 2010); this holds true for the context of Greater

Taipei where jobs are highly concentrated in the central districts where the CBD is also located (see Figure 4.2).

Residential self-selection bias correction. A measure calculated to counter residential self-selection bias (Houston et al., 2015; Shirgaokar, 2016; Zegras, 2010). It also reflects household vehicle ownership and can thus be a control variable in mode choice and VKT models. This was calculated using Equation 3.2:

$$SBC_l = \left(\frac{1}{K}\right)\sum_{k\neq c}^{K}\left(\frac{P_{l,k} * \ln P_{l,k}}{1 - P_{l,k}} + lnP_{l,c}\right)$$

(Equation 3.2.)

where, SBC_l is self-selection correction for household l, K is total number of alternatives, k is alternative index (0 or 1-plus private vehicles), c is chosen alternative index, $P_{l,k}$ is predicted probability of household l owing k vehicles.

Number of residents in household. The number of members of a household who live in the housing unit; also known as household size.

Annual income in quintile of the household. The quintile (one of five classes) in which the annual income of a household falls in. One means the lowest quintile, while five means the highest. Household annual income was already recorded as income bands in the household travel surveys, which as factor variables are a good approach to dealing with non-linearity, and this chapter further converted these income bands into five income groups, or quantiles, each of which consists of a number of households that was as close to one fifth of the size of the sample of the specific time period (2000 or 2009) as possible, so as to overcome the varying ranges of income and the change in the real value of the currency in different time periods.

Age of the trip maker. The actual age of years of the trip maker. Since adding the quadratic term of age to the models can reflect the effect of age at different ages, this was done in the models.

Male gender of the trip maker. A dummy variable indicating the trip maker being a male person.

Table 3.1: Descriptive statistics of the variables

Variable (unit)	*2000 data*		*2009 data*	
	Mean	*SD*	*Mean*	*SD*
Motorcycle travel characteristics of interest				
Motorcycles owned by household	1.31	1.07	1.46	1.13
Mode choice of motorcycle	0.43	--	0.47	--
Mode choice of bus	0.23	--	0.22	--
Mode choice of car	0.25	--	0.15	--
Mode choice of metro	0.04	--	0.11	--
Mode choice of cycling	0.04	--	0.05	--
Household motorcycle vehicle kilometers travelled	13.38	34.35	22.51	58.94
Built environment variables (households)				
Population density of TAZ (100,000 people/km^2)	0.29	0.17	0.29	0.17
Job density of TAZ (100,000 jobs/km^2)	0.24	0.22	0.15	0.21
Land use diversity index of TAZ (0-1)	0.55	0.15	0.46	0.17
Distance to CBD (100 km)	0.06	0.04	0.07	0.04
Whether within 800 meters (half-mile) from a metro station	0.52	--	0.53	--
Residential self-selection bias correction	-1.62	0.51	-1.67	0.57
Built environment variables (trips)				
Population density of TAZ (100,000 people/km^2)	0.27	0.17	0.27	0.16
Job density of TAZ (100,000 jobs/km^2)	0.17	0.20	0.22	0.29
Land use diversity index of TAZ (0-1)	0.53	0.17	0.49	0.18
Distance to CBD (100 km)	0.08	0.05	0.07	0.04
Whether within 800 meters (half-mile) from a metro station	0.39	--	0.64	--
Socioeconomic variables				
Number of residents in household	3.69	1.51	3.72	1.57

Annual household income in the lower quantile	0.19	--	0.12	--
Annual household income in the 2nd quantile	0.19	--	0.23	--
Annual household income in the 3rd quantile	0.20	--	0.29	--
Annual household income in the 4th quantile	0.26	--	0.18	--
Annual household income in the highest quantile	0.15	--	0.17	--
Age of trip maker	36.77	16.28	35.31	16.66
Male gender of trip maker	0.57	--	0.51	--
Number of observations: trips (N=)	84,614	--	8,618	--
Number of observations: households (N=)	23,650	--	4,104	--

Note: SD = standard deviation.

3.5. Methodology

Research hypotheses

Based on the literature review, below are the hypotheses to be tested in this chapter.

Hypothesis 1: The motorcycle ownership level of a household is statistically correlated with built environment variables in its residential location including but are not limited to population density (positively correlated), after controlling for socioeconomic variables.

Hypothesis 2: The likelihood of an individual's choice of the motorcycle as the mode of travel in a trip over other modes is statistically correlated with built environment variables in her trip origin, after controlling for socioeconomic variables as well as for residential self-selection bias.

Hypothesis 3: The amount of a household's motorcycle use, measured as household motorcycle VKT, is statistically correlated with built environment variables in its residential location including but are not limited to population density and land use diversity (both negatively correlated), after controlling for socioeconomic variables as well as for residential self-selection bias.

Hypothesis 4: Income is negatively correlated with motorcycle ownership, mode choice, and use.

Methodology

Two multinomial logistic regression models on household vehicle ownership and mode choice in a trip and a left-censored tobit regression model on household motorcycle VKT are estimated, using built environment explanatory variables and socioeconomic as well as self-selection bias correction control variables. Although ordered response models (such as ordered logit) and unordered response models (such as multinomial logit) have both been employed in vehicle ownership research, the latter tend to outperform the former (Bhat and Pulugurta, 1998; Guerra, 2015), and therefore multinomial logit was chosen for the modeling of vehicle ownership in this chapter. Six categories of household vehicle ownership options are defined, as described in Section 3.4. For the modeling of mode choice in a trip, the dependent variable is a multiple-choice variable, and its values are discrete as classes, so multinomial logistic regression is appropriate (Guerra & Li, 2021). Mode choice includes five categories: the motorcycle, the car, the bicycle, the buses, and the metro; other public transportation or other private motorized vehicles are not included in the mode choice modeling process due to their very small modal shares. The multinomial logit models are estimated using the R package “mlogit”. For household motorcycle VKT, this chapter specifies a left-censored tobit regression model because the response variable is a non-negative continuous distribution whose values include zeros, and the response variable is transformed into the natural log of “one plus household motorcycle VKT” (Guerra, 2014a). The tobit regression model is run using the R package “AER”. The version of the R statistical software used in this chapter is RStudio 2022.12.0 Build 353.

3.6. Results

Overview

The following subsections present and interpret the results of the models predicting household vehicle ownership, mode choice in trips, and household motorcycle VKT. Figure 3.9 visualizes the correlation between built environment variables and household income with the above motorcycle-related dependent variables. Being farther from the CBD and from metro stations are correlated with higher household motorcycle ownership levels, higher likelihood of motorcycle mode choice, and higher household motorcycle VKT. Higher population density is correlated with higher likelihood of motorcycle mode choice and higher household motorcycle VKT. Lower job density is correlated with higher household motorcycle ownership levels and higher household motorcycle VKT. Lower income is correlated with higher likelihood of owning motorcycles but no cars, higher motorcycle mode choice likelihood, and lower household motorcycle VKT.

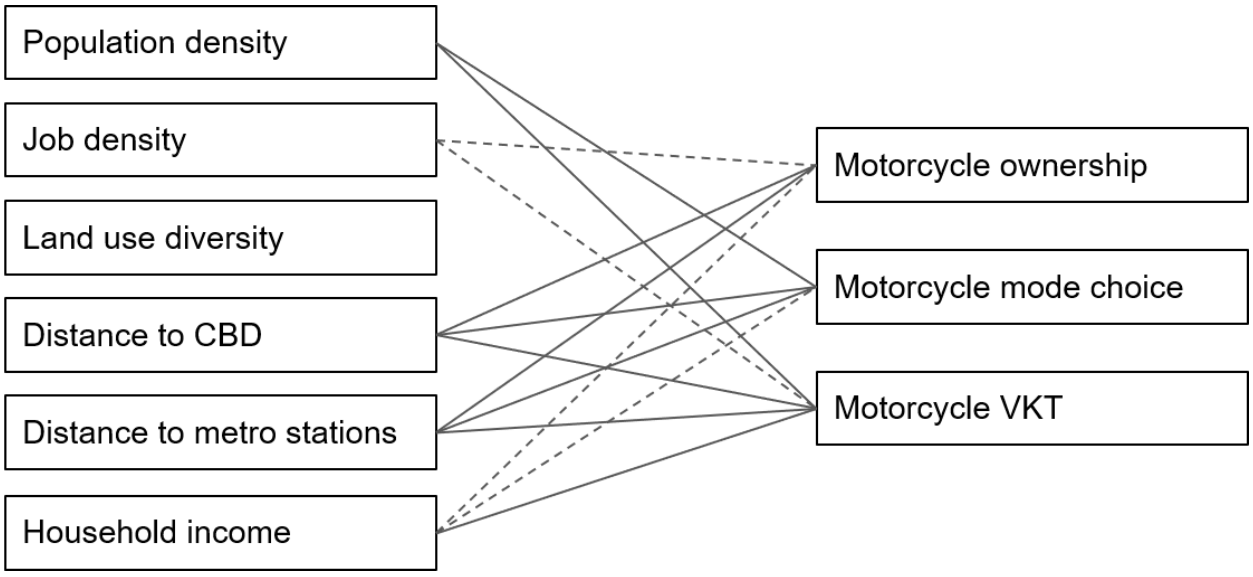


Figure 3.9: Correlation between built environment variables and household income with motorcycle ownership, mode choice, and VKT. Note: solid line = positive correlation; dotted line = negative correlation.

Household vehicle ownership

Table 3.2 presents the results of the model predicting household vehicle ownership. The multinomial logistic regression model on household vehicle ownership gives stable signs to the coefficient estimates of most of the variables over time. In addition to examining the signs carried by coefficient estimates to identify directions of correlation, interpretation of the model results also relies on examining the significance of the coefficient estimates and comparing the absolute values of coefficient estimates of the same variable across vehicle ownership options to identify the relative strength of effect of the variable on options. However, the absolute values of the coefficient estimates of different variables for the same vehicle ownership option are incomparable (Zegras, 2010).

For the built environment variables, lower job density and being farther from the CBD and from metro stations are correlated with higher household motorcycle ownership levels; in any circumstances, car-owning households are less inclined to increase motorcycle ownership than non-car-owning ones. Although increased population density is correlated with decreased likelihood that a non-vehicle-owning household chooses to own additional cars, such correlations for motorcycles is not stable over time as they turned from positive in 2000 to negative in 2009. On the contrary, increased job density is correlated with reduced likelihood that a household chooses to own an additional motorcycles or cars in both 2000 and 2009 (the correlation is statistically significant in both 2000 and 2009 only for the option of owning two or more motorcycles and one or more cars); such a relationship is stronger for the multiple-motorcycle-owning option than on single- or non-motorcycle-owning ones, and it is the strongest on the option with the most numerous vehicles, two or more motorcycles and one or more cars. Increased land use diversity is correlated with increased likelihood that a non-vehicle-owning household chooses to own either one motorcycle and one or more cars or two or more motorcycle and no cars (both correlations are only statistically significant in 2000 but not 2009), but the correlations for all the other options are not stable over time as they turned from positive in 2000 to negative in 2009. Increased distance to the CBD is correlated with increased likelihood that a household chooses to own additional motorcycles or cars. Lastly, being located within 800 meters from a metro station is correlated with reduced likelihood that a household chooses to own additional motorcycles or cars.

Lower income is associated with an increased likelihood of owning motorcycles but no cars, and there may be a substitution effect of cars for motorcycles. The coefficient estimates of the household income variables can be compared both across vehicle ownership options and across income quintiles. Firstly, findings from a comparison across vehicle ownership options are reported. All options are more preferred than the zero-vehicle option by households in all quintiles in both 2000 and 2009. Given the same car ownership level at zero, owning two or more motorcycles is more preferred than owning one across all quintiles in both 2000 and 2009. Given the same car ownership level at one or more, while owning two or more motorcycles is, generally speaking, more preferred than owning none by households in all quintiles in both 2000 and 2009, there is no definite superiority in preference between the options of owning two or more motorcycles and owning one for households in the second lowest and the middle quintiles. Given the same motorcycle ownership level (whether zero, one, or two or more), also owning cars is more preferred than owning no cars across all quintiles in both 2000 and 2009. Owning one motorcycle and one or more cars is more preferred than owning two motorcycles but no cars across all quintiles in both 2000 and 2009. Owning cars but no motorcycles is, generally speaking, more preferred than owning one motorcycle but no cars by households in all quintiles in both 2000 and 2009, except for those in the second lowest quintile in 2009. Lastly, findings from a comparison across income quintiles within vehicle ownership options are reported. Generally speaking, as income rises, the preference of owning cars but no motorcycles or any combinations of motorcycles and cars becomes stronger, leaving owning one motorcycle but no cars as the only option for which the preference weakens with rising income.

Table 3.2: Multinomial logistic regression on household vehicle ownership levels

0 motorcycles & 0 cars (base)	0 motorcycles & 1+ cars		1 motorcycle & 0 cars		1 motorcycle & 1+ cars		2+ motorcycles & 0 cars		2+ motorcycles & 1+ cars	
	Coef. & SE 2000	Coef. & SE 2009	Coef. & SE 2000	Coef. & SE 2009	Coef. & SE 2000	Coef. & SE 2009	Coef. & SE 2000	Coef. & SE 2009	Coef. & SE 2000	Coef. & SE 2009
Population density (100,000 people/km²)	-0.29 0.18	-2.36 0.49 ***	0.52 0.17 **	-0.33 0.42	0.20 0.17	-1.90 0.41 ***	0.98 0.19 ***	-0.57 0.44	0.43 0.17 *	-0.65 0.41
Job density (100,000 jobs/km²)	-0.05 0.15	-0.24 0.34	-0.05 0.15	-0.17 0.30	-0.02 0.14	-0.69 0.30 *	-0.13 0.17	-1.24 0.36 ***	-0.40 0.15 **	-1.55 0.33 ***
Land use diversity index (0-1)	0.73 0.19 ***	-0.13 0.45	0.41 0.19 *	-0.08 0.41	0.65 0.18 ***	0.14 0.39	0.56 0.21**	0.06 0.42	0.68 0.18 ***	-0.30 0.40
Distance to the central business district (100 km)	2.56 0.99 **	3.66 2.08 .	4.83 0.93 ***	2.20 1.88	7.44 0.88 ***	6.04 1.78 ***	10.00 0.99 ***	5.12 1.90 **	8.93 0.91 ***	5.93 1.80 ***
Whether located within 800 meters from a metro station (1/0)	-0.17 0.07 *	-0.10 0.16	-0.21 0.06 **	-0.21 0.14	-0.30 0.06 ***	-0.26 0.13 .	-0.26 0.07 ***	-0.37 0.14 *	-0.30 0.06 ***	-0.39 0.14 **
Number of residents in household	0.38 0.02 ***	0.45 0.06 ***	0.32 0.02 ***	0.30 0.06 ***	0.58 0.02 ***	0.60 0.06 ***	0.80 0.02 ***	0.75 0.06 ***	0.95 0.02 ***	0.93 0.06 ***
Household income in 2nd lowest quintile (base: lowest quintile) (1/0)	1.42 0.09 ***	0.73 0.24 **	0.85 0.08 ***	0.84 0.17 ***	1.63 0.08 ***	1.23 0.19 ***	1.25 0.09 ***	1.02 0.21 ***	1.47 0.09 ***	1.27 0.22 ***
Household income in middle quintile (") (1/0)	1.80 0.09 ***	1.42 0.25 ***	0.72 0.09 ***	0.85 0.19 ***	2.03 0.08 ***	1.79 0.20 ***	1.53 0.10 ***	1.53 0.22 ***	1.99 0.09 ***	2.09 0.22 ***
Household income in 2nd highest quintile (") (1/0)	2.34 0.10 ***	2.18 0.29 ***	0.46 0.10 ***	0.45 0.28	2.39 0.09 ***	2.17 0.25 ***	1.87 0.10 ***	1.62 0.27 ***	2.53 0.09 ***	2.62 0.27 ***
Household income in highest quintile (") (1/0)	2.50 0.12 ***	2.58 0.31 ***	0.01 0.13	0.43 0.32	2.18 0.11 ***	2.34 0.28 ***	1.24 0.13 ***	1.70 0.30 ***	2.52 0.11 ***	2.90 0.29 ***
Intercept	-2.51 0.17 ***	-1.93 0.38 ***	-1.46 0.15 ***	-0.86 0.33 **	-2.88 0.15 ***	-1.97 0.33 ***	-4.49 0.18 ***	-2.84 0.36 ***	-4.63 0.16 ***	-3.41 0.35 ***
Number of observations (N=)	23650	4104	23650	4104	23650	4104	23650	4104	23650	4104
Log-Likelihood	-36508	-6311.6	-36508	-6311.6	-36508	-6311.6	-36508	-6311.6	-36508	-6311.6
Pseudo R-squared	0.0969	0.0958	0.0969	0.0958	0.0969	0.0958	0.0969	0.0958	0.0969	0.0958

Notes: (1) Coef. = Coefficient estimate; SE = standard error; (2) Significance codes: *** p < 0.001; ** p < 0.01; * p < 0.05; . p < 0.1.

Mode choice in a trip

Table 3.3 presents the results of the model predicting mode choice in trips. The multinomial logistic regression model on mode choice in a trip gives stable signs to the coefficient estimates of most of the variables over time, although the coefficient estimates of job density and land use diversity show flipping of signs between the two surveys in some of the mode choice options.

For the built environment variables, higher population density, being farther from the CBD and from metro stations are correlated with higher mode choice likelihood for the motorcycle; population density and distance to metro stations are most strongly associated with the motorcycle's substitution with the metro than any other modes. Increased population density is correlated with increased likelihood of choosing to use a bicycle instead of a motorcycle in a trip, but it reduces the likelihood for all the other modes, and the negative effects are the strongest on the metro. Increased job density is correlated with reduced likelihood of choosing to use a bicycle instead of a motorcycle in a trip, but it is correlated with increased likelihood for the buses; on the car or the metro, the coefficient estimates changed signs from negative in 2000 to positive in 2009. Increased land use diversity is correlated with increased likelihood of choosing to use the buses and the metro instead of a motorcycle in a trip; on the bicycle or the car, the coefficient estimates changed signs from positive in 2000 to negative in 2009. Increased distance to the CBD is correlated with reduced likelihood of choosing to use any other mode instead of a motorcycle for a trip. Lastly, being within 800 meters from a metro station is correlated with increased likelihood of choosing to use a bicycle, a car, and the metro instead of a motorcycle in a trip, and the effect is the greatest on the metro.

Income is negatively correlated with motorcycle mode choice as the likelihood of choosing the buses, the car, and the metro instead of a motorcycle generally rises with income. Increased household size is correlated with increased likelihood of choosing to use a bicycle and the buses instead of a motorcycle in a trip; on the car or the metro, the coefficient estimates turned from positive in 2000 to negative in 2009. Increased age of a trip maker is correlated with reduced likelihood of choosing a bicycle, the buses, and the metro instead of a motorcycle in a trip, but such negative effects weaken with

age, suggesting a convex curve between age and mode choice likelihood for a bicycle, the buses, and the metro instead of a motorcycle. A male person is more likely than a female one to choose to use a car instead of a motorcycle in a trip, but it is the other way around for all the other modes. As for the household income variables, their coefficient estimates can be compared both across modes and across income quintiles. As income rises, the likelihood of choosing a bicycle instead of a motorcycle generally decreases in 2000, but such a tendency may or (as the coefficient estimates attached to all quintiles are statistically insignificant) may not remain in 2009; this might suggest a converge in the mode choice preference of the bicycle over the motorcycle by all income groups between the surveys. As income rises, the likelihood of choosing the buses instead of a motorcycle first decreases since the income exceeds the lowest quintile in both 2000 and 2009, and then, it increases once the income reaches the middle quintile in 2000, while in 2009 it may stay at the same level as for the lowest income quintile until the income reaches the highest quintile; this suggests a mode choice preference for the motorcycle over the buses in the two lowest income quintiles during both surveys and, potentially, a reduction in mode choice preference of the buses over the motorcycle in the middle and the second-highest income quintiles between the surveys. The likelihood of choosing a car instead of a motorcycle increases with income in both 2000 and 2009. The likelihood of choosing the metro instead of a motorcycle begins to increase since the income exceeds the second-lowest quintile in 2000 (as the coefficient estimate attached to the second-lowest quintile is statistically insignificant, suggesting no difference in such a likelihood between the lowest two quintiles), but in 2009, such a likelihood may either be higher only in the middle and second-highest income quintiles than in the lowest quintile but lower in the highest quintile, or (as the coefficient estimates attached to all quintiles are statistically insignificant) be the same for all income groups; either suggests a converge in the mode choice preference of the metro over the motorcycle by all income groups between the surveys. Lastly, among all the alternative modes to the motorcycle, only one, the bicycle, is more likely to be chosen by households in lower income quintiles than those in higher ones. Buses, the car, and the metro (2000 only, while 2009 showed a plateau in the middle and second highest income quintiles) demonstrate generally rising likelihood to occur as household income increases.

