Inequality in Shared Micromobility: Global, National, and Local Perspectives

by

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DISSERTATION ABSTRACT

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Title: Inequality in Shared Micromobility: Global, National, and Local Perspectives

Shared micromobility systems, such as shared bicycles and e-scooters, have seen substantial global growth over the past decade. Although these systems offer affordable, flexible, and environmentally friendly transportation options, their rapid proliferation has raised significant equity concerns. The unequal distribution of shared micromobility services may limit access for the transportation disadvantaged, which could exacerbate the inequalities in the existing transportation system. This dissertation examines inequalities in shared micromobility through three studies at global, national, and local scales.

The global-level study utilized world city theory to analyze the establishment and expansion of shared micromobility companies worldwide and employed mixed methods to explain what leads to the inequality in system distribution across cities. This study reveals that shared micromobility industries are associated with the world cities of ride-hailing, advanced producer services, and startups. Factors such as low demand for shared micromobility, unfriendly regulatory environments, and negative public and governmental attitudes towards shared micromobility are the major barriers to the adoption of shared micromobility systems at the city level.

The national-level study examines the effects of policies aimed at equalizing resources and opportunities on vehicle and trip inequalities within shared micromobility systems in the US. Resource-equalizing policies for shared micromobility aim to equalize the distribution of shared micromobility vehicles, which directly alleviates inequalities in vehicle distribution and

indirectly lessens trip distribution inequalities. In contrast, opportunity-equalizing policies subsidize people with less capability to use shared micromobility, such as low-income, unbanked, and non-tech-savvy people. However, policies for equal opportunity are less effective in addressing inequalities in shared micromobility.

The local-level study investigates the impact of introducing shared e-scooters on existing transportation modes—bikeshare, railway, bus, taxi, and ride-hailing—in Chicago's transportation equity priority areas, where residents face increased mobility barriers. The introduction of shared e-scooters results in distinct effects on different transportation modes between equity priority and non-equity priority areas. In the equity priority area, shared e-scooters significantly boost bikeshare usage and reduce taxi usage. In contrast, in the non-equity priority area, shared e-scooters notably reduce trips by bikeshare, railway, and taxis, but increase ride-hailing trips.

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To my wife and parents.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 16