Table 3.3: Multinomial logistic regression on mode choice likelihood of bus/car/metro/cycling relative to motorcycle in a trip

Motorcycle (base)	Bicycle		Bus		Car		Metro	
	Coef. & SE 2000	Coef. & SE 2009	Coef. & SE 2000	Coef. & SE 2009	Coef. & SE 2000	Coef. & SE 2009	Coef. & SE 2000	Coef. & SE 2009
Population density (100,000 people/km²)	1.03	0.73	-0.73	-1.16	-0.96	-1.18	-1.73	-1.75
	0.11 ***	0.32 *	0.06 ***	0.19 ***	0.06 ***	0.22 ***	0.11 ***	0.27 ***
Job density (100,000 jobs/km²)	-0.53	-0.54	0.25	0.63	-0.27	0.01	-0.40	0.48
	0.12 ***	0.24 *	0.06 ***	0.11 ***	0.06 ***	0.13	0.10 ***	0.14 ***
Land use diversity index (0-1)	0.11	-0.27	0.28	0.35	0.11	-0.12	0.52	0.16
	0.11	0.29	0.06 ***	0.17 *	0.05 *	0.18	0.10 ***	0.21
Distance to the central business district (100 km)	-2.97	-3.21	-6.61	-1.06	-2.02	-2.21	-4.21	-7.20
	0.48 ***	1.52 *	0.27 ***	0.86	0.23 ***	0.98 *	0.55 ***	1.24 ***
Whether trip started within 800 meters from a metro station (1/0)	0.09	0.23	-0.02	0.16	0.09	0.30	2.06	2.09
	0.04 *	0.11 *	0.02	0.06 *	0.02 ***	0.07 ***	0.05 ***	0.13 ***
Number of residents in household	0.07	0.20	0.21	0.16	0.05	-0.04	0.43	-0.21
	0.03 *	0.09 *	0.02 ***	0.05 **	0.02 **	0.06	0.04 ***	0.07 **
Household income in 2nd lowest quintile (base: lowest quintile) (1/0)	-0.06	0.06	-0.20	-0.22	0.30	0.23	0.02	0.001
	0.06	0.19	0.03 ***	0.12 .	0.04 ***	0.17	0.07	0.17
Household income in middle quintile (") (1/0)	-0.27	-0.03	0.08	-0.04	0.53	0.68	0.48	0.06
	0.07 ***	0.20	0.04 *	0.12	0.04 ***	0.17 ***	0.08 ***	0.17
Household income in 2nd highest quintile (") (1/0)	-0.23	-0.19	0.26	0.23	0.87	0.92	1.08	0.04
	0.10 *	0.25	0.05 ***	0.14	0.05 ***	0.18 ***	0.10 ***	0.19
Household income in highest quintile (") (1/0)	-0.37	-0.27	0.71	0.47	1.39	1.27	1.86	-0.19
	0.14 **	0.30	0.07 ***	0.17 **	0.07 ***	0.20 ***	0.14 ***	0.23
Age of trip maker	-0.14	-0.08	-0.18	-0.12	0.11	-0.002	-0.1	-0.06
	0.004 ***	0.01 ***	0.003 ***	0.01 ***	0.003 ***	0.01	0.005 ***	0.01 ***
(Age of trip maker)²	0.002	0.001	0.002	0.002	-0.001	0.0003	0.001	0.001
	0.00005 ***	0.0001 ***	0.00003 ***	0.0001 ***	0.00004 ***	0.0001 *	0.0001 ***	0.0001 ***
Male gender of trip maker (male=1, female=0)	-0.7	-0.71	-1.00	-1.08	0.61	0.40	-0.85	-0.86
	0.04 ***	0.10 ***	0.02 ***	0.06 ***	0.02 ***	0.07 ***	0.04 ***	0.08 ***
Residential self-selection bias correction	0.18	0.60	1.04	0.76	0.55	0.16	2.11	-0.40
	0.14	0.30 *	0.08 ***	0.17 ***	0.07 ***	0.19	0.16 ***	0.22 .
Intercept	0.32	-0.43	4.09	2.34	-2.92	-1.76	0.27	-0.70
	0.14 *	0.37	0.08 ***	0.22 ***	0.09 ***	0.28 ***	0.15 .	0.31 *
Number of observations (N=)	84614	8618	84614	8618	84614	8618	84614	8618
Log-Likelihood	-99728	-10763	-99728	-10763	-99728	-10763	-99728	-10763
Pseudo R-squared	0.1113	0.0833	0.1113	0.0833	0.1113	0.0833	0.1113	0.0833

Notes: (1) Coef. = coefficient estimate; SE = standard error; (2) Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$. (3) Other modes were excluded from modeling due to small modal shares.

Household motorcycle VKT

Table 3.4 presents the results of the model predicting household motorcycle VKT. The tobit regression model on household motorcycle VKT in a trip gives stable signs to the coefficient estimates of all variables over time, except for land use diversity.

Higher population density, lower job density, being farther from the CBD and from metro stations, and higher income are correlated with higher household motorcycle VKT. Increased population density is correlated with increased household motorcycle VKT. Increased job density is correlated with reduced household motorcycle VKT. Increased land use diversity is correlated with increased household VKT in 2000, but the correlation turned negative and became insignificant in 2009. Increased distance to the CBD is correlated with increased household motorcycle VKT. Lastly, being within 800 meters from a metro station is correlated with reduced household motorcycle VKT. Households in all income quintiles generate more motorcycle VKT than those in the lowest income quintile, and generally speaking a household generates more motorcycle VKT as its income increases. Lastly, increased household size is correlated with increased household motorcycle VKT.

Table 3.4: Left-censored tobit regression on the natural log of "one plus vehicle kilometers traveled" of all motorcycle trips made by a household within a day

	Coefficient estimate & Standard error, 2000		Coefficient estimate & Standard error, 2009	
Population density (100,000 people/km²)	0.51	(0.11) ***	0.83	(0.29)**
Job density (100,000 jobs/km²)	-0.02	(0.11) ***	-1.73	(0.26)***
Land use diversity index (0-1)	0.45	(0.12) ***	-0.24	(0.25)
Distance to the central business district (100 km)	6.94	(0.55) ***	8.52	(1.22)***
Whether located within 800 meters from a metro station (1/0)	-0.24	(0.05) ***	-0.35	(0.12)**
Number of residents in household	0.49	(0.05) ***	0.47	(0.12)***
Household income in 2nd lowest quintile (base: lowest quintile) (1/0)	0.62	(0.06) ***	1.01	(0.16)***
Household income in middle quintile (") (1/0)	0.81	(0.08) ***	1.09	(0.18)***
Household income in 2nd highest quintile (") (1/0)	1.03	(0.12) ***	1.14	(0.25)***
Household income in highest quintile (") (1/0)	0.98	(0.18) ***	1.25	(0.33)***
Residential self-selection bias correction	0.98	(0.20) ***	0.50	(0.44)
Log(scale)	0.91	(0.01) ***	0.90	(0.02)***
Intercept	-0.94	(0.13) ***	-1.03	(0.33)**
Number of observations (N=)	23649		4104	
Log-Likelihood	-38640		-7089	
Pseudo R-squared	0.0137		0.0283	

Notes: (1) Standard errors between brackets. (2) Significance codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; . $p < 0.1$.

Model fits

Regarding how the model fits are, in addition to the pseudo R-squared values in the above model results, Tables 3.5 and 3.6 presents the counts of correction predictions by the multinomial logistic regression models, calculated using the R package "nnet". Overall, the vehicle ownership model predicts poorly on the 2000 data but does fairly on some of the ownership options (no vehicles, one motorcycle only, one motorcycle and one car, and especially two motorcycles and one car) on the 2009 data; the mode choice model performs very well in predicting the choice of motorcycle on both the 2000 and 2009 data and fairly the choice of some modes in some years (bus in 2000 and 2009, and car in 2000). All in all, there are options that the models fail almost completely to predict: cars only and two motorcycles only

in the vehicle ownership model, and bicycle and metro in the mode choice model. Attempts were made to remove some of the explanatory variables that could be correlated with others, such as land use diversity index, distance to CBD, and job density, but little changed in the predicting power of the models. Potentially, there are variables other than those included in the models which can perform well in capturing the nuances in vehicle ownership choice and mode choice in Greater Taipei, such as education level and type of occupation.

Table 3.5: Counts of correction predictions by the multinomial logistic regression models on household vehicle ownership levels

		M0C0	M0C1	M1C0	M1C1	M2C0	M2C1
2000	Actual	2334	3148	3112	6375	2620	6053
	Predicted	225	22	74	556	0	495
	Fraction	0.096	0.007	0.024	0.087	0.000	0.082
2009	Actual	398	393	554	987	587	1185
	Predicted	159	4	123	374	0	853
	Fraction	0.399	0.010	0.222	0.379	0.000	0.720

Notes: M0C0 = 0 motorcycles and 0 cars; M0C1 = 0 motorcycles and 1 or more cars; M1C0 = 1 motorcycle and 0 cars; M1C1 = 1 motorcycle and 1 or more cars; M2C0 = 2 or more motorcycles and 0 cars; M2C1 = 2 or more motorcycles and 1 or more cars

Table 3.6: Counts of correction predictions by the multinomial logistic regression models on mode choice in a trip

		Bicycle	Bus	Car	Motorcycle	Metro
2000	Actual	3709	19513	21488	36097	3807
	Predicted	0	6600	5658	26659	0
	Fraction	0.000	0.338	0.263	0.739	0.000
2009	Actual	447	1884	1284	4082	921
	Predicted	1	464	48	3669	42
	Fraction	0.002	0.246	0.037	0.899	0.046

3.7. Discussion

Main takeaways

High population density may have resulted in a preference for using motorcycles over cars for private motorized transportation and the resulting motorcycle VKT generation due to parking concerns. Population density of a TAZ is positively correlated with the mode choice of motorcycle in a trip that originated within the TAZ. In other words, the more densely populated an area is, the more likely that a trip maker traveling from the area chooses to use a motorcycle. A possible explanation is that parking is a key factor to consider for mode choice in densely populated areas. Population density can be very high in East Asian cities like Taipei, and the rather late arrival of mass car ownership left these cities underprepared for accommodating the parking needs of cars. As Table 3.1 and Figure 3.1 show, the average population density of a TAZ is around 29,000 people per square kilometer, and the highest quintile of TAZ population densities can be as high as more than 50,000 people per square kilometer. Parking is a challenge for both cars and motorcycles given the constrained supply-demand relationship, especially for motorcycles. There were about 1.5 million cars and 1.2 million car parking spaces in Taipei, New Taipei, and Keelung Cities combined in 2009 (MOTC, 2022; TCG, 2022a; NTCG, 2022). Worse than the situation of cars, there were about 3.7 million motorcycles and only 0.8 million motorcycle parking spaces in Taipei and New Taipei Cities combined in 2012 (MOTC, 2022). However, unlike cars which are too big to be parked unnoticed outside of designated parking spaces, motorcycles can physically fit in small spaces. What is more, as the number of motorcycles has grown too large to be effectively regulated, parking enforcement is generally not strict in Taiwan, and using the pedestrian realm to park motorcycles is usually treated with a blind eye. Furthermore, free parking had long kept on-street parking turnover low. On-street parking in Greater Taipei was free of charge for all vehicles until 2015 when Taipei City began charging on-street parking universally for cars; in 2019, Taipei City finally began charging on-street parking for motorcycles in certain commercial sections and vowed to expand the motorcycle parking charge zone in phases (TCG, 2022b). All in all, high population density leads to low

parking availability for cars, and therefore motorcycles may have become the preferred mode of private motorized transportation for this reason.

Low job density may have increased the necessity of owning motorcycles because of the implied residential location in transit-poor suburban districts or distances of commutes that are too long for walking or cycling. Job density of a TAZ is negatively correlated with household motorcycle ownership. In other words, the more densely distributed jobs are in an area, the less motorcycles that a household living in the area is likely to own. There are two possible explanations. One is that the most job-dense areas are concentrated in the downtown districts (see Figure 3.2). The supply of public transit in the downtown, particularly the metro, is rich and came early, making the ownership of motorcycles not much of a necessity. Another is that, regardless of transit supply, the more job-dense an area for a household to live in or for an individual to start a trip from, the more likely their trip destinations are within the area. The closer to work a person lives, the more feasible traveling on foot or by bicycle, likewise making the ownership of motorcycles less of a necessity.

It is as expected that being farther from CBD and from metro stations are correlated with higher household motorcycle ownership levels, higher likelihood of motorcycle mode choice, and more household motorcycle VKT. As the literature review shows, increased presence of transit, especially high-capacity transit such as the metro, is linked to reduced motorcycle ownership, mode choice, and amount of use (see Section 3.2). As mentioned in the data overview, the distance to the CBD can act as a proxy of densities, land use diversity, and destination accessibility (Ewing & Cervero, 2010); in addition, being far from the downtown can also mean low transit supply, low intersection density, and low street connectivity in most contexts. Thus, the motorcycle may become more of a viable option among all modes of travel as distance from the CBD increases.

The unexpected finding that higher income is correlated with higher motorcycle VKT contradicts with other studies on Taiwan probably because the latter are nation-wide studies instead of single-city ones. Such an unexpected finding, although contradictory to findings of its fellow motorcycle-related studies on Taiwan (Chiou et al, 2009; Lai & Lu, 2007; Wen et al, 2012) probably because of a different

geographical scope of study, Taiwan at large, agrees with that on one single-city study in Mumbai, India (Shirgaokar, 2016).

Elasticity estimates

Reduced population density, increased job density, and improved land use diversity are associated with reduced motorcycle travel. Planning and policy implications of this chapter can be generated through elasticity estimates, a kind of scenario simulation. Elasticity estimates demonstrate the extent of change in the value of a dependent variable when one of its explanatory variables changes in value. Since planning and policy can affect some aspects of the built environment, this chapter estimated elasticity of motorcycle travel in the event of changes in population density, job density, and land use diversity on both the 2000 and 2009 travel survey data. Table 3.5 shows the results, which validate the findings from the models. The relationship between population density and motorcycle travel was stable over time: an overall 10% increase in population density is associated with a 0.5% rise in the weighted average of household motorcycle ownership, a rise more than 1% in the modal share of the motorcycle, and a 2% rise in household motorcycle VKT. A negative association between job density and motorcycle ownership and use stays consistent over time: an overall increase in job density is associated with a drop in the weighted average of household motorcycle ownership and in household motorcycle VKT. The association between land use diversity and motorcycle mode choice likelihood remains true over time, as an overall increase in land use diversity index is associated with a fall in motorcycle mode choice likelihood.

Table 3.7: Elasticity estimates of percent change in dependent variables in scenarios of built environment and transit supply changes

		Change in population density in all TAZs	*Change in job density in all TAZs*	*Change in land use diversity index in all TAZs*
Weighted average of household motorcycle ownership	2000	0.05	-0.02	0.02
"	2009	0.04	-0.04	-0.01
Modal share of motorcycle	2000	0.11	0.01	-0.06
"	2009	0.14	-0.04	-0.03
Household motorcycle VKT	2000	0.20	-0.01	0.35
"	2009	0.21	-0.23	-0.10

Note: (1) Elasticity is estimated by raising 10% in the built environment variables; (2) Actual means of household motorcycle VKT were much larger than tobit model-predicted means (see Table 3.1 in Section 3.4).

3.8. Conclusions

This chapter makes contributions to existing knowledge on the relationships between motorcycle travel and the built environment. The current understanding of the built environment effects on motorcycle ownership remains limited, and no built environment characteristics have been identified as predictors of motorcycle mode choice likelihood. This chapter fills these gaps in knowledge by examining the relationship between motorcycle travel and the built environment using the largest metropolis of Taiwan, home to the world's highest motorcycle ownership rate, as the study context. It specifies multinomial logistic and tobit regression models to examine the relationship between the built environment and household vehicle ownership, mode choice in a trip, and household motorcycle vehicle kilometers traveled (VKT), controlling for socioeconomic predictors of motorcycle travel. It uses the most recent trip and household datasets from both the 2000 and 2009 large-scale household travel surveys in the Taipei Metropolitan Area for analysis.

Findings suggest that being farther from the CBD and from metro stations are correlated with higher household motorcycle ownership levels, higher likelihood of motorcycle mode choice, and higher household motorcycle VKT; higher population density is correlated with higher likelihood of motorcycle mode choice and higher household motorcycle VKT; lower job density is correlated with higher household motorcycle ownership levels and higher household motorcycle VKT; lower income is correlated with

higher likelihood of owning motorcycles but no cars, higher motorcycle mode choice likelihood, and lower household motorcycle VKT.

The main takeaway for research from this chapter, which is also where its academic novelty lies, is that it rejects most of its literature-based hypotheses about motorcycle travel and the built environment. The theoretical expectation of this chapter is that motorcycle ownership is positively correlated with population density, motorcycle mode choice likelihood is correlated with built environment variables, household motorcycle VKT is negatively correlated with population density and land use diversity, and income is negatively correlated with motorcycle ownership, mode choice, and VKT. Findings of this chapter substantiate the hypotheses about the relationship between motorcycle travel in general and the built environment by identifying additional explanatory variables including job density, distance to the CBD, and distance to metro stations. More importantly, they reject the hypotheses about how the built environment and household income are related to motorcycle travel by indicating that motorcycle ownership may not be correlated with population density and that motorcycle VKT is in fact positively correlated with population density and income and uncorrelated with land use diversity.

The main takeaway for policy from this chapter is that transportation and land use policy in motorcycle-stressed cities should focus on expanding mass transit, developing suburban employment centers near metro stations, and reshaping the spatial distribution of population so that areas near metro stations become more densely populated than others. It goes without saying that new metro lines should be built to serve existing suburban employment centers and population clusters. An expanding metro system shortens distances from high-capacity transit and can disincentivize motorcycle ownership, mode choice, and VKT. Suburban employment centers near metro stations, ideally where lines intersect, both increase local job densities and make going to work by the metro, by bus, by bicycle, or even on foot viable to a larger portion of the metropolitan population, and thus this will reduce the necessity of owning motorcycles. Lastly, as an increasingly large share of the population live near metro stations, a continued modal shift from the motorcycle toward the metro can be expected.

Limitations of this chapter are multifold. Firstly, it determines the built environment effects on motorcycle travel using separate datasets from two time periods and omits the interpretation of the

coefficient estimates of those variables whose signs changed over time or which did not remain significant over time. Although pooling the datasets could be questioned due to the decade-long gap between the two surveys, some techniques, for example adding the interaction terms between time and each of the explanatory variables to the models (Guerra, 2014b) plus specifying appropriate treatment and control groups in the models may bypass such controversy in pooling and generate more insights on the relationship between motorcycle travel and the built environment, such as whether the relationship changes over time. Secondly, the predicting power of the models are weak; adding other variables that can affect household vehicle ownership choice or mode choice to the models, such as education level and occupation type, might strengthen the model fits. Thirdly, spatial dependency is highly expected for the datasets used in this chapter; such an issue can be addressed by, among other methods, running a Moran's I test on the models' error terms to test for spatial autocorrelation (error terms being correlated spatially), and if spatial autocorrelation does exist, running models that address spatial autocorrelation such as spatial regression models and showing whether the results are similar with the original models would determine if spatial dependency exists. Fourthly and lastly, the applicability of findings from this chapter using Taipei as case study to other cities is currently unknown because Taiwan is an obvious outlier in terms of income level and population density among countries with higher motorcycle-to-population ratios - nevertheless, as countries' income levels increase, more metro systems can be expected to be adopted in their cities, and the experience of Taipei as one of the earliest motorcycle-stressed cities that has adopted a metro system can provide useful lessons; Future research can prioritize cities with the most comparable built environment, socioeconomic, and transportation characteristics (precisely, the modal share of the motorcycle and the length of history of their metro systems), such as Bangkok and Kuala Lumpur, to see if findings are similar with those in Taipei.

CHAPTER 4: MASS TRANSIT EFFECTS ON MOTORCYCLE TRAVEL

4.1. Introduction

Many cities that have high motorcycle ownership rates have been establishing or expanding mass transit. Whether these transit investments can lure existing motorcycle users is of great policy concerns because such investments are costly and time-consuming. In addition, motorcycle-dependent cities adopted mass transit systems relatively late compared with car-dependent ones; such a lack of precedents can pose uncertainties on transit investment decisions in motorcycle-dependent cities. One of the earliest cities with high motorcycle ownership rates to do so, Taipei joined Bangkok and Kuala Lumpur in opening their first metro systems in the late 1990s with the launch of the Taipei Metro. The existing literature on motorcycle travel leaves two gaps in knowledge. First, existing research on the relationship between transit investments and motorcycle travel has yet explored that for mass rapid transit systems. Second, studies on mode choice involving the motorcycle have hardly taken the influence of the built environment into account. The objective of this chapter is to fill these gaps in knowledge by examining the effects of a metro system on motorcycle travel, using the Taipei Metropolitan Area as the study context.

Does the introduction of metro stations in Taipei affect motorcycle travel around them? This chapter examines the treatment effects of the introduction of metro stations on mode choice in trips and motorcycle vehicle kilometers traveled (VKT) of households within their 800-meter (half-mile) proximity by specifying binomial logistic and tobit regression models, controlling for built environment and socioeconomic predictors of motorcycle travel; difference-in-differences, an econometric method of causal inference, was employed in the models. It uses trip and household datasets from both the 2000 and 2009 large-scale household travel surveys in the Taipei Metropolitan Area, the most recent two in the metropolis, with a total 93,230 trips not limited to any specific type of origins, destinations, and purposes as well as 27,754 households being used for analysis.

This chapter makes several academic and policy contributions to existing knowledge on the relationship between motorcycle travel and transit investments. This chapter verifies a literature-based hypothesis that motorcycle use, measured in the chance of mode choice and the amount of use, decreases around mass rapid transit stations, after controlling for socioeconomic and built environment variables that can also influence motorcycle use. This chapter also makes policy recommendations on how multimodal transportation should be improved to influence motorcycle travel for any cities around the world that have high rates of motorcycle ownership and motorcycle-predominant traffic and have been or will be establishing or expanding mass rapid transit.

4.2. Literature review

Transit effects on vehicle use

Transit investments influence mode choice by changing the relative travel costs between transit and private vehicles. Improvement in transit systems may reduce travel costs including the time spent on accessing transit from home thanks to reduced distances from transit, and a cost-minimizing traveler may switch from private vehicle to transit if the improvement significantly reduces the total travel costs by rail to the extent that they become cheaper than those by private vehicle travel (Baum-Snow & Khan, 2000). Transit investments provide new travel options where sufficient transit services did not previously exist, and users of private vehicles may adopt this new travel option to avoid the expenses, hassle, or accident mortality associated with vehicles and thereby reaping the direct mobility benefits brought by the new transit (Schweitzer, 2017). For rail transit investments, since their primary associated social benefit is reducing trip times, they are more likely to attract riders in denser and more centralized cities where congestion is worse and trip distances are shorter (Baum-Snow & Khan, 2000, 2005).

Existing research from the US has agreed over the negative effects of transit investments including commuter rail, light rail, and express buses, on automobile travel (Bhattacharjee & Goetz, 2012; Deka & Marchwinski, 2014; Hu & Schneider, 2015; Spears et al, 2017).

Globally, differences across regions in the mode choice effects of transit investments might be attributable to culture and the built environment. The modal split of cities worldwide reveals obvious regional differences: for metropolitan areas with over 1 million inhabitants where transit systems are present, Asian, European, and Latin American cities whose transit modal shares range between 15% and around 80% dominate the upper half of the ranking, while the lower half is populated by North American and Oceanian cities whose transit modal shares range between 1% and around 30%. It is noteworthy that a North American city like San Francisco that is considered to have successful transit and an Asian city like Jakarta that is well-known for serious traffic congestion are on a par with each other in terms of transit modal share at around 20%. While the similarities between the regions with high transit use is unclear, what could possibly group North America and Oceania together is culture (Anglo-Saxon majority), which may have influenced lifestyle preferences (individualism), the built environment (lower development densities), travel patterns (automobile dependence), and transportation investments (highways). Certainly, cultures are changing, and so are those aspects of life influenced by culture, but the existing built environment and transportation investments may take a particularly long time to change, if they are to change at all.

Research on motorcycle travel has shown that increased presence of transit is linked to reduced change and amount of motorcycle use. Within a city, the distance to certain forms of high-capacity transit was correlated with private motorcycle travel, as a longer distance to railway or bus rapid transit (BRT) from the residential location was correlated with a higher likelihood of motorcycle mode choice or higher motorcycle VKT, but such relationships did not exist if the transit station concerned was a bus stop. Three studies on Asia support such findings. Shirgaokar (2016) in his Mumbai, India study found that a 10% increase in the distance between the home and railway station would result in a 0.6% increase in motorized two-wheeler VKT. Satiennam et al (2016) studied Khon Kaen, Thailand to assess the potential of BRT for attracting travelers from passenger cars and motorcycles and found that motorcycle users whose residential location was within 400 meters from the station were more likely to switch to BRT than those whose residential location was further than 400 meters. Herwangi et al (2018) studied Yogyakarta,

Indonesia and found that the distance to a bus stop had no effect on motorcycle dependence, as those who owned a motorcycle would prefer to use it even if they were close to a bus stop.

Built environment and socioeconomic effects on motorcycle use

Apart from high-capacity transit supply, built environment and socioeconomic characteristics also affect mode choice involving motorcycles as well as motorcycle VKT. Mode choice between motorcycle and other modes of travel is associated with socioeconomic variables including the income and age of a trip maker. Income is negatively correlated with the mode choice of motorcycles (Chang & Wu, 2008; Chen & Lai, 2011; Irza et al, 2021). Likewise, age is negatively correlated with the mode choice of motorcycles (Chang & Wu, 2008; Irza et al, 2021; Satiennam et al, 2016).

Motorcycle VKT by household is associated with built environment and socioeconomic variables including population density, land use diversity, household size, car ownership level, the age of the principal user, and income. However, the role played by income remains in disagreement. Population density is negatively correlated with the amount of motorcycle use, suggested by studies on motorcycle use in Mumbai, India (Shirgaokar, 2016) and across cities of Indonesia (Wandani et al, 2018). Land use diversity, although only identified by one single study on motorcycle use, can have a notably large negative impact on the private motorcycle VKT, a measure of the amount of a household's daily motorcycle use, as Shirgaokar (2016) found in Mumbai, India that a one-unit increase in land use diversity index resulted in a notable 40% decrease in motorized two-wheeler use; he called for more studies to verify such a finding, especially in the motorcycle-stressed South Asian and Southeast Asian context. The number of household members, or household size, is positively correlated with the amount of motorcycle use (Shirgaokar, 2016; Thu Huyen & Tu, 2019). Car ownership level is negatively correlated with the amount of motorcycle use (Chiou et al, 2009; Kepaptsoglou et al, 2011). The age of the principal user is negatively correlated with the amount of motorcycle use (Chiou et al, 2009; Lai & Lu, 2007). Income can be negatively correlated (Chiou et al, 2009; Kepaptsoglou et al, 2011; Wen et al, 2012), positively correlated (Shirgaokar, 2016), or uncorrelated (Lai & Lu, 2007) with the amount of

motorcycle use in different contexts. Disagreement over the effect of income on motorcycle use may have arisen from the disparity in economic development levels between countries. Income is negatively correlated with motorcycle use in Greece (Kepaptsoglou et al, 2011) and Taiwan (Chiou et al, 2009; Wen et al, 2012) but positively correlated in India (Shirgaokar, 2016). This echoes the findings about the relationship between the level of economic development of a country and its level of motorcycle ownership, which is a correlation that is first positive and then turns negative as an economy develops, with the change of direction of the correlation occurs at a threshold level that falls roughly between US$5,000 and $7,000 (Nishitateno & Burke, 2014; Law et al, 2015). The current nominal GDP per capita of India, less than US$3,000, is below such a level, and those of Greece and Taiwan, around US$21,000 and US$36,000, respectively, are above it (IMF, 2022). However, at the domestic level, disagreement remains between studies on Taiwan over whether income negatively affects (Chiou et al, 2009; Wen et al, 2012) or does not affect (Lai & Lu, 2007) motorcycle use.

Residential location choice and vehicle use

Residential self-selection complicates the relationship between the built environment and vehicle use. Residential location can be a choice that people make based on their preference of certain travel modes over others, which informs their residential selection of locations with built environment characteristics that allow such travel options, such as homes close to transit or highways, thus their vehicle ownership and use levels are so shaped (Cervero, 2007; Brownstone, 2008; Ewing & Hamidi, 2014; Houston et al., 2015; Weinberger & Goetzke, 2010). In research, the failure to account for residential self-selection can cause overestimates or underestimates of the relationship between the built environment and travel, which is the so-called self-selection bias (Cao et al., 2009; Chatman, 2009; Mokhtarian & Cao, 2008). While including sociodemographic control variables in statistical models can account for some residential self-selection (Bhat & Guo, 2007; Brownstone & Golob, 2009; Guerra, 2014b), self-selection bias can also be corrected via being computed and used as a covariate in models (Houston et al., 2015; Shirgaokar, 2016; Zegras, 2010).

Cross-context differences can exist in terms of residential location choice and vehicle use. For example, the downtown/suburban distinction can be relevant or irrelevant in predicting vehicle use. While in North America it is the households who choose to live in suburbs have higher car use than those who choose to live downtown (Zhou & Kockelman, 2008), in Asian cities such as Mumbai, downtown households have higher car use and peripheral ones have higher motorized two-wheeler use (Shirgaokar, 2016). As another example, distance to transit may or may not matter in vehicle use. In some cities, transit stations can become centers of clusters of employment and entertainment, thus attracting households who are of higher income who can afford the resulting heightened housing prices and who tend to own and use vehicles more, and households who cannot afford to live close to transit stations may also own and use vehicles to access transit, employment, and entertainment (Bhat & Guo, 2007; Guerra, 2015; Shirgaokar, 2016).

Gaps in knowledge on transit and motorcycle use

The current literature on the relationship between transit and motorcycle travel has yet to consider mass rapid transit. So far, such studies have only covered BRT (Satiennam et al, 2016), conventional railway (Shirgaokar, 2016), and conventional buses (Herwangi et al, 2018). This is perhaps because most motorcycle-dependent cities have not had a metro system and multi-year household travel survey data is rarely available.

Built environment characteristics have hardly been considered in studies of motorcycle mode choice. Although motorcycles are often considered having advantages of time and cost savings compared with other modes, these advantages should be subject to the built environment characteristics. For example, seen from the mode share perspective, while in some contexts the motorcycles prove a time-saving mode compared to other surface modes such as cars and buses in times of traffic congestion, they are still less preferred than cars in low-density contexts including most parts of the US and less preferred than the public transport in contexts with extensive public transport networks such as Bogota, Colombia and Tokyo, Japan (LTA, 2011). The small number of studies on mode choice involving

motorcycles that include built environment variables in their analyses (Herwangi et al, 2018; Jou & Chen, 2014; Satiennam et al, 2016; Yagi et al, 2014) may have prevented the forming of agreement on the effect of built environment variables on mode choice.

To sum up, more research is needed for understanding the relationship between mass rapid transit supply and motorcycle travel while taking the built environment into consideration. Households or individuals might have become motorcycle-dependent for a mix of reasons involving the built environment and public transport supply in addition to high population density and the resulting contested road space and parking spaces: low land use diversity and the resulting long travel distances between homes, jobs, and other daily activities; dense road networks with pedestrian-unfriendly design characteristics; and the lack of viable public transport and other travel options other than private vehicles to reach destinations. A small but increasing number of studies have identified the potential of these variables in affecting motorcycle travel, such as land use diversity in affecting motorcycle ownership (Doddamani & Manoj, 2021; Yamamoto, 2009) and VKT (Shirgaokar, 2016). New motorcycle-travel studies that join existing ones to take into account mass rapid transit and the built environment will help form stronger academic agreements that can improve land use and transport policies.

4.3. Context: Taipei Metropolitan Area

Household travel surveys in 2000 and 2009

The 2000 and 2009 household travel surveys in the Taipei Metropolitan Area offer the opportunity to understand how trip-level travel behavior changed as the metro system expanded and modal split shifted at the metropolitan scale. The first survey “DOTS-II” was conducted immediately after the Taipei Metro first formed a connected network in December 1999. The second survey “TRTS-IV” was conducted immediately after the metro system reached Neihu, a suburban district to the northeast of downtown with the most rapid job growth in the metropolitan area.

The first of the two household travel surveys used in this chapter was conducted in 2000 and covered a total of 129,139 trips (not including trips on foot). The survey was conducted between April 1 and June 30, 2000. The survey was conducted by the Taipei-based Asian Technical Consultants, Inc., commissioned by the Department of Transportation of the Taipei City Government. The geographical scope of the study included Taipei City, Taipei County (today's New Taipei City), Keelung City, plus Guishan Township of Taoyuan County (today's Guishan District of Taoyuan City). The survey drew up 383 traffic analysis zones (TAZs) based on villages, including 376 within the study area and 7 outside of it. The survey covered socioeconomic and trip characteristics of 117,066 persons from 32,217 households (1.5% of all households in the study area) as an effective sample who reported trips. (ATCI, 2001)

The second of the two household travel surveys used in this chapter, being the most recent survey conducted in Greater Taipei, was conducted in 2009 and covered a total of 64,904 trips (including trips on foot). The survey was conducted partly (a minority of trips reported, about 10%) between May 1 and June 30, 2009, and mostly between September 1, 2009 and January 22, 2010. The survey was conducted by the Taipei-based THI Consultants Inc., commissioned by the Department of Rapid Transit Systems of the Taipei City Government. The geographical scope of the study was the same as that of the 2000 survey except that Keelung City was excluded. The survey drew up 601 TAZs, including 571 within the study area and 30 outside of it. The survey covered socioeconomic and trip characteristics of 32,136 persons from 9,000 households (0.39% of all households in the study area) as the sample, who reported trips. Note that only the approximately 10% earliest trips reported to the survey were made before the Taipei Metro extended further into the eastern inner suburbs, beginning to serve Taipei City's Neihu District, home to the strongest job growth in the metropolitan area between the two surveys. (THI, 2012)

The major differences between the 2000 and 2009 household travel surveys can be summarized as the following. Firstly, in terms of geographical sampling, the 2000 survey included Keelung City while the 2009 one excluded it, and the latter demarcated TAZs in a more fine-grained way, almost double the number of those drawn by the former. Secondly, in terms of survey methods, the 2000 survey excluded trips on foot while the 2009 one included such trips. Thirdly, in terms of modal split, if excluding the trips

on foot in the 2000 survey, the modal share of the motorcycle, the most popular mode in both surveys, is larger in the 2009 survey (53%) than in the 2000 one (42%), mainly because of a drop in the modal share of the car (see Figure 4.7).

The estimation of the number of jobs at the TAZ level in this chapter relies partly on the household travel surveys. Unlike population, the number of jobs in a TAZ was not available in the household travel survey datasets, and the number of jobs in Taiwan is only counted at the district level, not at the more fine-grained level of the village, every five years in the nationwide Industry and Service Censuses (ISCs). As a result, the approach to estimating TAZ-level jobs in this chapter was to use a TAZ's share in work trips that ended in a district in a household travel survey as the proxy of a TAZ's share in jobs located in a district (assumption: Total jobs in a TAZ / Total jobs in a district = Work trips to a TAZ / Work trips to a district), as well as to use the district-level job count in the closest ISC year to a household travel survey year as the proxy of the district-level job count in the household travel survey year; this chapter used two ISC years, 2001 and 2011, as proxies of the two household travel survey years, 2000 and 2009. Finally, the ArcGIS Pro software was used to calculate TAZ-level job density as the result of estimated TAZ-level jobs divided by TAZ total area.

Spatial distribution of population and jobs

The 2000-2009 period in Greater Taipei, which comes between the two household travel surveys from which trip and household data are available, was characterized by a dispersion of population and jobs from the downtown to the suburbs. Such a phenomenon can be seen at the TAZ level. Greater Taipei saw major growth in population in the western suburbs and major growth in jobs in an eastern suburb. Major suburban population growth occurred to the west of the downtown, while the downtown and the areas to the east of downtown experienced population losses. It is not surprising that the downtown lost population and many of the suburbs gained population, because housing prices are much higher in the central city than in the suburbs, pushing homebuyers to the peripheral areas. As for jobs, while the number of jobs grew throughout the region, the greatest job growth occurred in an eastern inner

suburb, Neihu, with the presence of a fast-growing major business park. Figures 5.1 and 5.2 show increases in population and job densities in TAZs beyond the downtown between the 2000 and 2009 household travel surveys.

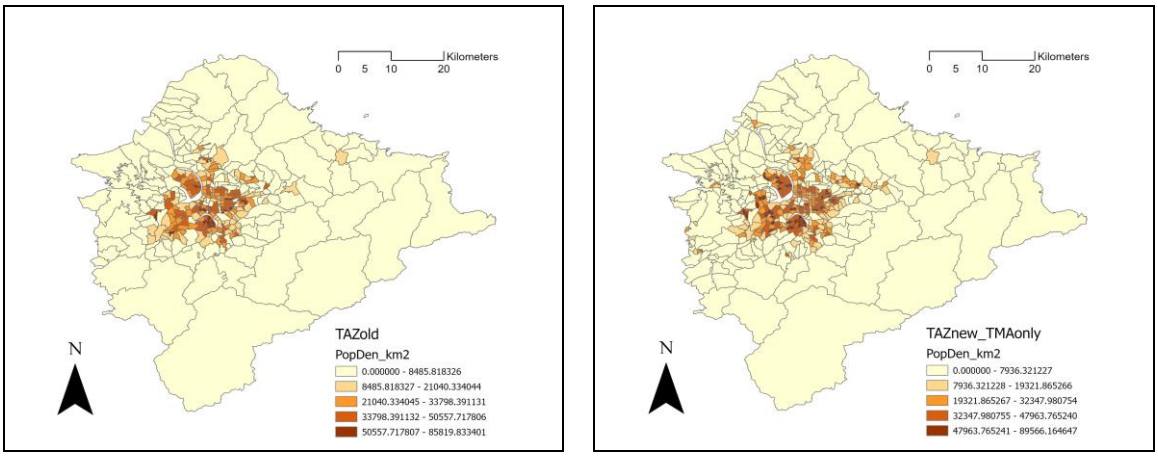


Figure 4.1: Population density (people/km^2) by TAZ during the 2000 (left) and 2009 (right) surveys

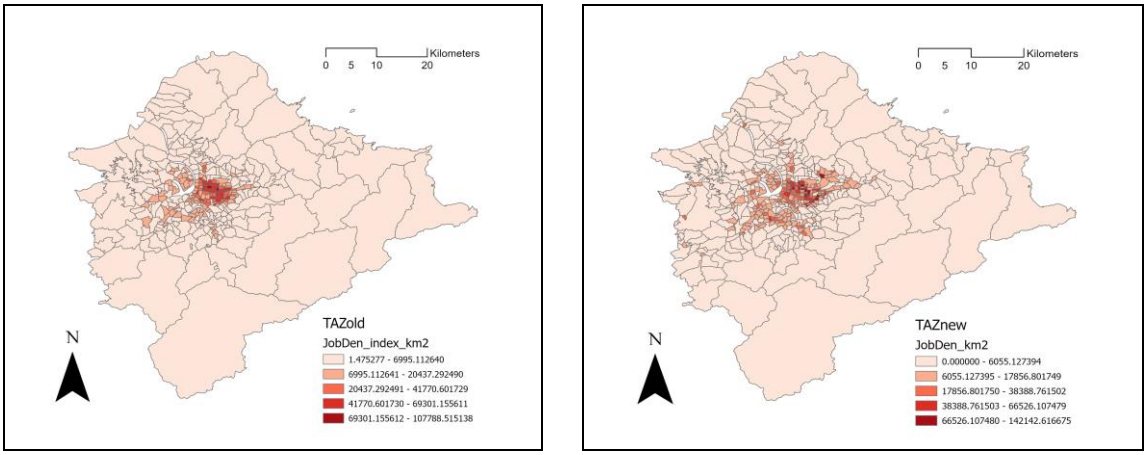


Figure 4.2: Job density (jobs/km^2) by TAZ during the 2000 (left) and 2009 (right) surveys

Metro expansion

The Taipei Metro system initially linked the downtown only with the northern and southern inner suburbs, leaving the eastern and western inner suburbs unserved until the late 2000s. The Taipei Metro expanded its network rapidly, from the initial 11 total revenue kilometers in 1996 to 146 in 2020 (see Figure 5.3). Initially, the system connected the downtown with the southern inner suburbs, the northern inner suburbs, and a northern outer suburb; a connected network first formed by joining separate lines in December 1999, and the 2000 household travel survey used in this chapter was conducted with this scope of the metro network. Then, the network expanded and first reached an eastern inner suburb in late 2000, completed most of its eastern-suburb route in 2009 just before about 90% of the trips reported in the 2009 household travel survey occurred (in other words, the 2009 household travel survey used in this chapter was mostly conducted with this scope of the metro network), and finally all of it by 2011. The network first reached a western inner suburb in 2010, and it completed its western-suburb route in 2013. The first suburb-to-suburb connection was not launched between the southern and western inner suburbs until 2020. (MOTC, 2022)