1.1. Research Context 16

1.2. Research Gaps in the Literature 20

1.3. Research Aims and Scopes 23

1.4. Structure of the Dissertation 25

II. GLOBAL PERSPECTIVE 26

2.1. Introduction 26

2.2. Literature Review 30

2.2.1. From Classical Foundations to New Economic Geography and Beyond 30

2.2.2. World City Theories 32

2.2.3. Inequality in Shared Micromobility Service Geography among Cities 35

2.3. Methods 38

2.3.1. Study Design 38

2.3.2. World City Analysis 41

2.3.3. Qualitative Data and Analysis 45

2.3.4. Quantitative Data and Analysis 47

2.4. World Cities of Shared Micromobility 51

2.4.1. The Headquarters of Top 30 Shared Micromobility Companies 51

2.4.2. World City Network of Shared Micromobility 57

2.5. The Inequality in Shared Micromobility Systems 59

2.6. Factors Impacting the Unequal Distribution of Shared Micromobility Systems 63

Chapter Page

2.6.1. Demand-related Factors 64

2.6.2. Regulatory Environment 68

2.6.3. Clutter, Parking Non-compliance, Safety Concerns, and Insufficient Infrastructure 70

2.6.4. The Coalition between Groups with Opposite Interests 73

2.6.5. The Absence of Active Transportation in Long-term Planning 75

2.7. Conclusions 76

III. NATIONAL PERSPECTIVE 80

3.1. Introduction 80

3.2. Literature Review 84

3.2.1. Equity as Distributive Justice 84

3.2.2. Equity Principles in Transportation Planning 85

3.2.3. Strict Egalitarianism versus Luck Egalitarianism 87

3.3. Theoretical Framework 89

3.4. Methods 95

3.4.1. Study Area 95

3.4.2. Data Collection 97

3.4.3. Structural Equation Modeling 99

3.5. Results 103

3.5.1. The Characteristics of Shared Micromobility Equity Policies in the US 103

3.5.2. The Inequalities in Shared Micromobility Systems in the US 105

3.5.3. The Associations between Equity Policies and Inequalities 110

3.6. Discussion and Policy Implications 112

Chapter Page

3.7. Conclusions 120

IV. LOCAL PERSPECTIVE 121

4.1. Introduction 121

4.2. Literature Review 122

4.2.1. Surveys 123

4.2.2. Cross-sectional GIS-based Studies 126

4.2.3. Experimental Studies 130

4.2. Theoretical Framework 131

4.3. Methods 133

4.3.1. Study Area and the 2019 E-scooter Pilot Program 133

4.3.2. Data, Analysis Units, and Variables 136

4.3.3. Geographic Analysis 140

4.3.4. PSM-DID Analysis 141

4.3.5. Statistical Tests 143

4.4 Results 144

4.4.1 Where Were Trips Before Scooters Came to Chicago? 144

4.4.2. The Effects of Scooters on Trips by Existing Modes 147

4.5. Discussion 149

4.5.1. Shared Micromobility 149

4.5.2. Public Transit 151

4.5.3. For-hire Motorized Mobility 153

4.5.4. Limitations 154

Chapter Page

4.6. Policy Recommendations 155

4.6.1. Shared Micromobility 155

4.6.2. Public Transit 156

4.6.3. For-hire Motorized Mobility 157

4.7. Conclusions 158

V. CONCLUSIONS 160

APPENDICES 163

Appendix A. Interview Guide for City Staff and Scholars 163

Appendix B. Interview Guide for Employees in Shared Micromobility Companies 165

Appendix C. The Relations Between Variables in the Structural Equation Model 166

Appendix D. Equitable Transportation Policies and Programs Implemented in Chicago 167

Appendix E. The Characteristics of Neighborhoods in Chicago 169

Appendix F. Average Weekly Trips of Different Transportation Modes 172

Appendix G. Balancing and Common Support Tests 175

Appendix H. Kernel Density Analysis 177

Appendix I. Common Trend Tests 179

REFERENCES 182

LIST OF FIGURES

Figure Page

1-1. The research scopes of inequality studies in transportation 18

1-2. The research scopes of equity studies in transportation 19

2-1. Procedural framework 41

2-2. World cities of shared micromobility 53

2-3. World cities of ride-haling, global advanced producer services, and startups 54

2-4. Locations of regional offices of shared micromobility 57

2-5. The distribution of shared micromobility by county 60

2-6. The frequency by the number of systems for cities worldwide 61

2-7. City-level characteristics by the presence of a shared micromobility system 63

3-1. Shared micromobility ridership in the U.S. and Canada, 2010-2022 81

3-2. The illustration of luck egalitarian objectives with two policy scenarios 90

3-3. The illustration of luck egalitarian objectives with the effort of constant 92

3-4. The illustration of the theoretical framework and empirical model 94

3-5. Cities with general bikeshare feed specification 96

3-6. The illustration of the algorithm calculating aggregated vehicles and trips 98

3-7. Path diagram for structural equation modeling 100

3-8. Availability of equity requirements and types 104

3-9. Program counts by the number of equity requirements 105

3-10. The scatter plot between Gini coefficients 106

3-11. Inequalities by the presence of equity requirements 108

3-12. Inequalities by system types 108

Figure Page

3-13. The scatter plot between Gini coefficients and covariates 109

3-14. Results of the structural equation modeling 110

3-15. The number of equity requirements by system type 117

4-1. Potential interactions between shared e-scooters and existing travel modes 133

4-2. Study area and analysis units 136

4-3. Timeline of e-scooter pilot program and data collection 137

4-4. The spatial distribution of ridership of transportation modes 146

F-1. Average weekly trips by bikeshare 173

F-2. Average weekly trips by railway 173

F-3. Average weekly trips by bus 173

F-4. Average weekly trips by ride-hail 174

F-5. Average weekly trips by taxi 174

G-1. The balancing and common support tests, bikeshare 175

G-2. The balancing and common support tests, railway 176

G-3. The balancing and common support tests, bus 176

G-4. The balancing and common support tests, taxi and ride-hail 176

H-1. Kernel density of the propensity score, bikeshare 177

H-2. Kernel density of the propensity score, railway 177

H-3. Kernel density of the propensity score, bus 178

H-4. Kernel density of the propensity score, taxi and ride-hail 178

I-1. Results of parallel trend test after propensity score matching, bikeshare 179

I-2. Results of parallel trend test after propensity score matching, railway 179

Figure Page

I-3. Results of parallel trend test after propensity score matching, bus 180

I-4. Results of parallel trend test after propensity score matching, ride-hail 180