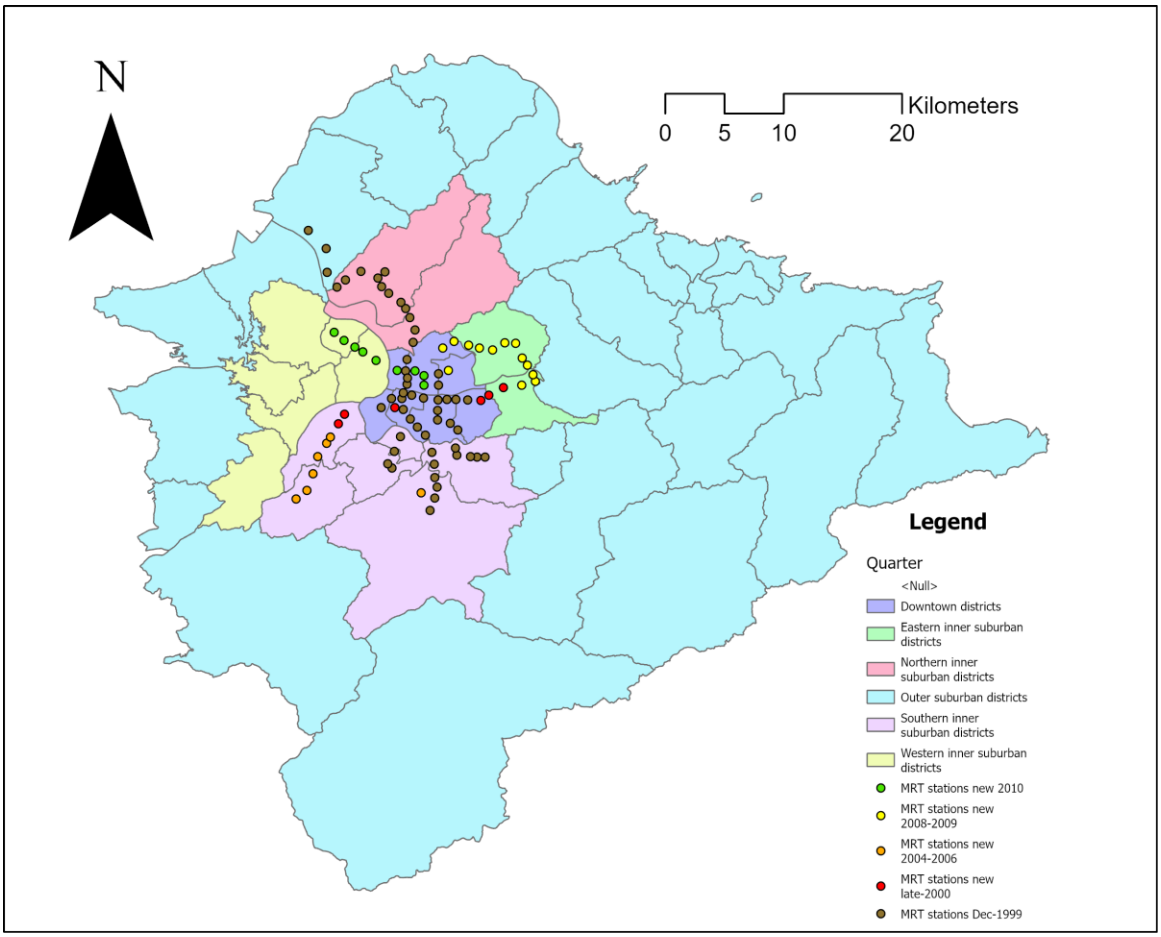


Figure 4.3: Incremental expansions of the Taipei Metro network up to November 2010 and their relationship with the quarters of Greater Taipei

Metro ridership

Metro ridership grew continuously and rapidly ever since the opening of the system in 1996. The Taipei Metro has spanned across Taipei and New Taipei Cities since the very first day of operation, so the system-wide ridership equals ridership in the two cities combined. The metro ridership grew from 31 million in 1997 to 790 million in 2019. On average, the entire metro system gained around 27 million additional passengers per year over between 2000 and 2019, excluding the extreme years such as the

pre-2000 years when the network only had two disconnected separate lines and the post-2000 years when transit ridership was affected by the COVID-19 pandemic; the AAGR was 5.84% (MOTC, 2022). (See Figure 4.4)

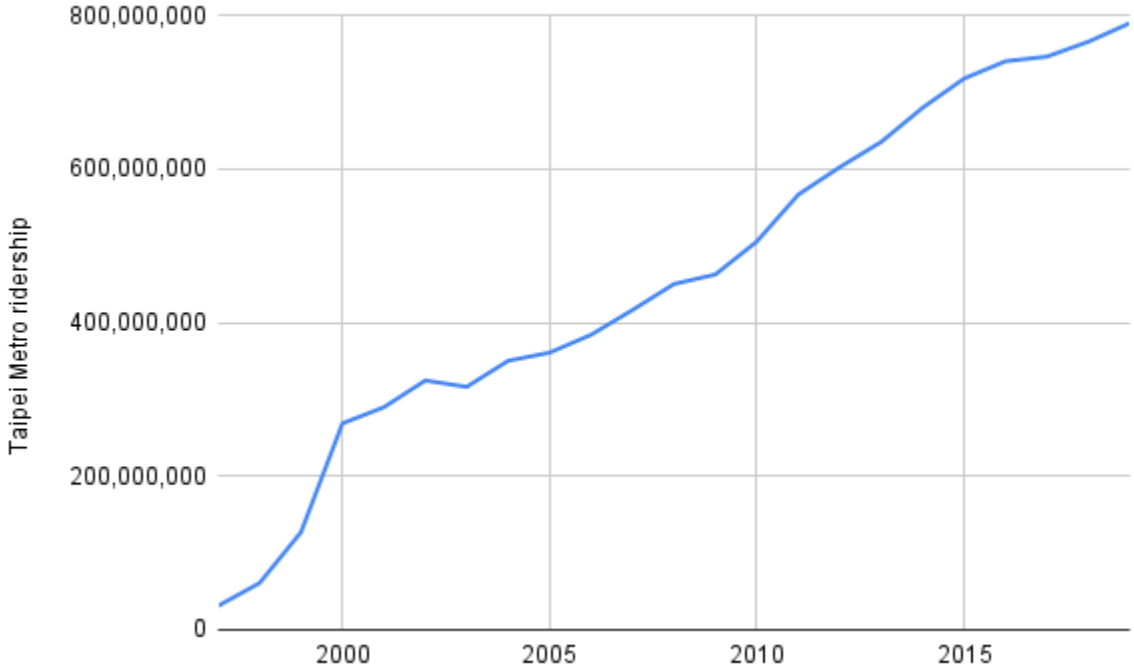


Figure 4.4: Taipei Metro ridership, 1997-2019

Motorcycle and car ownership

The motorcycle as the dominant type of private vehicles boasts a much larger fleet than the cars, but it has decreased in both total number and ownership rate since around 2011; nevertheless, from 2000 to 2009, household motorcycle ownership had grown, and the share of non-motorcycle-owning households had decreased across all income groups. The car, on the contrary, grew in number in a generally continuous fashion (See Figures 4.5 and 4.6). The motorcycle ownership rate has been high,

but it peaked 15 years after the introduction of the metro system and declined steadily since. The total number of registered motorcycles in Taipei, New Taipei, and Keelung Cities combined was 2.2 million in 1996, peaked at 3.7 million in 2012, and declined steadily to 3.3 million in 2020. Taking population into consideration, the number of registered motorcycles per thousand people was 352 in 1996, peaked at 526 in 2011, and declined steadily to 478 in 2020 (MOTC, 2022). Household motorcycle ownership had grown across all income groups. Data from the 2000 and 2009 household travel surveys show that, between the two surveys, the share of households owning no motorcycles dropped both for the entire sample and across all income quintiles; there were considerable gains in the shares of households owning multiple (two or above) motorcycles. It is noteworthy that the lowest-quintile income group has had the largest share of non-motorcycle-owning households among all income groups. Car ownership rate has generally been growing. The total number of registered automobiles in Taipei, New Taipei, and Keelung Cities combined was 1.2 million in 1996 and grew to 1.7 million in 2020. Taking population into consideration, the number of registered automobiles per thousand people was 192 in 1996 and, despite slight fluctuations, grew to 247 in 2020. On average, the three cities altogether gained over 21,000 additional registered automobiles per year over this period; the AAGR was 1.48% (MOTC, 2022).

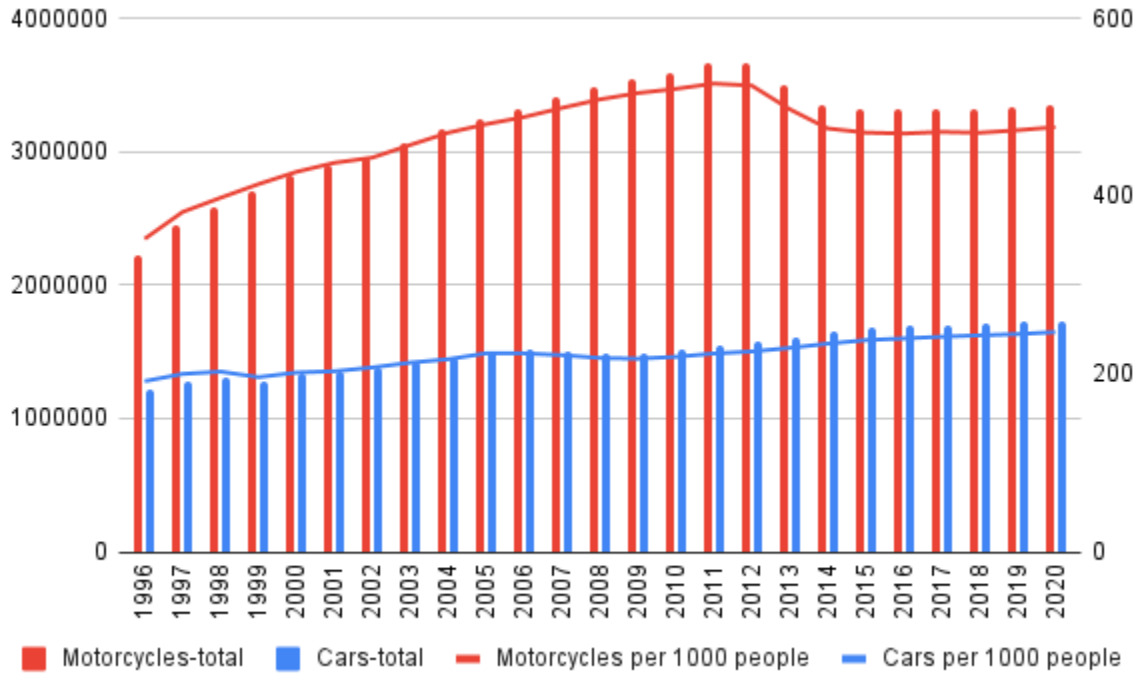
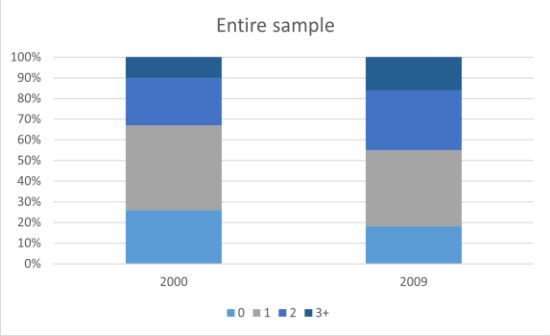
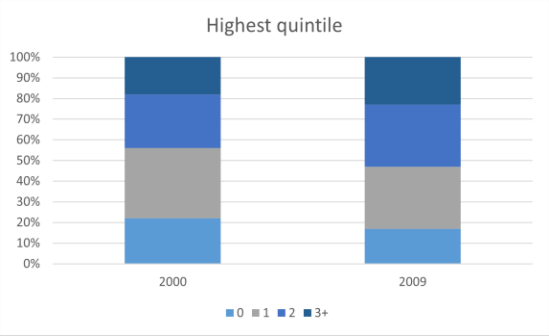


Figure 4.5: Changes in total ownership and ownership per thousand people of registered cars and motorcycles in Taipei, New Taipei, and Keelung Cities combined, 1996-2020





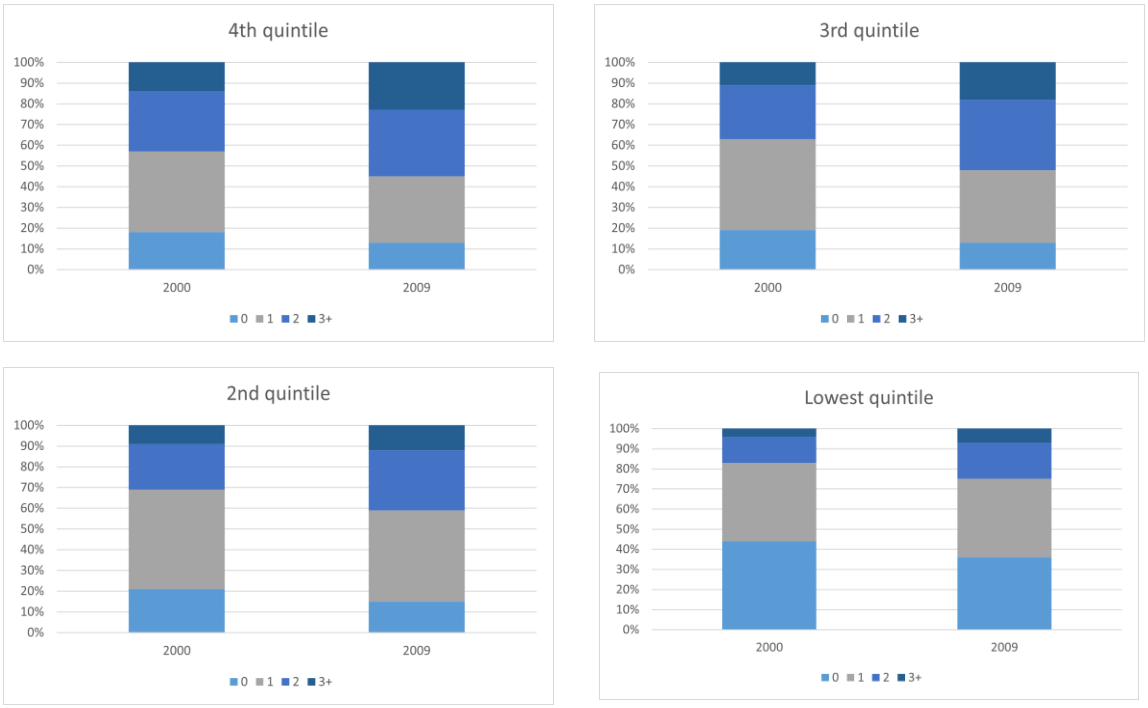


Figure 4.6: Changes in household motorcycle ownership by income quintile in the Taipei Metropolitan Area, 2000 and 2009

Modal split

The motorcycle as the dominant primary mode in all trips saw its popularity rising not only in all trips but also in trips to work in the office during the study period of this chapter. According to the trip datasets from the 2000 and 2009 household travel surveys before data-cleaning, the modal share of the motorcycle in all trips increased from 42% to 53% over the period (see Figure 4.7), and that of the motorcycles in commuting trips from 48% to 58% (see Figure 4.8), both calculated with walking (available only in the 2009 survey), other modes, and unidentifiable modes being excluded from the overall modal split. The modal share of the car shrank considerably, and that of the buses decreased while that of the metro increased.

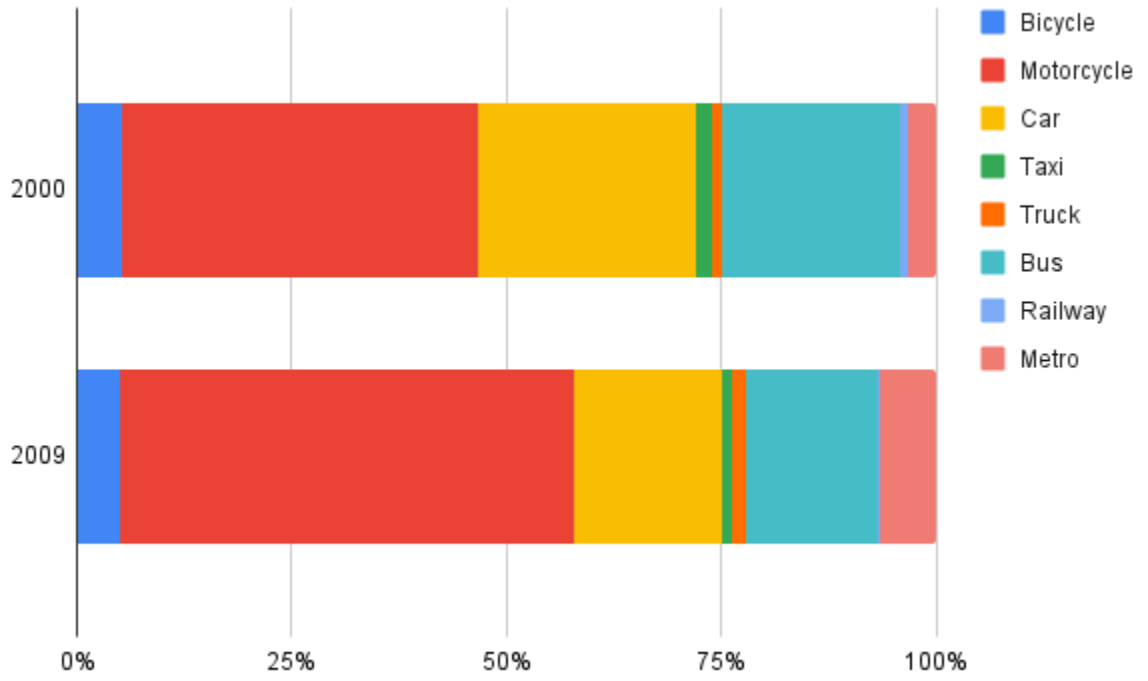


Figure 4.7: Changes in modal split of all trips in the Taipei Metropolitan Area, according to the 2000 and 2009 household travel surveys (before data-cleaning), excluding walking (available only in 2009 survey), other modes, and unidentifiable modes

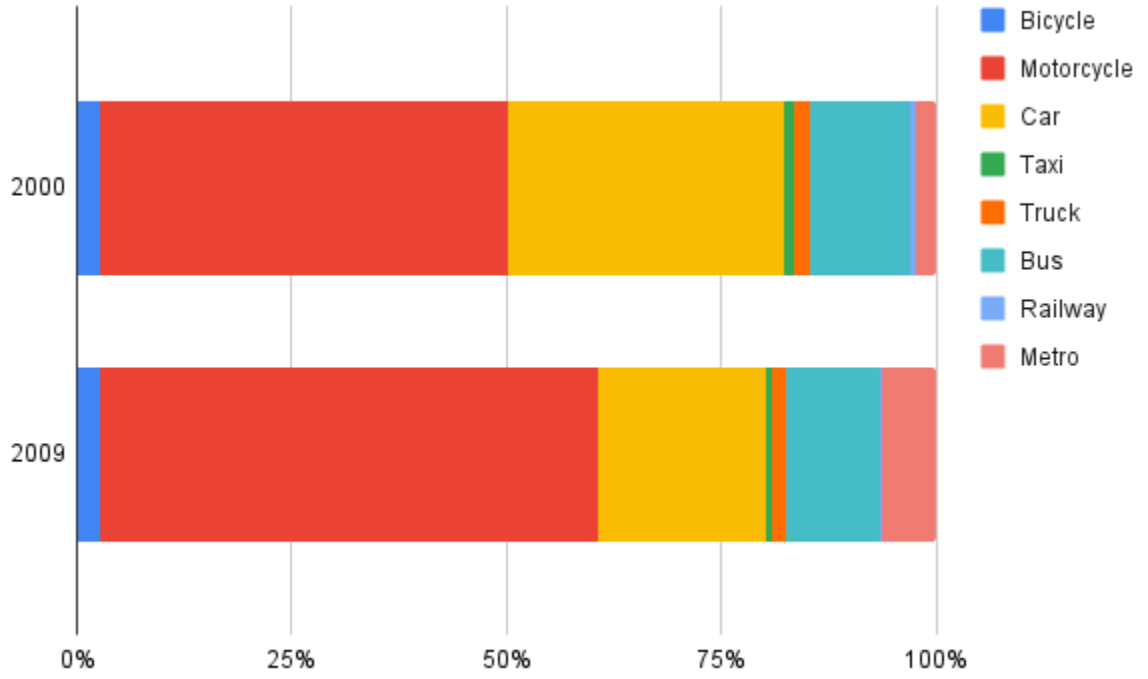


Figure 4.8: Changes in modal split of trips to work in the office in the Taipei Metropolitan Area, according to the 2000 and 2009 household travel surveys (before data-cleaning), excluding walking (available only in 2009 survey), other modes, and unidentifiable modes

4.4. Data

The data used in this chapter are pooled datasets that combine household and trip data from the 2000 and 2009 household travel surveys in Greater Taipei, the most recent two in the metropolis; the chapter also uses population and employment statistics publicly available to generate data for the variables needed in the models. Trips used for analysis in this chapter are not limited to any specific type of origins, destinations, and purposes; a total of 93,230 trips remain after data cleaning (linking trips, trip makers, households, and TAZs) among all 203,175 trips from the two household travel surveys

combined. Meanwhile, data-cleaning leaves 27,754 households remaining among all 41,217 households from both surveys.

Potential built environment and socioeconomic predictors of motorcycle travel behavior are selected to be included in the models as control variables based on the literature review. These include the spatial relationship with metro stations, population density, land use diversity, the number of household members, the age of the trip maker, and household income; as for car ownership level, it is reflected in residential self-selection bias correction which is included as a control variable in the mode choice and household motorcycle VKT models. In addition, three other variables are added to the list of control variables, including job density, distance to the central business district (CBD), and the gender of the trip maker, among which the distance to the CBD can act as a proxy of destination accessibility, another built environment variable that can affect vehicle use (Ewing & Cervero, 2010). Intersection density, street connectivity, and other design characteristics of the built environment are also commonly used control variable in built environment-travel research (Ewing & Cervero, 2010), but such variables are difficult to be calculated for Taipei due to the lack of available spatial data. Lastly, it is noted in this chapter that population density may be related to the probability of treatment, which is the introduction of metro stations, because transit investments often prioritize densely populated areas; this issue was addressed via the use of treatment and control groups, in which the sample was limited to only the more centrally located geographies so that their population densities and thus the probabilities of receiving treatment are comparable to each other. The following paragraphs describe each of the variables, and Table 4.1 provides their descriptive statistics.

Dependent variables:

Odds of mode choice of motorcycle instead of bus/car/metro/bicycle. The odds that a trip maker chooses to use a motorcycle instead of an alternative mode to fulfill a trip.

Household motorcycle VKT. The sum of the distances, measured in kilometers, of all motorcycle trips made by members of the same household within a day.

Explanatory variables:

Population density. Number of persons, measured in 100,000, per square kilometers in a TAZ.

Job density. Number of jobs, measured in 100,000, per square kilometers in a TAZ.

Land use diversity index. A measure of land use diversity. A value that reflects the level of balance between different land uses of a TAZ. Perfect balance is denoted as the highest possible value 1, and the lowest value 0 indicates perfect imbalance (Rajamani et al, 2003; Zegras, 2010). Because direct data of land uses or zoning would not reflect the reality of the distribution of activities in high-density Greater Taipei where multistory buildings are the norm and mix of uses are common across all categories of zoning, this research used trip destinations as a proxy of the locations of activities (Guerra, 2014b; Shirgaokar, 2016) with one caveat: this research was only able to use three types of activities - homes, work, and school, because besides these three, all other trip purposes are categories that combine multiple kinds of activities. Equation 3.1 is the formula for calculating the land use diversity index.

$$DI = 1 - \frac{\sum_{i=1}^{3} \left| \frac{D_i}{D_t} - \frac{1}{3} \right|}{\frac{2}{1.5}}$$

(Equation 3.1.)

where DI is land use diversity index in a TAZ, D_i is the number of trip destinations of each of the three categories including homes, work, and school, and D_t is the total number of trip destinations of the three categories.

Distance to the CBD. Distance, measured in 100 kilometers, between the CBD of Greater Taipei, the Xinyi Special District located in the southeast of Taipei City, and the centroid of the TAZ. A measure of destination accessibility, because jobs or other attractions of trips tend to be the highest at central locations and lowest at peripheral ones (Ewing & Cervero, 2010); this holds true for the context of Greater Taipei where jobs are highly concentrated in the central districts where the CBD is also located (see Figure 4.2).

Residential self-selection bias correction. A measure calculated to counter residential self-selection bias (Houston et al., 2015; Shirgaokar, 2016; Zegras, 2010). It also reflects household vehicle ownership and can thus be a control variable in mode choice and VKT models. This was calculated using Equation 3.2:

$$SBC_l = \left(\frac{1}{K}\right)\sum_{k \neq c}^{K}\left(\frac{P_{l,k} * \ln P_{l,k}}{1 - P_{l,k}} + lnP_{l,c}\right)$$

(Equation 3.2.)

where, SBC_l is self-selection correction for household l, K is total number of alternatives, k is alternative index (0 or 1-plus private vehicles), c is chosen alternative index, $P_{l,k}$ is predicted probability of household l owing k vehicles.

Number of residents in household. The number of members of a household who live in the housing unit; also known as household size.

Annual income in quintile of the household. The quintile (one of five classes) in which the annual income of a household falls in. One means the lowest quintile, while five means the highest. Household annual income was already recorded as income bands in the household travel surveys, which as factor variables are a good approach to dealing with non-linearity, and this chapter further converted these income bands into five income groups, or quantiles, each of which consists of a number of households that was as close to one fifth of the size of the sample of the specific time period (2000 or 2009) as possible, so as to overcome the varying ranges of income and the change in the real value of the currency in different time periods.

Age of the trip maker. The actual age of years of the trip maker. Since adding the quadratic term of age to the models can reflect the effect of age at different ages, this was done in the models.

Male gender of the trip maker. A dummy variable indicating the trip maker being a male person.

Table 4.1: Descriptive statistics of the variables

Variable (unit)	*Pooled data of 2000 and 2009 surveys*	
	Mean	*Standard deviation*
Motorcycle travel characteristics of interest		
Mode choice of motorcycle	0.43	--
Mode choice of bus	0.23	--
Mode choice of car	0.24	--
Mode choice of metro	0.05	--
Mode choice of bicycle	0.04	--
Household motorcycle VKT	14.73	39.11
Treatments and controls (households)		
Control group: no stations during 2000-2009	0.39	--
Treatment group: older stations during 2000-2009	0.50	--
Treatment group: new stations during 2000-2009	0.11	--
Second time period: the 2009 household travel survey	0.15	--
Treatments and controls (trips)		
Control group: no stations during 2000-2009	0.47	--
Treatment group: older stations during 2000-2009	0.40	--
Treatment group: new stations during 2000-2009	0.13	--
Second time period: the 2009 household travel survey	0.09	--
Built environment variables (household)		
Population density of TAZ (100,000 people/km^2)	0.29	0.17
Job density of TAZ (100,000 jobs/km^2)	0.23	0.22
Land use diversity index of TAZ (0-1)	0.54	0.16
Distance to CBD from TAZ (100 km)	0.07	0.04
Built environment variables (trip)		
Population density of TAZ (100,000 people/km^2)	0.27	0.17
Job density of TAZ (100,000 jobs/km^2)	0.17	0.21
Land use diversity index of TAZ (0-1)	0.52	0.17

Distance to CBD from TAZ (100 km)	0.08	0.04
Socioeconomic variables		
Number of residents in household	3.70	1.52
Annual household income in the lower quantile	0.18	--
Annual household income in the 2nd quantile	0.19	--
Annual household income in the 3rd quantile	0.22	--
Annual household income in the 4th quantile	0.25	--
Annual household income in the highest quantile	0.16	--
Age of trip maker	36.64	16.33
Male gender of trip maker	0.57	--
Residential self-selection bias correction of household	-1.63	0.52
Number of observations: trips (N=)	93,230	--
Number of observations: households (N=)	41,217	--

4.5. Methodology

Research hypothesis

Based on the literature review, below is the hypothesis to be tested in this chapter.

Hypothesis: Motorcycle use, measured in the chance of mode choice and the amount of use, decreases around mass rapid transit stations, after controlling for socioeconomic and built environment variables that can also influence motorcycle use.

Methodology

This chapter applies the difference-in-differences (DD) approach to make inference on the treatment effect of the introduction of new metro stations on motorcycle use within their proximity. The motorcycle use characteristics of interest, which were the dependent variables, are: (1) mode choice odds of the motorcycle over an alternative mode in a trip (for which binomial logistic regression models were estimated, details provided later in this section), and (2) household motorcycle VKT (for which a tobit regression model were estimated, details provided later in this section). DD is an econometric technique for causal reference based on the "common trend" assumption that trends would be the same in a treatment group and a control group in the absence of the treatment, such as a policy change, and the treatment induces a deviation from this common trend (Angrist & Pischke, 2008). DD estimates a causal effect of a treatment of interest through estimating the coefficient of the interaction term of a dummy variable for a time period after a treatment and a dummy variable for the treatment group (Wooldridge 2010; Angrist & Pischke, 2015). Since the use of the DD technique involves changes over time, this chapter pools datasets from two time periods to enable the use of DD.

The treatment effect of metro stations, both new ones introduced during the study period 2000-2009 and older pre-existing ones introduced before it, on areas in their proximity can be seen by comparison with a control group, which is the areas not close to any stations throughout the study period. This chapter chooses treatment and control groups based on the time of introduction of metro stations (see Figure 4.9). Instead of considering all geographies of varying built environment characteristics, this chapter chooses to limit the sample to only the more centrally located geographies so that, given population and jobs are generally more densely distributed in the central areas of the metropolis than in the outer areas (see Figures 4.1 and 4.2), they are more comparable to each other; as a result, this chapter only includes TAZs in the downtown and the inner suburbs in its designation of treatment and control groups, thereby excluding all outer-suburban TAZs except for those already included in the treatment or control groups, which are the TAZs in proximity to the three northernmost stations of the Taipei Metro network that sit within an outer suburb, Tamsui District of New Taipei City. This chapter defines two treatment groups as TAZs whose centroids are located within 800 meters (half mile), a distance generally considered acceptable for a transit rider to walk instead of using other modes (Guerra

et al, 2012), from metro stations introduced during the study period (“Gt”), and those within 800 meters from metro stations introduced before (“Gc”). This chapter defines one control group: TAZs whose centroids were never located within 800 meters from a metro station throughout the study period (“G0”). Instead of further refining the selection of treatment and control groups based on built environment characteristics, this chapter chooses to include built environment control variables into the models.

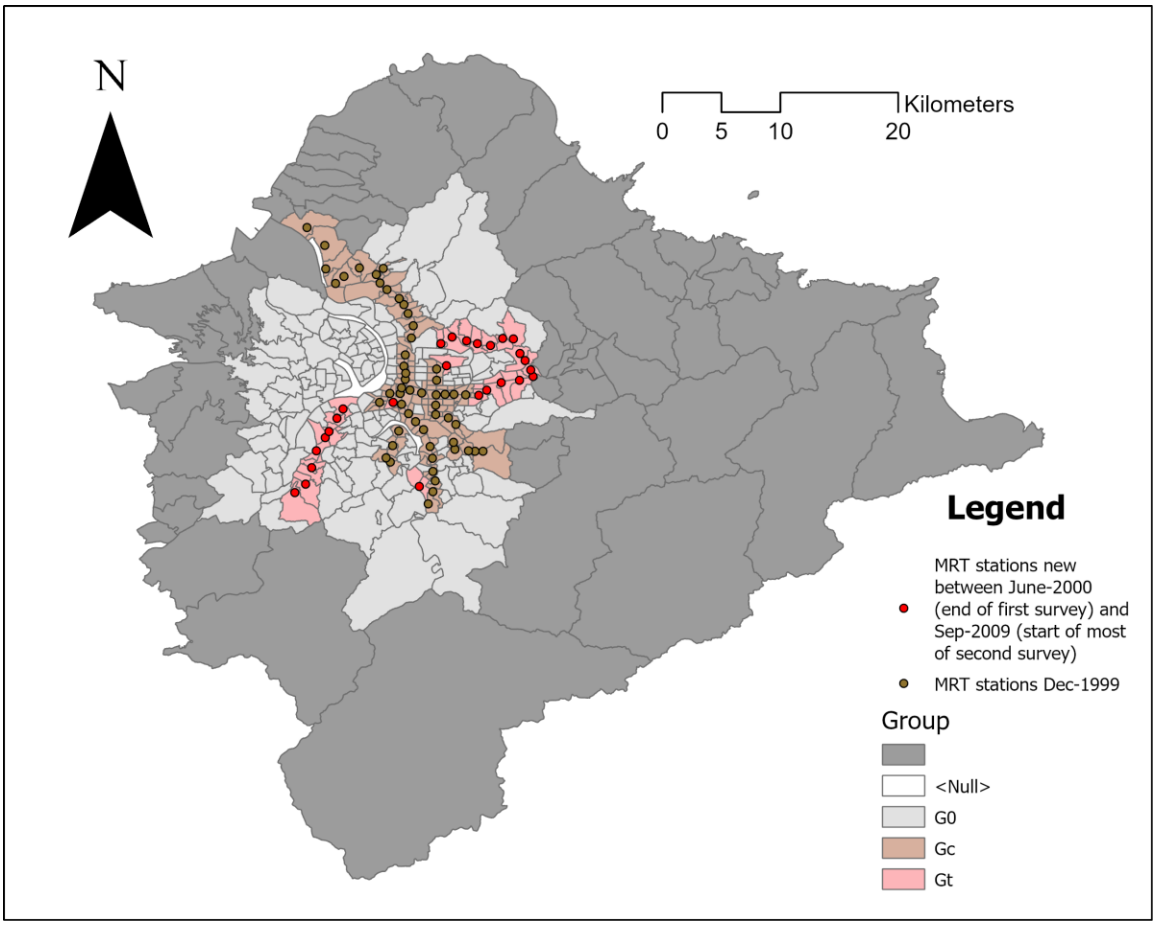


Figure 4.9: TAZs selected for trips in the treatment groups (Gt and Gc) the control group (G0) and the pre-existing and newly introduced metro (MRT) stations between 2000 and 2009

Although not presenting its results, this chapter also attempts another statistical method of causal inference, propensity score matching, to match the data base on their probability of receiving the

treatment (Braitman & Rosenbaum, 2002), and then apply the DD technique on the matched data, a practice that can be referred to as matched DD (Wetwitoo & Kato, 2019); however, the matched DD approach demonstrates almost identical results with the DD approach, and therefore its results are omitted.

Model specifications

Four binomial logistic regression models are estimated for pairwise mode choice odds, and a left-censored tobit regression model for household motorcycle VKT, both using the DD approach with treatment and control groups as well as built environment and socioeconomic control variables. The units of analysis are a trip and a household in the above two types of models respectively. Although multinomial logistic regression is most suitable for mode choice analysis, it is not well-suited to be used together with DD because it imposes parametric assumptions that complicate the interpretation of regression coefficients as treatment effects (Graves et al, 2022). Therefore, this chapter uses binomial logistic regression on mode choice odds regarding mode choice as a dichotomous case in which a trip maker chooses between two outcomes: the motorcycle and an alternative mode. In other words, this chapter makes pairwise comparisons between motorcycle and the buses, motorcycle and car, motorcycle and the metro, and motorcycle and cycling, using data restricted to trips by either motorcycle or the buses, trips by either motorcycle or car, trips by either motorcycle or the metro, and trips by either motorcycle or walking/cycling, respectively (all the other modes are excluded due to their very small modal share, and trips made on foot were also excluded because they were only included in the 2009 survey, not the 2000 one); in each mode pair, 1 represents the mode choice of motorcycle and 0 that of the other mode. By doing this, this chapter closely imitates what a multinomial logistic regression would achieve in mode choice analysis, and although in each analysis this chapter is unable to use all the data, the large sample sizes alleviate such a disadvantage. Mode choice involving other public transportation or other private motorized vehicles are not included in the modeling process due to their very small modal shares. For household motorcycle VKT, due to the fact that the response variable is a non-negative

continuous distribution whose values include zeros, a left-censored tobit regression model is estimated, and the response variable is transformed into the natural log of “one plus household motorcycle VKT” (Guerra, 2014a). The binomial logit regression model is run using the glm() function and the tobit regression model the package “AER” in the R statistical software, whose version is RStudio 2022.12.0 Build 353. The below equation shows the model specification of the regression models in which the DD technique (see Equation 4.1) is used in mathematical form.

$$y = \beta_0 + \beta_1 G_t + \beta_2 G_c + \delta_0 year2 + \delta_A (G_t \cdot year2) + \delta_B (G_c \cdot year2) + \beta_x X_i + u$$

(Equation 4.1)

Where:

y = A dependent variable measuring motorcycle mode choice likelihood or amount of use,

G_t = A dummy variable capturing the difference between the treatment group of new metro stations and the control group in the absence of treatment,

G_c = A dummy variable capturing the difference between the treatment group of older metro stations and the control group with earlier treatments,

year2 = A dummy variable capturing the common difference across all treatment and control groups before and after the treatment,

δ_A and δ_B = The treatment effects of interest,

X_i = A vector of control variables that might be influential on a dependent variable, and

u = An error term.

4.6. Results

Overview

The following subsections present and interpret the model results on the effect of proximity to metro stations identified by DD estimation. Figure 4.10 visualizes the percent change in the odds of mode choice of motorcycle instead of an alternative mode as well as in household motorcycle VKT between 2000 and 2009; the bars for the areas not close to any metro stations can be seen as reflecting the metropolitan trends in changes of mode choice odds and household motorcycle VKT, and the bars for areas near new or older stations reflect actual changes in these dependent variables but, being juxtaposed with the metropolitan trends, relative increases or decreases can be concluded. The treatment effects of newly introduced metro stations and older pre-existing ones in reducing the motorcycle mode choice odds relative to that of the metro for trips originating in their close proximity were confirmed to exist, by 207% and 40% respectively when compared with areas not close to any stations, by the binomial logistic models. On the other hand, the tobit model confirmed the treatment effects of new and older metro stations in reducing household motorcycle VKT in their proximity as relative to areas not close to any stations, by 65% and 56% respectively.

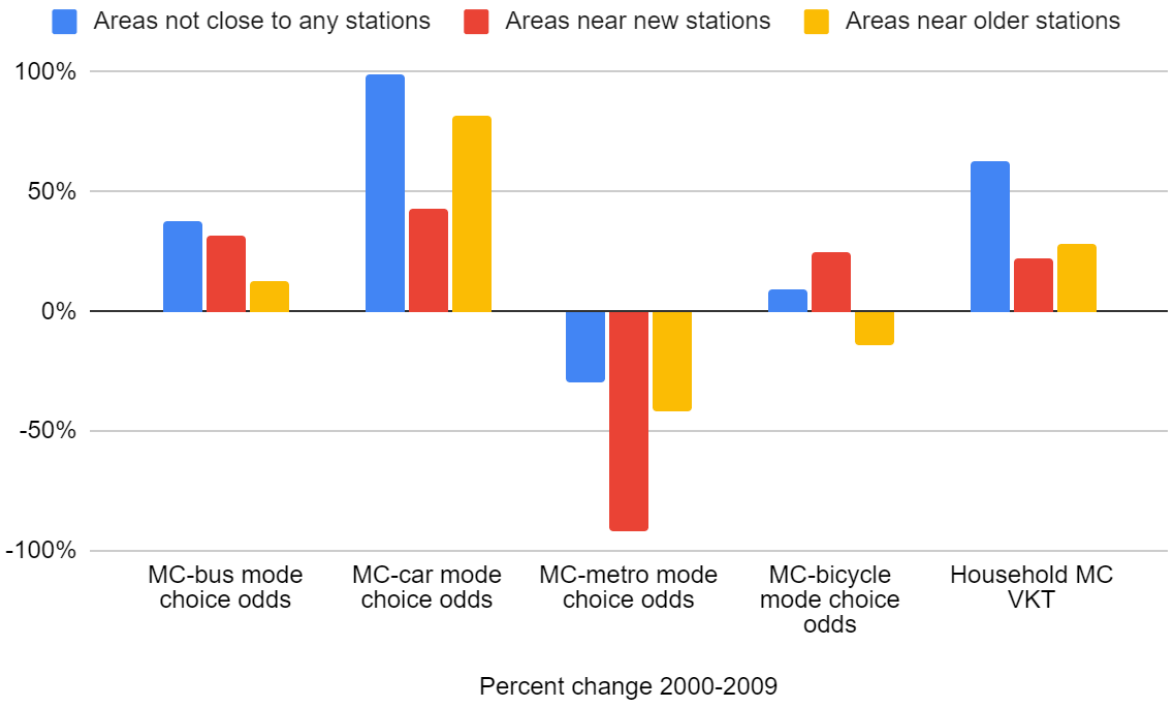


Figure 4.10: Percent change in the odds of mode choice of motorcycle (MC) instead of the buses, the car, the metro, or bicycle as well as in household motorcycle VKT, 2000-2009

Mode choice of an average trip maker in a trip

Table 4.2 presents the model results on the mode choice effect of proximity to metro stations identified by DD estimation. The binomial logistic models in which the DD technique is employed suggest the potential existence of the treatment effect of newly introduced metro stations in reducing the motorcycle mode choice odds relative to that of the buses, the car, and the metro for trips originating within their 800-meter proximity. In addition, older stations may have been effective in reducing motorcycle mode choice odds relative to the buses, the car, the metro, and the bicycle. Logistic models allow using the exponent of the coefficient estimates to interpret the model results.