I-5. Results of parallel trend test after propensity score matching, taxi 181

LIST OF TABLES

Table Page

2-1. Descriptions of variables for world city analysis 42

2-2. The top thirty shared micromobility companies 43

2-3. Descriptions of qualitative data in this study 46

2-4. Themes and potential codes 47

2-5. Descriptions of variables for the regression analysis 49

2-6. Factors associated with the number of shared micromobility systems 65

3-1. Descriptions of data applied in this study 98

3-2. The descriptives of Gini coefficients of vehicles and trips and covariates 105

3-3. Model fit indices.....110

3-4. The estimated parameters of the structural equation model.....111

4-1. Share of trips replaced by shared e-scooters by transportation modes 124

4-2. Descriptions of data applied in this study 137

4-3. The specification of dependent variables for research questions.....139

4-4. Bivariate Moran's I analysis of trips by transportation modes in Chicago 147

4-5. Impacts of shared e-scooters pilot on weekly trips 148

D-1. Equitable transportation policies and programs implemented in Chicago.....167

E-1. Summary statistics of block-group level neighborhood characteristics.....170

CHAPTER I

INTRODUCTION

> Infinite faraway lands and countless faraway people are all connected to me.
>
> -Lu Xun, *This, Too, Is Life*

> Two things fill the mind with ever new and increasing admiration and awe, the oftener and the more steadily we reflect on them: the starry heavens above and the moral law within.
>
> -Immanuel Kant, *Critique of Practical Reason*

> The creed which accepts as the foundation of morals, Utility, or the Greatest Happiness Principle, holds that actions are right in proportion as they tend to promote happiness, wrong as they tend to produce the reverse of happiness. By happiness is intended pleasure, and the absence of pain; by unhappiness, pain, and the privation of pleasure.
>
> -John Stuart Mill, *Utilitarianism*

1.1. Research Context

Shared micromobility systems, such as public bikeshare and shared e-scooters, have experienced rapid global proliferation since 2016 (Abduljabbar et al., 2021; O'Brien et al., 2022). Defined as the low-speed, short-term access, and as-needed transportation mode (Shaheen & Cohen, 2019), shared micromobility can provide solutions for mid-range travel (1-3 miles) and address the "last mile problem" by connecting users to the broader transportation network (Jiao & Bai, 2020; Shaheen & Chan, 2016). Research suggests that shared micromobility may offer affordable, convenient, and healthy travel alternatives for individuals (Chen et al., 2020), mitigate the negative impacts of motorization on our cities (Liao & Correia, 2022), and

contribute to achieving sustainability goals (Olabi et al., 2023).

However, a comprehensive review shows that shared micromobility services are concentrated in white and affluent communities, and disadvantaged people, such as low-income and minority groups, are excluded from these shared micromobility systems (Dill & McNeil, 2020). Unequal distribution of shared micromobility may lead to limited access to this new transportation service for certain social groups in certain areas. Then, integrating shared micromobility into the urban transportation system may not be able to address but exacerbate the existing inequalities in transportation. For instance, deploying shared micromobility vehicles in areas with existing transit services could facilitate the use of public transit by addressing the first-/last-mile problem, but it will increase the gap in ridership between transit-rich areas and transit deserts. The inequalities in shared micromobility and transportation are contrary to the United Nations' Sustainable Development Goal 11: "Make cities inclusive, safe, resilient and sustainable (United Nations, 2015)."

Therefore, many transportation studies focused on inequality and equity issues in shared micromobility, aiming to provide policy recommendations for creating more just and inclusive shared micromobility systems. Before identifying the research gaps in the literature on inequality in shared micromobility, it is necessary to differentiate the inequality and equity studies in transportation as these terms are used in a typically haphazard manner across different disciplines. Inequality studies in transportation tend to be *positive*[1], focusing on the *distribution* of transportation benefits and/or harms as well as the determinants and influences of the unequal

[1] It should be noted that the concepts of inequality or equality can have normative connotations, such as formal equality and substantive equality. However, "inequality" in this dissertation denotes unequal distribution among populations or geographic areas. This definition can better differentiate equality and equity for this dissertation to avoid misconceptions.

distribution, without a clear normative framework evaluating the distribution pattern (Figure 1-1). For instance, many studies on inequality in shared micromobility focus on the unequal distribution of shared micromobility vehicles among communities, the effects of neighborhood-level factors on the distribution pattern (determinant), and the impacts of distribution patterns on physical activity levels (influence).