Areas near new stations saw a relative decrease (about 16%) in the odds of choosing the motorcycle instead of the buses for a trip than areas not close to any stations, although there was a metropolitan-wide absolute increase. Motorcycle-versus-bus odds ratio for areas not close to any stations during the 2009 survey versus the 2000 survey is exp(0.32)=1.38; that is, for trips originating in areas not close to any stations, the odds of choosing to use a motorcycle instead of the buses are estimated to have increased by 38% between the two surveys. For areas near new stations, exp(0.32-0.04)=1.32; that is, increased by 32%. For areas near older stations, exp(0.32-0.20)=1.13; that is, increased by 13%; note the larger relative decrease (about 66%) in the odds of motorcycle mode choice against the buses as opposed to the metropolitan trend in areas near older stations than in areas near new ones.

The odds of choosing the motorcycle instead of the car for a trip decreased considerably (about 57%) in areas near new stations relative to areas not close to any stations, although there was a metropolitan-wide absolute increase. Motorcycle-versus-car odds ratio for areas not close to any stations during the 2009 survey versus the 2000 survey is exp(0.69)=1.99; that is, for trips originating in areas not close to any stations, the odds of choosing to use a motorcycle instead of a car are estimated to have increased by 99% between the two surveys. For areas near new stations, exp(0.69-0.33)=1.43; that is,

increased by 43%. For areas near older stations, exp(0.69-0.09)=1.82; that is, increased by 82%; note the much smaller relative decrease (about 17%) in the odds of motorcycle mode choice against the cars as opposed to the metropolitan trend in areas near older stations than in areas near new ones.

An enormous relative decrease (about 207%) in the odds of choosing to use a motorcycle instead of the metro occurred in areas near new stations, and there was a metropolitan-wide absolute decrease. Motorcycle-versus-metro odds ratio for areas not close to any stations during the 2009 survey versus the 2000 survey is exp(-0.35)=0.70; that is, for trips originating in areas not close to any stations, the odds of choosing to use a motorcycle instead of the metro are estimated to have decreased by 30% between the two surveys. For areas near new stations, exp(-0.35-2.22)=0.08; that is, decreased by 92%. For areas near older stations, exp(-0.35-0.20)=0.58; that is, decreased by 42%; note the relative decrease in mode choice odds of the motorcycle instead of the metro as opposed to the metropolitan trend in areas near older stations, despite being a much smaller decrease (about 40%) than that in areas near new ones.

Finally, the odds of choosing the motorcycle instead of the bicycle for a trip increased considerably (about 178%) in areas near new stations relative to areas not close to any stations, although there was a metropolitan-wide absolute increase. Motorcycle-versus-bicycle odds ratio for no stations during the 2009 survey versus the 2000 survey is exp(0.09)=1.09; that is, for trips originating in areas not close to any stations, the odds of choosing to use a motorcycle instead of a bicycle are estimated to have increased by 9% between the two surveys. For areas near new stations, exp(0.09+0.13)=1.25; that is, increased by 25%. For areas near older stations, exp(0.09-0.24)=0.86; that is, decreased by 14%; note that the trend around older stations is opposite to the metropolitan trend.

Table 4.2: Model results of binomial logistic regression on pairwise mode choice with the treatment effect of proximity to newly introduced metro stations identified by DD estimation

	Motorcycle (1) vs. Bus (0)		Motorcycle (1) vs. Car (0)		Motorcycle (1) vs. Metro (0)		Motorcycle (1) vs. Bicycle (0)	
	Coef.	Std.error	Coef.	Std.error	Coef.	Std.error	Coef.	Std.error
Time effect	0.32	0.05 ***	0.69	0.06 ***	-0.35	0.13 **	0.09	0.09
Treatment effect, new stations	-0.04	0.11	-0.33	0.11 **	-2.22	0.20 ***	0.13	0.20
Treatment effect, older stations	-0.20	0.07 **	-0.09	0.08	-0.20	0.14	-0.24	0.11 *
Group effect, new stations	-0.08	0.03 *	-0.18	0.03 ***	0.59	0.12 ***	0.07	0.06
Group effect, older stations	-0.004	0.02	-0.13	0.02 ***	-2.02	0.05 ***	-0.12	0.04 **
Population density (100,000 people/km^2)	0.76	0.06 ***	1.02	0.05 ***	1.86	0.11 ***	-0.99	0.1 ***
Job density (100,000 jobs/km^2)	-0.36	0.05 ***	0.18	0.05 ***	0.23	0.08 **	0.59	0.11 ***
Land use diversity index (0-1)	-0.26	0.06 ***	0.01	0.05	-0.32	0.10 ***	-0.07	0.11
Distance to CBD (100 km)	6.28	0.26 ***	1.96	0.23 ***	4.92	0.53 ***	3.44	0.47 ***
Household size	-0.18	0.02 ***	-0.04	0.02 *	-0.17	0.03 ***	0.02	0.03
Household income in 2nd quintile (base: lowest quintile) (1/0)	0.22	0.03 ***	-0.30	0.04 ***	0.17	0.06 **	0.27	0.05 ***
" in 3rd quintile (") (1/0)	-0.03	0.04	-0.56	0.04 ***	-0.05	0.07	0.56	0.07 ***
" in 4th quintile (") (1/0)	-0.21	0.05 ***	-0.90	0.05 ***	-0.34	0.08 ***	0.65	0.09 ***
" in the highest quintile (") (1/0)	-0.62	0.07 ***	-1.42	0.07 ***	-0.75	0.11 ***	0.87	0.12 ***
Age of trip maker	0.19	0.003 ***	-0.07	0.003 ***	0.01	0.002 ***	0.05	0.004 ***
(Age of trip maker)^2	-0.002	0.00003 ***	0.001	0.00004 ***	-0.00004	0.00001 ***	-0.001	0.00005 ***
Male gender of trip maker (1/0)	1.05	0.02 ***	-0.52	0.02 ***	0.83	0.03 ***	0.63	0.03 ***
Self-selection bias correction	-0.93	0.07 ***	-0.54	0.07 ***	-0.98	0.12 ***	0.12	0.12
Log(scale)	--	--	--	--	--	--	--	--
Intercept	-4.31	0.08 ***	2.16	0.08 ***	1.27	0.13 ***	0.98	0.13 ***
Number of observations (N=)	61574		62951		44907		44335	
Log-Likelihood	-33232		-38564		-12283		-12981	
Pseudo R-squared	0.1644		0.0639		0.1872		0.0589	

Notes: (1) Coef. = Coefficient estimate; Std.error = standard error. (2) Significance codes: *** p < 0.001; ** p < 0.01; * p < 0.05; . p < 0.1.

Motorcycle VKT of an average household within a day

Table 4.3 presents the model results on the household motorcycle VKT effect of proximity to metro stations identified by DD estimation. The tobit model in which the DD technique is employed suggests the potential existence of the treatment effect of newly introduced metro stations in reducing the household motorcycle VKT for households located within their 800-meter proximity. In addition, older stations may have been effective in reducing household motorcycle VKT too. By running the regression on the natural log of household motorcycle VKT, a tobit model allows using the exponent of the coefficient estimates to interpret the model results.

Areas near new stations saw a considerable relative decrease (about 65%) in household motorcycle VKT than other areas, although there was a metropolitan-wide absolute increase. Household motorcycle VKT for areas not close to any stations during the 2009 survey versus the 2000 survey is exp(0.49)=1.63; that is, for trips originating in areas not close to any stations, household motorcycle VKT is estimated to have increased by 63% between the two surveys. For areas near new stations, exp(0.49-0.29)=1.22; that is, increased by 22%. For areas near older stations, exp(0.49-0.24)=1.28; that is, increased by 28%; note the relative decrease in household motorcycle VKT in areas near older stations, despite being a slightly smaller decrease (56%) than that in areas near new ones.

Table 4.3: Model results of left-censored tobit regression on the natural log of "one plus household motorcycle VKT", with the treatment effect of proximity to newly introduced metro stations identified by DD estimation

	Household motorcycle VKT	
	Coefficient estimate	Standard error
Time effect	0.49	0.07 ***
Treatment effect, new stations	-0.29	0.15 .
Treatment effect, older stations	-0.24	0.10 *
Group effect, new stations	-0.14	0.06 *
Group effect, older stations	-0.14	0.05 **
Population density (100,000 people/km^2)	0.48	0.10 ***
Job density (100,000 jobs/km^2)	-0.22	0.09 *
Land use diversity index (0-1)	0.19	0.11 .
Distance to CBD (100 km)	6.92	0.49 ***
Household size	0.39	0.04 ***
Household income in 2nd quintile (base: lowest quintile) (1/0)	0.60	0.06 ***

" in 3rd quintile (") (1/0)	0.69	0.07 ***
" in 4th quintile (") (1/0)	0.79	0.1 ***
" in the highest quintile (") (1/0)	0.64	0.14 ***
Age of trip maker	--	--
(Age of trip maker)^2	--	--
Male gender of trip maker (1/0)	--	--
Self-selection bias correction	0.46	0.16 **
Log(scale)	0.91	0.01 ***
Intercept	-1.11	0.11 ***
Number of observations (N=)	27753	
Log-Likelihood	-45790	
Pseudo R-squared	0.0159	

Notes: Significance codes: *** p < 0.001; ** p < 0.01; * p < 0.05; . p < 0.1.

Model fits

Regarding how the model fits are, in addition to the pseudo R-squared values in the model results, Table 4.4 presents the counts of correction predictions by the binomial logistic regression models, calculated using the R package "nnet".

Table 4.4: Counts of correction predictions by the binomial logistic regression models on pairwise mode choice in a trip

		Motorcycle	The alternative mode
Motorcycle vs. Bus	Actual	40179	21395
	Predicted	28458	11766
	Fraction	0.708	0.550
Motorcycle vs. Car	Actual	40179	22772
	Predicted	24445	12590
	Fraction	0.608	0.553
Motorcycle vs. Metro	Actual	40179	4728
	Predicted	39131	453
	Fraction	0.974	0.096
Motorcycle vs. Bicycle	Actual	40179	4156
	Predicted	40065	51
	Fraction	0.997	0.012

4.7. Discussion

Main takeaways

Findings of this chapter are consistent with what is known from the literature: motorcycle use, measured in mode choice odds and household VKT, had decreased around mass rapid transit stations, after controlling for socioeconomic and built environment variables that can also influence motorcycle use. In the Taipei Metropolitan Area where the motorcycle is the dominant mode of transportation, between 2000 and 2009, there were metropolitan-wide mode choice trends of increased preference of the motorcycle over the buses, the car, or the bicycle, decreased preference of the motorcycle over the

metro, and increased average household motorcycle VKT. However, under these trends, areas near newly introduced metro stations demonstrated an enormous relative decrease in the mode choice preference of the motorcycle over the metro, the buses, and the car, as well as a considerable relative decrease in household motorcycle VKT. Furthermore, areas near older pre-existing metro stations also saw a relative decrease in mode choice preference of the motorcycle over the metro, the buses, the car, and the bicycle, as well as in household motorcycle VKT.

The metro may be effective in enabling modal shift from the motorcycle to the metro, and in reducing or at least limiting the growth in motorcycle use, even over time. Both areas near new stations and those with older stations demonstrated reduced odds of motorcycle mode choice relative to that of the metro. Such reduction is larger in the former than in the latter, which suggests the possibility of a steep initial travel behavioral change around new metro stations and a sustained yet milder change around older ones.

There is potentially a relationship between the metro and the modal shift from the motorcycle to the bus, but only with some delay in time. The odds of motorcycle mode choice relative to the buses decreased in both areas near newer and older stations, but the extent of the decrease is larger for the latter. This could be because older metro stations tend to be located in areas where the level of bus services had already been high, such as the city center, or, as another way to look at the same situation, because it takes time for the level of bus services to be sufficiently improved around new metro stations which tend to be located in the suburbs (see Figure 4.9).

Also, there is potentially a relationship between the metro and the modal shift from the motorcycle to the car, which may be explained by gentrification. As metro stations are introduced, activities may agglomerate around them, which proves attractive for new residential development; as a result, higher-income households, who tend to be able to afford to purchase homes in near-transit locations and to own and use cars, may move in and drive up the overall mode choice preference of the car over the motorcycle in the area; and the larger relative decrease around new stations than around older ones may be due to that new stations tend to be located in the suburbs, with more car parking spaces available than in the downtown.

Scenario simulation

A continuously expanding metro network may effectively reduce the modal share of the motorcycle and household motorcycle VKT. Planning and policy implications of this chapter can be generated through scenario simulation. Scenario simulation demonstrates the values of dependent variables when their explanatory variables change in value. Since planning and policy can affect transit supply, this chapter simulated modal split and household motorcycle VKT in scenarios of mass transit supply on both the 2000 and 2009 travel survey data. Table 4.3 shows the results, which suggest that if mass transit fully covers all the surveyed households with its 800-meter zones, the modal share of the motorcycle will be reduced by 3-4 percentage points and household motorcycle VKT will be reduced by about 15%, compared with actual situations.

Table 4.3: Scenario simulation of percent change in dependent variables in scenarios of built environment and transit supply changes

		2000			2009		
		*Actual, or model-predicted mean**	*If metro's 800-meter zones cover 0% of surveyed households*	*If metro's 800-meter zones cover 100% of surveyed households*	*Actual, or model-predicted mean**	*If metro's 800-meter zones cover 0% of surveyed households*	*If metro's 800-meter zones cover 100% of surveyed households*
Modal shares	*Motorcycle*	42.66%	44.30%	39.90%	47.37%	54.57%	43.40%
	Bicycle	4.38%	4.41%	4.35%	5.19%	5.24%	5.18%
	Bus	23.06%	24.44%	21.34%	21.86%	23.47%	21.06%
	Car	25.40%	25.53%	25.31%	14.90%	14.28%	15.28%
	Metro	4.50%	1.32%	9.10%	10.69%	2.45%	15.08%
Household motorcycle VKT		0.71	0.83	0.60	1.14	1.33	0.97

Note: Actual means of household motorcycle VKT were much larger than tobit model-predicted means (see Table 4.1 in Section 4.4).

4.8. Conclusions

This chapter makes contributions to the knowledge about the transit-motorcycle relationship. The current transit-motorcycle literature has yet to cover mass rapid transit systems, and built environment characteristics have hardly been considered in studies of mode choice involving the motorcycle. This chapter fills these gaps in knowledge by examining the effects of mass rapid transit on motorcycle travel using Taipei, one of the world's earliest cities with high motorcycle ownership rates to have adopted the metro, as the study context. It specifies binomial logistic and tobit regression models in which difference-in-differences, an econometric method of causal inference, was employed to examine the treatment effects of metro stations on mode choice in trips and household motorcycle vehicle kilometers traveled (VKT) within their proximity, controlling for built environment and socioeconomic predictors of motorcycle travel. It uses the most recent trip and household datasets from both the 2000 and 2009 large-scale household travel surveys in the Taipei Metropolitan Area for analysis.

Findings suggest that areas near newly introduced metro stations demonstrated an relative decrease in the mode choice preference of the motorcycle over the metro (by 207%), the buses (by 16%), and the car (by 57%) as well as in household motorcycle VKT (by 65%), when compared with areas not close to any stations; furthermore, areas near older pre-existing metro stations also saw a relative decrease in mode choice preference of the motorcycle over the metro (by 40%), the buses (by 66%), the car (by 17%), and the bicycle (by 56%) as well as in household motorcycle VKT (by 56%), when compared with areas not close to any stations.

The main takeaway for research from this chapter, which is also where its academic novelty lies, is that it advances transit-motorcycle research frontiers by examining a mass rapid transit system and concluding that the metro reduces nearby motorcycle use. The theoretical expectation is that motorcycle use, measured in chance of mode choice and amount of use, decreases around mass rapid transit stations, after controlling for socioeconomic and built environment variables that can also influence motorcycle use. Findings of this chapter validate this hypothesis. In addition, this chapter fills the gap in

the transit-motorcycle literature which has so far only covered such transit modes as BRT, railway, and the buses by empirically examining the effects of a metro system on motorcycle travel.

The main takeaway for policy from this chapter is that transportation and land use policy in motorcycle-stressed cities should focus on expanding mass transit and enhancing the local bus services, cycling and pedestrian infrastructure to further facilitate the modal shift from the motorcycle to the metro. An expanding metro system shortens distances to high-capacity transit and can disincentivize motorcycle mode choice and the generation of motorcycle VKT. As the effects of metro stations in encouraging the mode choice of the metro over the motorcycle are likely to exist, the ease of access to the stations should be improved. Better public buses, bicycle lanes, and sidewalks will serve well commuters who use the metro to go to faraway job locations, who may therefore find it unnecessary to own and use motorcycles.

Limitations of this chapter are multifold. Firstly, it uses a short study period. Travel effects may take several years if not decades to be observed. However, due to data availability, this chapter was only able to obtain household travel survey data from 2000 and 2009 in order to examine the impacts of metro stations. Future research should benefit from the availability of more recent data so that a longer period can be used to examine the effects of metro stations. Secondly, it does not fully analyze the effects of land use changes around metro stations and how they may have impacted travel behavior. Thirdly, the chapter does not analyze the use of motorcycles to fulfill the needs of traveling between home and transit, that is, first- and last-mile trips, particularly for populations outside of the 800-meter walking distance circle around metro stations. Fourth and finally, the chapter does not include an origin-destination assessment to determine if motorcycles are being used for long-distance trips or short-distance ones which can impact mode choice due to concerns of time and cost savings.

CHAPTER 5: MASS TRANSIT EFFECTS ON URBAN DEVELOPMENT

5.1. Introduction

For many cities that have been establishing or expanding mass transit, a common policy goal in such transit investments besides traffic congestion alleviation is to stimulate the economy through reshaping urban development patterns. However, the existing literature on the transit-development relationship leaves two gaps in knowledge. First, transit, in theory, can concentrate population and employment to its proximity, but empirical evidence has hardly agreed on such effects. Second, transit effects on population have been much more studied than that on employment, potentially due to the latter's rare data availability at neighborhood levels. The objective of this chapter is to fill these gaps in knowledge by examining the effects of a metro system on urban development, using the Taipei Metropolitan Area, home to Taiwan's first metro system that opened in 1996, as the study context.

Does the introduction of metro stations in Taipei affect urban development around them? This chapter examines the treatment effects of the introduction of metro stations on population density and job density within their 800-meter (half-mile) proximity by specifying ordinary least squares regression models, in which difference-in-differences, an econometric method of causal inference, was employed to examine the treatment effects of metro stations on population and job densities within their proximity, with treatment and control groups of areas selected in a way that excludes outer-suburban ones for the purpose of comparability of density changes. It uses data of 2000 and 2009, the years of the two most recent large-scale household travel surveys in the Taipei Metropolitan Area for analysis to address the unavailability of employment statistics at the neighborhood level.

This chapter makes several academic and policy contributions to existing knowledge on the relationship between motorcycle travel and transit investments. This chapter verifies a literature-based hypothesis that mass rapid transit investments are effective in increasing population and employment densities in the proximity of the stations. This chapter also makes policy recommendations on how transportation and land use should be coordinated to influence urban development for any cities around

the world that have economic development expectations in transit investments. More than thirty metro systems under construction are planned for opening by 2030 around the world. Most of these new metro systems are in middle-income countries. As stimulating economic development through reshaping urban development is often a policy goal of transit investments, the urban development effects of earlier metro systems like the Taipei Metro will be of interest for policy makers in these countries.

5.2. Literature review

Transit, in theory, can concentrate population and employment to its proximity, but empirical research has hardly agreed on such effects. Transit effects on population have been much more studied than that on employment, potentially due to the latter's rare data availability at local levels.

Transit effects on urban development

The supply of transit infrastructure may affect urban development patterns by concentrating activities to its proximity. New transportation infrastructure guides the changes in land use patterns that are compatible with the transportation systems. Transit investments have redistributive impacts on urban development by means of concentrating economic activities to the proximity to transit corridors (Meyer & Miller, 2001). Earlier research on the Bay Area Rapid Transit (BART) system suggested that it contributed to concentrated and mixed-use land use changes, with certain stations attracting significant commercial and residential development to its immediate vicinity, and the greatest impact occurred in the already vibrant San Francisco downtown where favorable zoning and properties available for redevelopment were available (Cervero & Landis, 1995).

However, empirical findings about transit's urban development impacts do not agree. Among recent studies on transit impacts on urban development, some identified a population increase around transit stations (Basheer et al, 2020; Calvo et al, 2013; Guerra, 2014a) while some rejected any transit-induced population changes (Jun, 2012), and findings about indicators of employment activities including

commercial and industrial land uses have been mixed (Bhattacharjee & Goetz, 2015; Hurst & West, 2014; Jun, 2012).