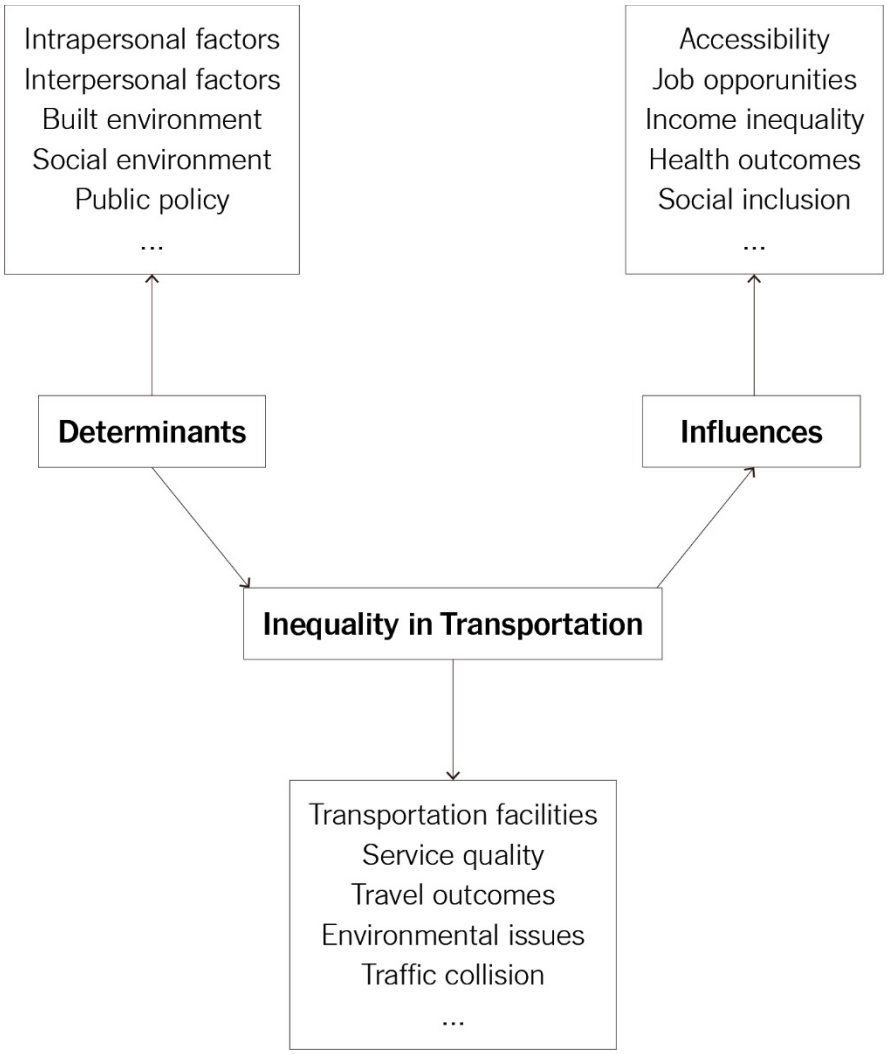


Figure 1-1. The research scopes of inequality studies in transportation.

Note: the arrows in this diagram are equivalent to those in the path diagram of the structural equation modeling.

By comparison, equity studies in transportation tend to be *ethical*, focusing on the principles for transportation planning, the fundamental normative principles, and the applications of equitable principles in the specific planning or policymaking process (Figure 1-2). For instance, sufficientarianism is a normative theory of distributive justice, focusing on the identification of a threshold for distributing goods and services and prioritizing people below this threshold (Crisp, 2003). Sufficient accessibility is a transportation equity principle derived from sufficientarianism, which utilizes the indicator of accessibility to identify the transportation poverty line (Martens et al., 2014). Based on this transportation equity principle, transportation and land use policies and projects should enhance accessibility levels for people below the accessibility poverty line.