Gaps in knowledge on transit and urban development

While transit effects on population have been abundantly studied, little research examined that on employment. Some scholars have considered transit impacts on indicators of employment activities, such as commercial and industrial land uses (Bhattacharjee & Goetz, 2015; Hurst & West, 2014; Jun, 2012). Nevertheless, potentially due to its rare availability at local levels, direct employment statistics have hardly been used in any transit-impact studies since that of Cervero & Landis (1997) who used job counts at the zipcode level for analysis. A recent attempt to analyze employment changes at the local level was made by Guerra (2014b) who used the destinations of work trips in household travel surveys as proxies of employment locations.

5.3. Context: Greater Taipei

Household travel surveys in 2000 and 2009

Although local-level employment statistics are unavailable in Taiwan, the two most recent household travel surveys in the Taipei Metropolitan Area, also known as Greater Taipei, offer the opportunity to use the destinations of work trips as proxies of employment locations (Guerra, 2014a). The first survey “DOTS-II” was conducted immediately after the Taipei Metro first formed a connected network in December 1999. The second survey “TRTS-IV” was conducted immediately after the metro system reached Neihu, a suburban district to the northeast of downtown with the most rapid job growth in the metropolitan area.

The first of the two household travel surveys used in this chapter was conducted in 2000 and covered a total of 129,139 trips (not including trips on foot). The survey was conducted between April 1 and June 30, 2000. The survey was conducted by the Taipei-based Asian Technical Consultants, Inc., commissioned by the Department of Transportation of the Taipei City Government. The geographical scope of the study included Taipei City, Taipei County (today's New Taipei City), Keelung City, plus Guishan Township of Taoyuan County (today's Guishan District of Taoyuan City). The survey drew up 383 traffic analysis zones (TAZs) based on villages, including 376 within the study area and 7 outside of it. The survey covered socioeconomic and trip characteristics of 117,066 persons from 32,217 households (1.5% of all households in the study area) as an effective sample who reported trips. (ATCI, 2001)

The second of the two household travel surveys used in this chapter, being the most recent survey conducted in Greater Taipei, was conducted in 2009 and covered a total of 64,904 trips (including trips on foot). The survey was conducted partly (a minority of trips reported, about 10%) between May 1 and June 30, 2009, and mostly between September 1, 2009 and January 22, 2010. The survey was conducted by the Taipei-based THI Consultants Inc., commissioned by the Department of Rapid Transit Systems of the Taipei City Government. The geographical scope of the study was the same as that of the 2000 survey except that Keelung City was excluded. The survey drew up 601 TAZs, including 571 within the study area and 30 outside of it. The survey covered socioeconomic and trip characteristics of 32,136 persons from 9,000 households (0.39% of all households in the study area) as the sample, who reported trips. Note that only the approximately 10% earliest trips reported to the survey were made before the Taipei Metro extended further into the eastern inner suburbs, beginning to serve Taipei City's Neihu District, home to the strongest job growth in the metropolitan area between the two surveys. (THI, 2012)

The major differences between the 2000 and 2009 household travel surveys can be summarized as the following. Firstly, in terms of geographical sampling, the 2000 survey included Keelung City while the 2009 one excluded it, and the latter demarcated TAZs in a more fine-grained way, almost double the number of those drawn by the former. Secondly, in terms of survey methods, the 2000 survey excluded trips on foot while the 2009 one included such trips. Thirdly, in terms of modal split, if excluding the trips

on foot in the 2000 survey, the modal share of the motorcycle, the most popular mode in both surveys, is larger in the 2009 survey (53%) than in the 2000 one (42%), mainly because of a drop in the modal share of the car.

The estimation of the number of jobs at the TAZ level in this chapter relies partly on the household travel surveys. Unlike population, the number of jobs in a TAZ was not available in the household travel survey datasets, and the number of jobs in Taiwan is only counted at the district level, not at the more fine-grained level of the village, every five years in the nationwide Industry and Service Censuses (ISCs). As a result, the approach to estimating TAZ-level jobs in this chapter was to use a TAZ's share in work trips that ended in a district in a household travel survey as the proxy of a TAZ's share in jobs located in a district (assumption: Total jobs in a TAZ / Total jobs in a district = Work trips to a TAZ / Work trips to a district), as well as to use the district-level job count in the closest ISC year to a household travel survey year as the proxy of the district-level job count in the household travel survey year; this chapter used two ISC years, 2001 and 2011, as proxies of the two household travel survey years, 2000 and 2009. Finally, the ArcGIS Pro software was used to calculate TAZ-level job density as the result of estimated TAZ-level jobs divided by TAZ total area.

Spatial distribution of population and jobs

The 2000-2009 period in Greater Taipei, which comes between the two household travel surveys from which trip and household data are available, was characterized by a dispersion of population and jobs from the downtown to the suburbs. Such a phenomenon can be seen at the TAZ level. Greater Taipei saw major growth in population in the western suburbs and major growth in jobs in an eastern suburb. Major suburban population growth occurred to the west of the downtown, while the downtown and the areas to the east of downtown experienced population losses. It is not surprising that the downtown lost population and many of the suburbs gained population, because housing prices are much higher in the central city than in the suburbs, pushing homebuyers to the peripheral areas. As for jobs, while the number of jobs grew throughout the region, the greatest job growth occurred in an eastern inner

suburb, Neihu, with the presence of a fast-growing major business park. Figures 5.1 and 5.2 show increases in population and job densities in TAZs beyond the downtown between the 2000 and 2009 household travel surveys.

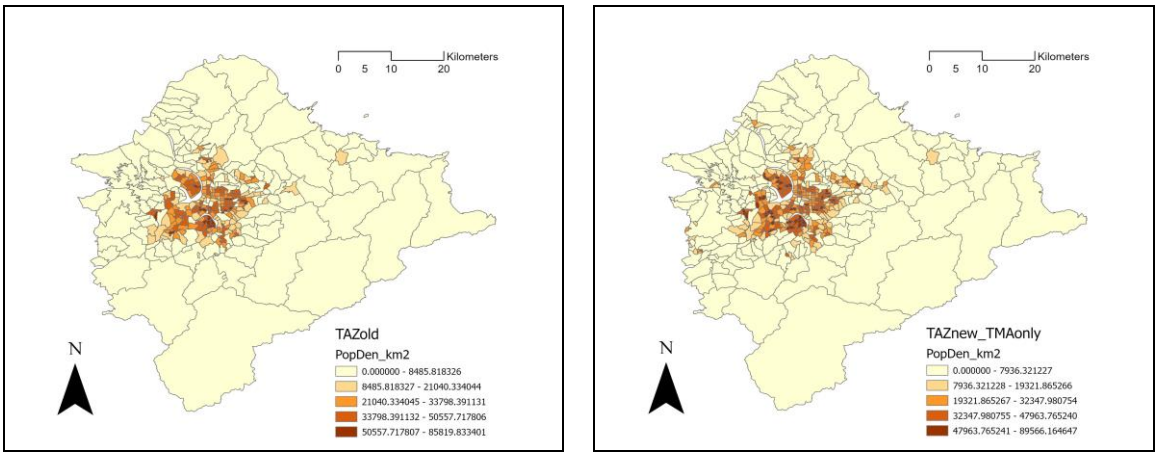


Figure 5.1: Population density (people/km^2) by TAZ during the 2000 (left) and 2009 (right) surveys

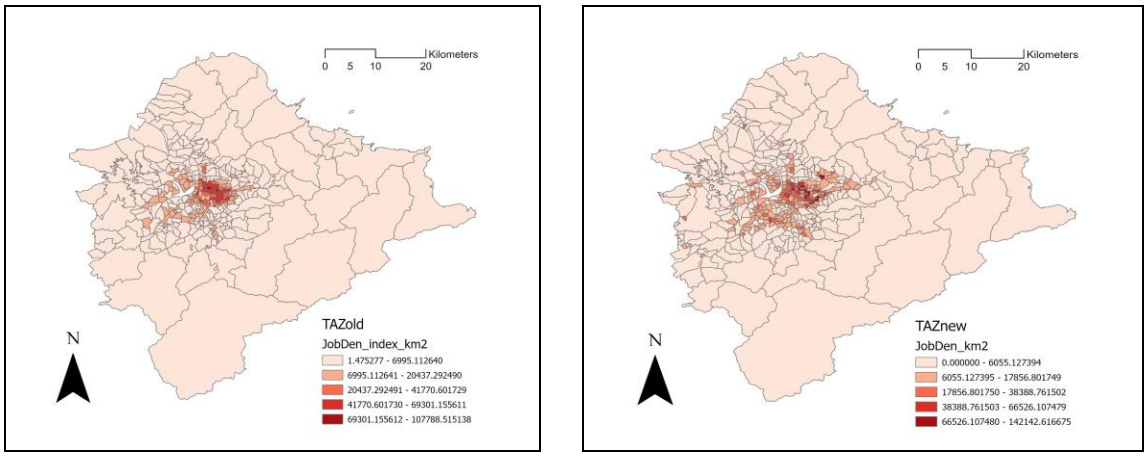


Figure 5.2: Job density (jobs/km^2) by TAZ during the 2000 (left) and 2009 (right) surveys

Metro expansion

The Taipei Metro system initially linked the downtown only with the northern and southern inner suburbs, leaving the eastern and western inner suburbs unserved until the late 2000s. The Taipei Metro expanded its network rapidly, from the initial 11 total revenue kilometers in 1996 to 146 in 2020 (see Figure 5.3). Initially, the system connected the downtown with the southern inner suburbs, the northern inner suburbs, and a northern outer suburb; a connected network first formed by joining separate lines in December 1999, and the 2000 household travel survey used in this chapter was conducted with this scope of the metro network. Then, the network expanded and first reached an eastern inner suburb in late 2000, completed most of its eastern-suburb route in 2009 just before about 90% of the trips reported in the 2009 household travel survey occurred (in other words, the 2009 household travel survey used in this chapter was mostly conducted with this scope of the metro network), and finally all of it by 2011. The network first reached a western inner suburb in 2010, and it completed its western-suburb route in 2013. The first suburb-to-suburb connection was not launched between the southern and western inner suburbs until 2020. (MOTC, 2022)

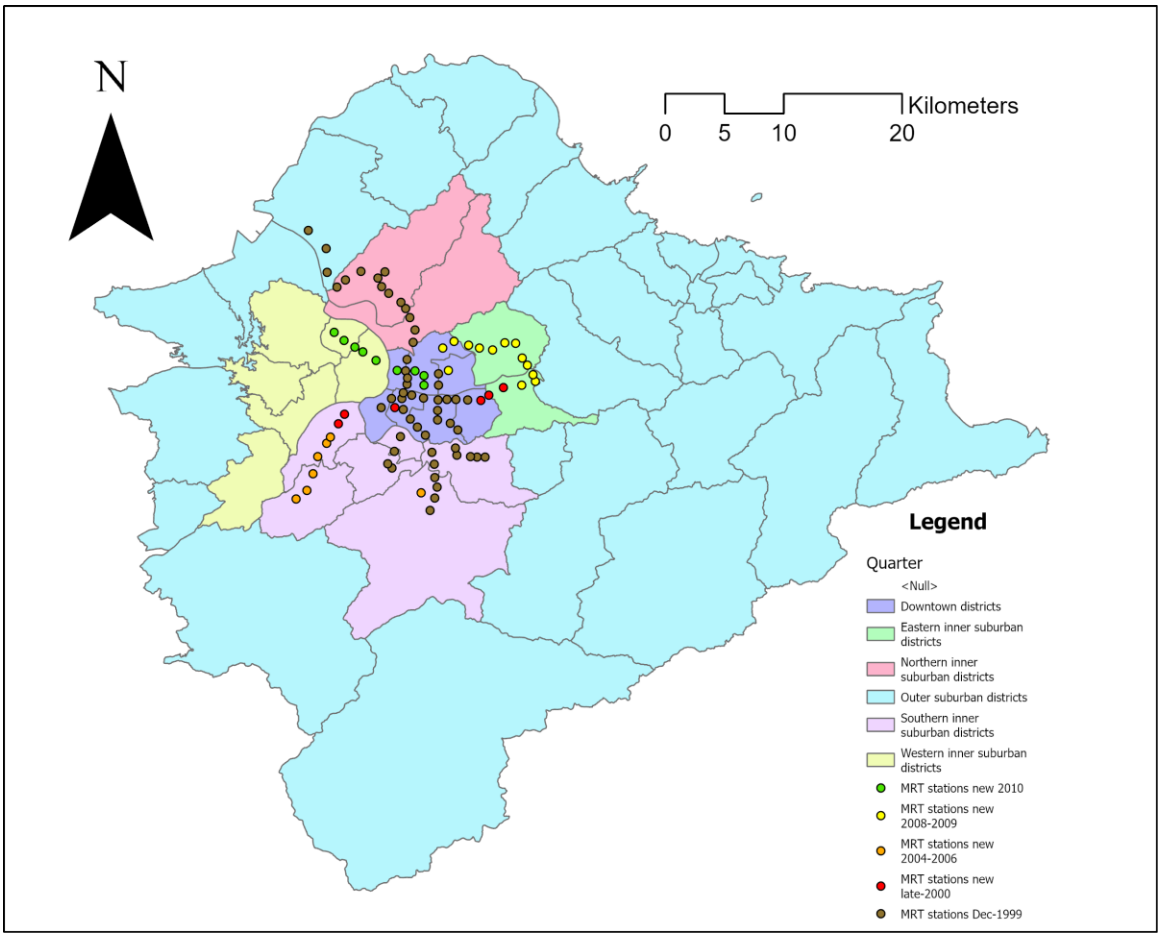


Figure 5.3: Incremental expansions of the Taipei Metro network up to November 2010 and their relationship with the quarters of Greater Taipei

5.4. Data

The data used in this chapter are pooled datasets that combine TAZ-level population and estimated employment data for 2000 and 2009 in Greater Taipei. TAZ-level population and employment are the dependent variables used in the models in this chapter, and a dummy variable representing the second time period, the year 2009, is used as a control variable in the difference-in-differences technique

of causal inference (see Section 5.5 for details). The following paragraphs describe each of the variables, and Table 5.1 provides their descriptive statistics.

Dependent variables:

Population density. Number of persons per square kilometers of a traffic analysis zone (TAZ). The population density of a TAZ is calculated based on actual population. The population of each TAZ is available from the 2000 survey but not the 2009 survey. For the 2009 TAZ population, the village population data of 2009 is purchased from the Ministry of the Interior, and then village population is aggregated into TAZ population based on the village-TAZ matching table available in the 2009 survey report. Finally, the ArcGIS Pro software is used to calculate TAZ population density as the result of TAZ population divided by TAZ total area.

Job density. Number of jobs per square kilometers of a TAZ. The job density of a TAZ is calculated using the destinations of work trips in household travel surveys as a proxy of the locations of jobs. For details on how job density is estimated, see Section 5.3.

Control variable:

The second time period. The year 2009. Because the two household travel surveys divided the Taipei Metropolitan Area into TAZs differently, this chapter uses the TAZs in the first survey as the standard and converted the TAZs in the second surveys into what is in line with those in the first. Finally, this chapter adds the dummy variable for the second survey to those TAZs in the second survey and pools the TAZs from both surveys into one dataset. A handful of TAZs in the pooled dataset have zeros in either population density or job density, and such TAZs are removed from the pooled data before the models are run.

Table 5.1: Descriptive statistics of the variables

Variable (unit)	*Pooled 2000 and 2009 data*	
	Mean	*Standard deviation*
Urban development characteristics of interest		
Population density (1,000 people/km^2)	25.13	19.33
Job density (1,000 jobs/km^2)	14.54	19.47
Time control variable		
The second time period	0.48	--

5.5. Methodology

Research hypotheses

Based on the literature review, below is the hypothesis to be tested in this chapter.

Hypothesis: Mass rapid transit investments are effective in increasing population and employment densities in the proximity of the stations.

Methodology

This chapter applies the difference-in-differences (DD) technique to make inference on the treatment effects of metro stations on urban development within their proximity. The urban development characteristics of interest, which are the dependent variables, are: (1) TAZ-level population density, and (2) TAZ-level job density. DD is an econometric technique for causal reference based on the “common trend” assumption that trends would be the same in a treatment group and a control group in the absence of the treatment, such as a policy change, and the treatment induces a deviation from this common trend

(Angrist & Pischke, 2008). DD estimates a causal effect of a treatment of interest through estimating the coefficient of the interaction term of a dummy variable for a time period after a treatment and a dummy variable for the treatment group (Wooldridge 2010; Angrist & Pischke, 2015). Since the use of the DD technique involves changes over time, this chapter pools datasets from two time periods to enable the use of DD.

The treatment effects of metro stations, both new ones introduced during the study period 2000-2009 and older pre-existing ones introduced before it, on areas in their proximity can be seen by comparison with a control group, which is the areas with no stations throughout the study period. This chapter chooses treatment and control groups based on the time of introduction of metro stations (see Figure 5.4). Instead of considering all geographies of varying built environment characteristics, this chapter chooses to limit the sample to only the more centrally located geographies so that, given population and jobs are generally more densely distributed in the central areas of the metropolis than in the outer areas (see Figures 5.1 and 5.2), they are more comparable to each other; as a result, this chapter only includes TAZs in the downtown and the inner suburbs in its designation of treatment and control groups, thereby excluding all outer-suburban TAZs except for those already served by the metro system, which are the TAZs in proximity to the three northernmost stations of the Taipei Metro that sit within an outer suburb, Tamsui District of New Taipei City. This chapter defines two treatment groups as TAZs whose centroids are located within 800 meters (half mile), a distance generally considered acceptable for a transit rider to walk instead of using other modes (Guerra et al, 2012), from metro stations introduced during the study period (“Gt”), and those within 800 meters from metro stations introduced before (“Gc”). This chapter defines one control group: TAZs whose centroids were never located within 800 meters from a metro station throughout the study period (“G0”).

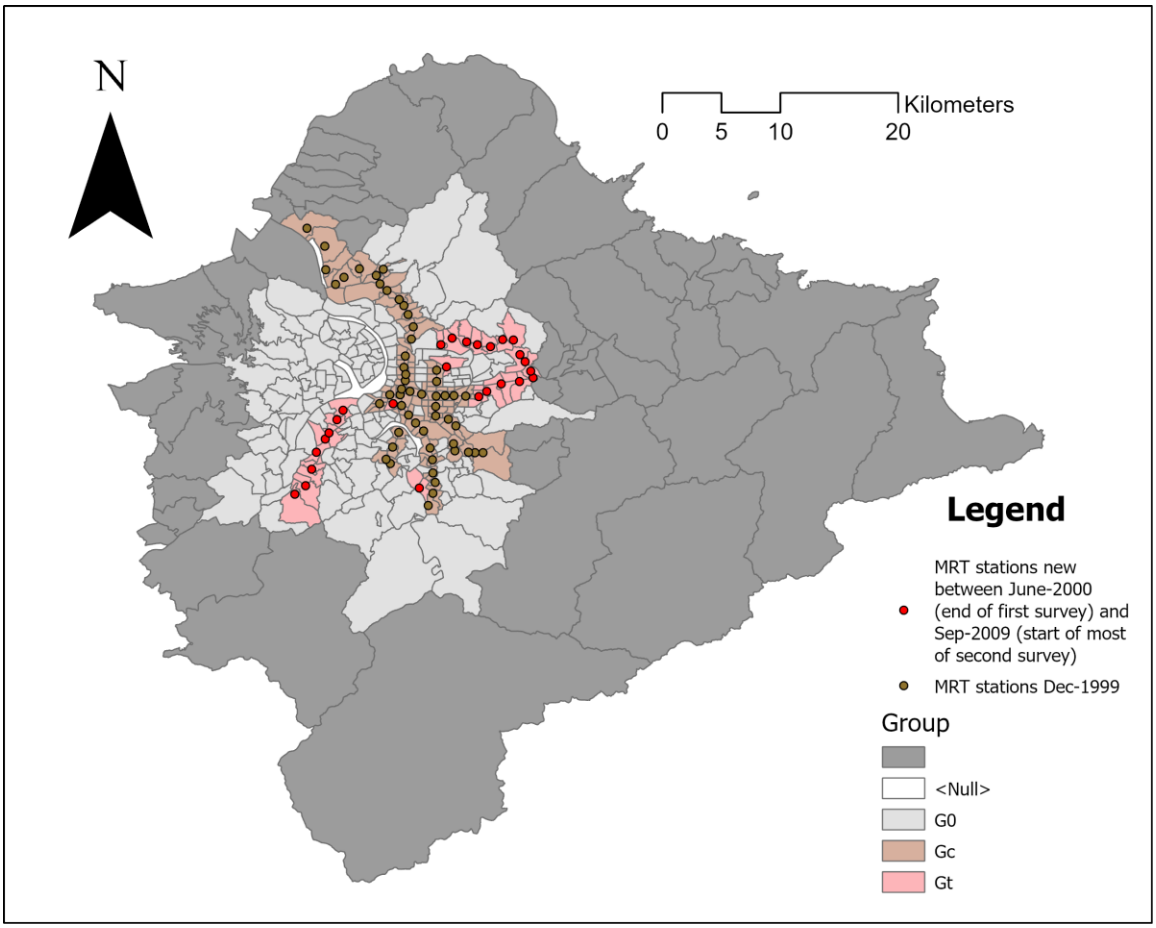


Figure 5.4: TAZs selected for trips in the treatment groups (Gt and Gc) the control group (G0) and the pre-existing and newly introduced metro (MRT) stations between 2000 and 2009

Model specifications

Ordinary least squares (OLS) regression models are estimated, within which the DD technique is employed to examine the treatment effects of metro stations on population and job densities of TAZs, the units of analysis. The OLS regression models are specified and run using the base command lm() in the R statistical software. The version of the R statistical software used is RStudio 2022.02.3 Build 492.

Equation 5.1 shows the model specification in mathematical form.

$$y = \beta_0 + \beta_1 G_t + \beta_2 G_c + \delta_0 year2 + \delta_A (G_t \cdot year2) + \delta_B (G_c \cdot year2) + u$$

(Equation 5.1.)

Where:

y = A dependent variable measuring urban development, either TAZ-level population density or TAZ-level job density,

G_t = A dummy variable capturing the difference between the treatment group of new metro stations and the control group in the absence of treatment,

G_c = A dummy variable capturing the difference between the treatment group of older metro stations and the control group with earlier treatments,

year2 = A dummy variable capturing the common difference across all treatment and control groups before and after the treatment,

δ_A and δ_B = The treatment effects of interest, and

u = An error term.

5.6. Results

The treatment effects of metro stations in affecting the population and job densities of TAZs within their 800-meter proximity are rejected by the DD models (see Table 5.2). None of the time effect, which reflects a study area-wide trend in TAZ-level population and job densities, as well as the treatment effects of older and new metro stations is statistically significant.

Table 5.2: Model results of ordinary least square regression on TAZ-level population and job densities, with the treatment effect of proximity to metro stations identified by DD estimation

	TAZ-level population density		TAZ-level job density	
	Coefficient estimate	Standard error	Coefficient estimate	Standard error
Time effect	1.96	2.20	-0.03	2.10
Treatment effect, new stations	-1.16	4.87	4.98	4.63
Treatment effect, older stations	0.83	3.31	1.97	3.15
Group effect, new stations	1.56	3.39	-1.85	3.23
Group effect, older stations	8.44	2.29 ***	14.59	2.18 ***
Intercept	20.63	1.52 ***	8.46	1.45 ***
Number of observations (N=)	606		606	
Log-Likelihood	-2638		-2609	
Adjusted R-squared	0.0431		0.1451	

Notes: Significance codes: *** p < 0.001; ** p < 0.01; * p < 0.05; . p < 0.1.

5.7. Discussion

Metro stations did not cause changes in either population density or job density at the TAZ level that are statistically significant. This is hardly surprising given the larger context (see Section 5.3) that, at the district level, there was already a disconnect between population and job growth and mass transit expansion in Greater Taipei during the study period of 2000-2009, where no linkage between transit investments and population or job changes can be observed.

The downtown-suburban gap in housing prices may have pushed home buyers to peripheral areas where the metro system has yet to reach. Housing prices are much higher in the downtown than in the suburbs of Greater Taipei (see Section 2.4). The concentration of operating metro stations in the downtown in the early years of the system may have driven up housing prices even more. In fact, the home price-to-income ratio of Taipei is among the highest in the world; an estimate gave Taipei a ratio of 35, while the highest ratio given to US cities is 10 for New York City (Numbeo, 2022). Wage growth in real terms has been slow in Greater Taipei (see Section 2.5). As a result, new housing units that emerged near new metro stations may well have become objects of investors' speculations rather than actual residences for the average home buyer. Home buyers would head for what they can really afford, that is, cheaper suburban properties, regardless of the distance from the metro system; evidence of this locational preference of home buyers is that, during the past decade, housing prices in the suburbs, despite being much lower than in the central city, have increased twice more rapidly than those in the central city (see Section 2.4).

Metro stations are mostly located in dense, hard-to-redevelop areas and thus can hardly provide room for much new development. As Cervero & Landis (1997) noted in their study on the BART system in San Francisco, the availability of vacant and developable land strongly predicts whether land-use changes occurred near transit stations. In Taipei, the concentration of operating metro stations in the downtown in the early years of the system might have somewhat boosted commercial activities around the stations, but there may not have been enough room for redevelopment in these already crowded station-proximate areas to house many new jobs. In the meantime, major employers such as IT and manufacturing companies may well have preferred spacious locations, often not close to existing metro stations. Seen beyond the study period 2000-2009, even for a longer period of 1991-2016, job growth in Greater Taipei has been driven primarily by growth in the suburbs, and all those districts in Greater Taipei that had strong job growth are either home to the CBD or business parks (see Section 2.5).

Zoning or other land use policies that accompany the transit investments may play a role as important as, if not more important than, that of transit to ignite land use changes. Research on the land value premium in the proximity of the LRT systems in Chicago and San Diego suggested that the effect may be conditional upon and due more to permissive zoning regulations or other accompanying land use policies than the transit service itself (McMillen & McDonald 2004; Duncan, 2011). This may be why transit investments in Mexico City have not had the expected effects on the downtown commercial development (Guerra, 2014b), because there have been few planning incentives to concentrate growth near station nodes (Cervero, 1998). Meyer & Miller (2001) noted that, if conducive market factors encouraging government policies are in place, rail investments affect land use by attracting potential development near stations; they also called for more research on whether a proactive land-use policy can be combined with transit investment decisions to provide a more desirable urban form, with the key to the land use/transportation strategy being probably on the land-use side.

5.8. Conclusions

This chapter makes contributions to the knowledge about the transit-development relationship. Empirical studies disagree on the effects of transit on concentrating population and employment to its proximity. Transit effects on population have been much more studied than that on employment, potentially due to the latter's rare data availability at local levels. This chapter fills these gaps in knowledge by examining the effects of mass rapid transit on urban development using Taipei, home to Taiwan's first metro system that opened in 1996, as the study context. Ordinary least squares regression models are estimated, in which difference-in-differences, an econometric method of causal inference, is employed to examine the treatment effects of metro stations on population and job densities within their proximity, with treatment and control groups of areas selected in a way that excludes outer-suburban ones for the purpose of comparability of density changes. It uses data of 2000 and 2009, the years of the two most recent large-scale household travel surveys in the Taipei Metropolitan Area for analysis to address the unavailability of employment statistics at the neighborhood level.

Findings suggest that the treatment effects of metro stations in affecting the population and job densities of traffic analysis zones (TAZs) within their 800-meter proximity are rejected by the models, and that none of the time effect, which reflects a study area-wide trend in TAZ-level population and job densities, as well as the treatment effects of older and new metro stations was statistically significant.

The main takeaway for research from this chapter, which is also where its academic novelty lies, is that it rejects the hypothesis that transit can affect urban development, sustaining the academic quest for the transit-development relationship. The theoretical expectation of this chapter is that mass rapid transit investments are effective in increasing population and employment densities in the proximity of the stations. Findings reject such a hypothesis, presenting evidence that policymakers should not expect transit systems alone to affect urban development and that the disconnect between transit investments and urban development changes should be remedied by intentional planning measures that concentrate population and jobs to the proximity of metro stations.

The main takeaway for policy from this chapter is that land use policy in cities with metro systems should focus on proactive densification around metro stations. Because transit systems alone cannot be expected to affect urban development, only intentional planning measures can concentrate population

and jobs to the proximity of metro station, thereby increasing metro ridership and station-adjacent property values and therefore the return on transit investments and economic development.

A major limitation of this chapter is its use of a short study period. Future research on transit effects on urban development should use longer study periods. Urban development effects may take several years if not decades to become observable. However, due to data availability, this chapter is only able to obtain household travel survey data from 2000 and 2009 to examine the neighborhood-level population and employment impacts of metro stations. Future research should benefit from the availability of more recent data so that a longer period supported by more than two household travel surveys can be used to examine the effects of metro stations.

CHAPTER 6: CONCLUSIONS

6.1. Summary of key findings

This dissertation explores the relationship between motorcycle travel and the built environment, the mass transit effects on motorcycle travel, and the mass transit effects on urban development between 2000 and 2009 in the Taipei Metropolitan Area, Taiwan. Firstly, the relationship between motorcycle travel and the built environment was studied. The motorcycle travel characteristics of interest were: (1) household vehicle ownership, (2) mode choice in a trip, and (3) household motorcycle vehicle kilometers traveled (VKT). Findings suggest:

- Being farther from the CBD and from metro stations are correlated with higher household motorcycle ownership levels, higher likelihood of motorcycle mode choice, and higher household motorcycle VKT.
- Higher population density is correlated with higher likelihood of motorcycle mode choice and higher household motorcycle VKT.
- Lower job density is correlated with higher household motorcycle ownership levels and higher household motorcycle VKT.
- Lower income is correlated with higher likelihood of owning motorcycles but no cars, higher motorcycle mode choice likelihood, and lower household motorcycle VKT.

Secondly, the mass transit effects on motorcycle travel were studied. The motorcycle travel characteristics of interest were: (1) mode choice in a trip, and (2) household motorcycle VKT. Findings suggest:

- Both newly introduced metro stations and older pre-existing ones were effective in reducing the motorcycle mode choice odds relative to that of the metro for trips originating in their proximity.
- Both new and older metro stations were effective in reducing household motorcycle VKT in their proximity.

Lastly, the mass transit effects on urban development were studied. The urban development characteristics of interest were: (1) population density of a traffic analysis zone (TAZ), and (2) job density of a TAZ. Findings suggest:

- Neither newly introduced metro stations nor older pre-existing ones were effective in affecting the population density or the job density of TAZs in their proximity.

To sum up, this dissertation finds that motorcycle travel is generally correlated with high population density, low job density, long distance from downtown, and long distance from metro stations, that the metro system reduces motorcycle travel around stations, and that the metro system does not affect population or job densities around stations.

6.2. Policy implications

Transportation and land use

Transportation policy in Greater Taipei should continue to expand the metro network and enhance intermodal transportation connections with the metro, including bus services, cycling and pedestrian infrastructure, to reduce motorcycle ownership and use. An expanding metro system shortens distances from high-capacity transit and can disincentivize motorcycle ownership, mode choice, and VKT. New metro lines should be built to serve existing population clusters and suburban employment centers. As the effects of metro stations in encouraging the mode choice of the metro over the motorcycle are likely to exist, the ease of access to the stations should be improved; and public buses, bicycle lanes, and sidewalks with improved connectivity with the metro will serve well commuters who use the metro to go to work, who may therefore find it unnecessary to own and use motorcycles.

Land use policy in Greater Taipei should develop suburban employment centers near key metro stations and concentrate population to the proximity of metro stations. Policy-makers should not expect transit systems alone to affect urban development, and that the disconnect between transit investments and urban development changes should be remedied by intentional planning measures that concentrate

population and jobs to the proximity of metro stations. A continued modal shift from the motorcycle toward the metro can be expected as an increasingly large share of the population live near metro stations. Suburban employment centers near metro stations should make going to work by the metro, by bus, by bicycle, or even on foot viable to a larger portion of the metropolitan population, and thus this will reduce the necessity of owning motorcycles.

All in all, to alleviate the harms brought by motorcycles to Greater Taipei, transportation and land use policies should be organized under the umbrella of one overarching concept: transit-oriented development (TOD).

Transit-oriented development

Transit and land use can work together in the form of TOD to affect travel behavior. TOD is a particular form of growth that takes place around transit stations. TODs are dense, mixed-use, and walkable nodes on transit networks that encourage transit use and discourage vehicle travel. TOD is supported by a growing literature that confirms its effectiveness in reducing vehicle dependence. On vehicle ownership, Thrun et al (2016) found that jurisdictions with TOD zoning had significantly higher percentages of occupied housing with no vehicle than those without TOD zoning. Much more research focuses on vehicle use. Arrington & Sloop (2009) found that the Institute of Transportation Engineers (ITE) trip generation rate overestimates automobile trips for TOD housing by approximately 50%; they were joined by Tian et al (2016) who studied Redmond, Washington and found the TOD areas there have actual vehicle trips that are only 37 % of the ITE expected value. Nasri & Zhang (2014) found that people living in TOD areas tend to drive less, reducing their vehicle miles traveled (VMT) by around 20% in Washington, D.C. and 21% in Baltimore, compared to the residents of the non-TOD areas even with similar land use patterns. Park et al (2018) found that TOD motivates residents to drive less, and that vehicle use is associated with land-use diversity and street network design of a station area. Chatman et al (2019) found that, when living in TODs, higher income households reduce VMT more than do poorer households. Nasri & Zhang (2019) found that the probability of choosing transit and non-motorized modes

is higher for trips originating and ending in TOD areas, that the magnitude of this TOD effect is larger at trip origin compared to destination, and that higher residential and employment densities at both ends of a trip are also associated with lower probability of automobile mode choice and higher probability of transit and non-motorized mode choices.

The academic literature on transportation in Asian and Global South cities with high rates of motorcycle ownership supports the application of the TOD concept. The need to travel for a long time leads to the preference of motorcycles over bicycles in cities like Kuala Lumpur (Yamamoto, 2009). The lack of improvements in the integration of transportation and surrounding land uses or the quality of the pedestrian environment would force suburban residents to turn to private motorcycles as incomes allow (Cervero et al, 2017). Land use and infrastructure supply measures have good predictive power for motorcycle use in Mumbai, meaning that such policies can impact motorcycle use (Shirgaokar, 2016). Research in Vietnam also suggested that walking activities are correlated with the intentions of transit use (Hoang & Okamura, 2020). Good pedestrian infrastructure with good penetration into residential areas should be provided to meet the first- and last-mile travel needs between home and metro stations.

However, it cannot be expected that transportation and land use policies alone can shift motorcyclist travel behavior massively. Research in Taipei suggested that past overindulging of motorcycle use may have raised the dependence on motorcycles, which might result in inefficiency in subsequent investments in public transportation, as even in Taipei where mass public transit and bus services have been established, operated, and intensively promoted, the high dependence on motorcycles has remained hard to change, and a significant proportion of travelers would not switch from motorcycles to public transportation (Chang & Wu, 2008). Policies that increase the cost of motorcycle travel relative to other means of transportation are thus as important as, if not more important than, transit investments.

Pricing on motorcycle parking

Regulatory approaches could be taken to price motorcycle parking, and measures to boost its political feasibility are readily available.

Three primary economic factors influence mode choice for a given trip: the income of the traveler, the travel time, and the monetary costs of travel. Not all these factors can be affected by policies for motorcyclists. The modest income of many motorcyclists is known as a given that determines their mode choice of motorcycles instead of cars or transit. The travel time advantage of motorcycles is also impossible to change due to their small size and easy maneuverability unless finding a space for parking is made more time-consuming. The monetary costs of motorcycle travel are surely something that policies can affect.

One approach to influencing the monetary costs of motorcycle travel is pricing on motorcycle parking, particularly by-the-hour pricing. Motorcycles have become a preferred mode in Asia because of easy parking which help save time and money (Chiu & Tseng, 1999; Law et al, 2015; Guerra, 2017), and in Taipei it has been easier to find a free motorcycle parking space than a free or even paid but cheap automobile parking space (Chang & Wu, 2008). Charging motorcycle parking can change this, and that can begin with introducing by-the-hour parking charges for all vehicles in a city including motorcycles. Per-day parking fees are not enough to reflect the consumption of land value by parked vehicles and are also not enough to increase the turnover at parking spaces, resulting in ever-increasing difficulty for motorcyclists to find a parking space as spaces are filled by ever-increasing motorcycles. Pricing on street parking can be set at such a level that keeps occupancy at approximately 85%, maintaining a few vacant spaces so that everyone can see that convenient parking is still available everywhere (Shoup, 2005). The ability of the by-hour motorcycle parking charge to generate more available spaces for all, if well communicated to the public, is itself a persuasive point for the political feasibility of the policy. Furthermore, returning the on-street motorcycle parking meter revenue to the neighborhoods that generate it will make the policy politically popular, and it is socially equitable because users of the motorcycle parking spaces pay to benefit the neighborhoods. Residents in eligible areas can purchase on-street motorcycle parking permits that exempt them from the by-hour meter charging. While these permits assist residents in finding parking spaces near their homes, enhancing the quality of life in

residential areas with insufficient on-street parking, the likely effects are that few residents would buy the permits and many would shift to other modes such as walking, cycling and transit, therefore owning fewer motorcycles in the longer run (Shoup, 2005). Research in Taiwan advocated policies on parking charges at metro stations for the purpose of effective parking demand management (Wen et al, 2012).

6.3. Areas for future research

The applicability of the findings about the relationship between the built environment from this dissertation using Taipei as case study to other cities is currently unknown, not only because the findings reject most of the literature-based hypotheses but also because Taiwan is an obvious outlier in terms of income level and population density among countries with higher (more than 100) motorcycle-to-population ratios (see Figure 6.1); nevertheless, as countries' income levels increase, more metro systems can be expected to be adopted in their cities, and the experience of Taipei as one of the earliest motorcycle-stressed cities that has adopted a metro system can provide useful lessons. Future research can prioritize cities with the most comparable built environment, socioeconomic, and transportation characteristics (precisely, the modal share of the motorcycle and the length of history of their metro systems), such as Bangkok and Kuala Lumpur, to see if findings are similar with those in Taipei.

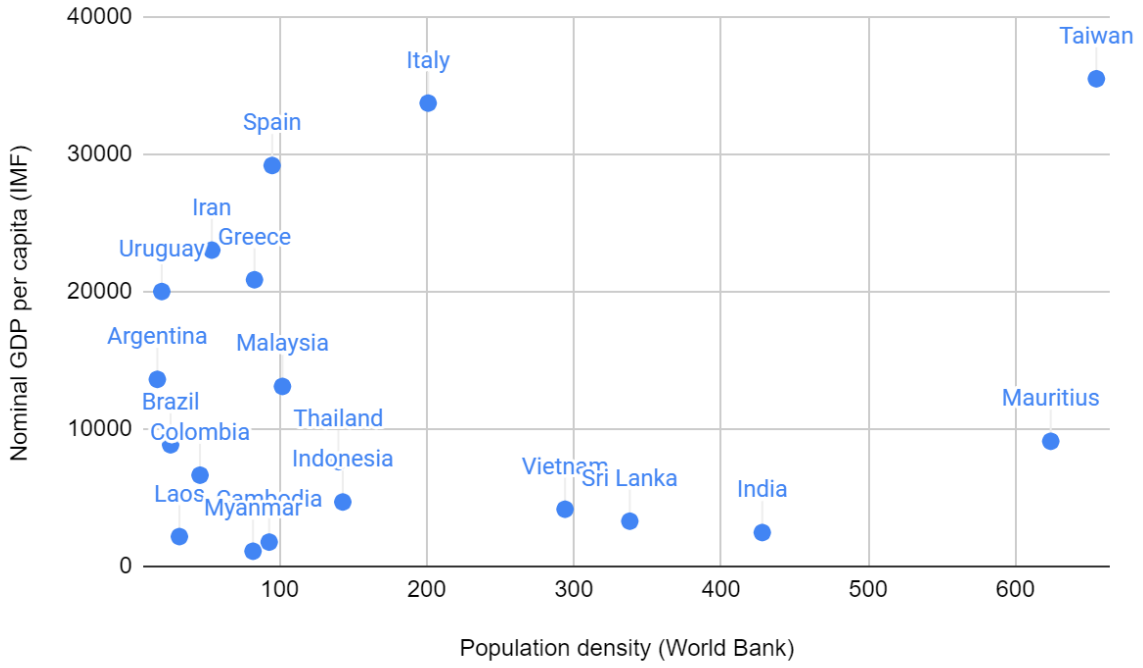


Figure 6.1: Income level and population density of countries with more than 100 motorcycle-to-population ratios

Future research on mass transit effects on motorcycle travel and urban development should use longer study periods. Travel and development effects may take several years to become observable. However, due to data availability, this dissertation was only able to obtain data from 2000 and 2009 in order to examine the impacts of metro stations. Future research should benefit from the availability of more recent data so that a longer period supported by more than two household travel surveys can be used to examine the effects of metro stations.

Lastly, it is not impossible that questionnaire-based household travel surveys will be replaced in the future by the use of travel data collected through connected mobile devices. What unanswered research questions could be answered through the use of such data? How should the data be reorganized for the purpose of analysis? What data analysis techniques are appropriate? Technical issues like these, if not also ethical and legal issues, await further exploration.

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