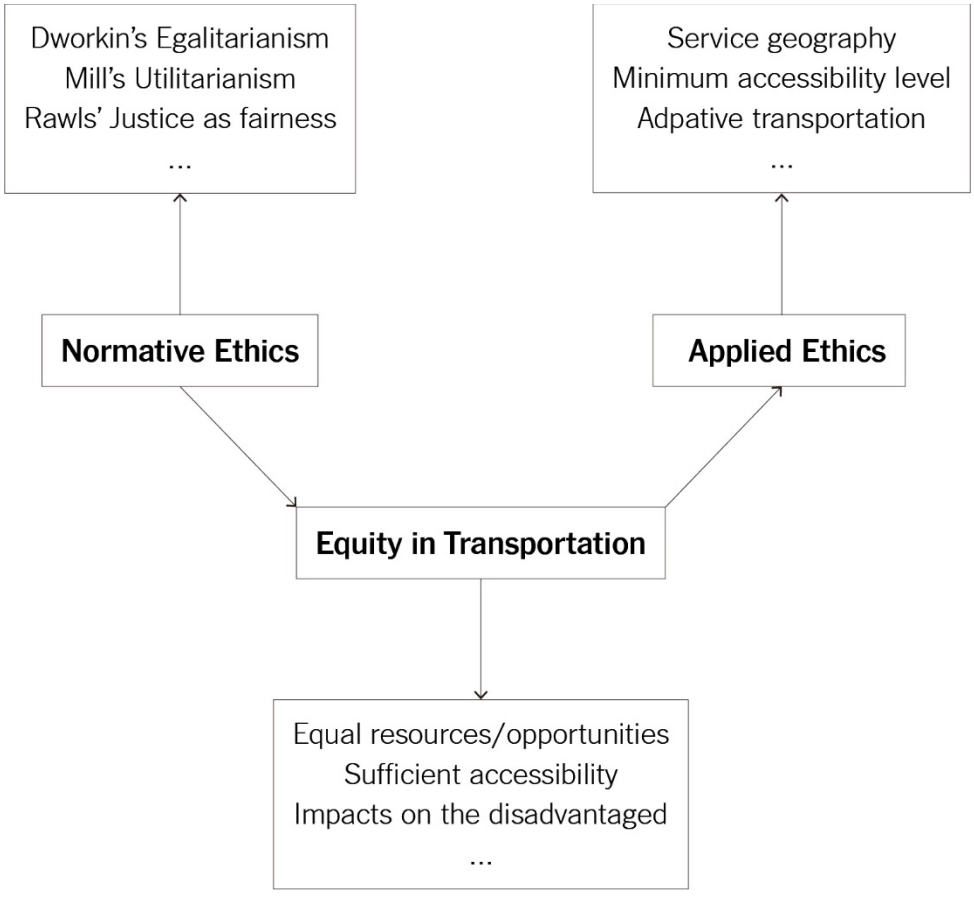


Figure 1-2. The research scopes of equity studies in transportation.

Note: the arrows in this diagram are equivalent to those in the path diagram of the structural equation modeling.

Additionally, inequality and equity in transportation are deeply related to each other in academic studies and planning practice. Certain equity principles and policies can yield specific implications for the distribution of transportation resources and travel outcomes, which may alleviate or aggravate the inequality in transportation. On the other hand, examining the influences of inequality in transportation can help researchers and policymakers rethink the preferred equity planning principles. Investigating the causes of inequality in transportation enables practitioners to develop effective policies and programs for managing the inequalities.

This dissertation, as illustrated by the title, focuses on inequality rather than equity in shared micromobility. Therefore, this dissertation does not aim to provide normative guidance for policymakers and practitioners on how transportation equity policies and requirements *should* be developed, nor does this study attempt to identify the *most equitable* transportation policies and practices. Instead, the goal of this dissertation is to ascertain the *causes of inequalities* in shared micromobility and *the ways* of mitigating these inequalities. Once the policymakers have established clear equity goals and objectives, the findings of this dissertation can contribute to making specific transportation policies and programs to manage the inequalities in shared micromobility for realizing these equity goals.

1.2. Research Gaps in the Literature

Most studies on inequality in shared micromobility are empirical, investigating the distribution of shared micromobility services (e.g., bikeshare stations, vehicles, and micromobility facilities) and travel outcomes (e.g., trip frequency, travel distance, and travel

time) among different demographic groups and communities. These studies typically adopt the socio-ecological model, which posits that travel behaviors are influenced by multi-level factors: individual characteristics, social environment, built environment, and policies (Sallis & Owen, 2015). By controlling covariates, researchers can isolate how specific sociodemographic, economic, or environmental factors affect transportation services or travel outcomes. Additionally, qualitative research through interviews and focus groups has delved deeper into the barriers to accessing shared micromobility (Fishman et al., 2012; McNeil et al., 2018; Pimentel & Lowry, 2020; Sanders et al., 2020), providing complementary insights into the causes and consequences of inequalities in micromobility.

However, research on the diffusion of shared micromobility systems at the city level remains limited. In studying the development of shared micromobility systems, scholars have mostly examined the historical evolution of these systems (DeMaio, 2009; Fishman, 2016) and proposed future deployment and expansion strategies (Dehdari Ebrahimi et al., 2021; Tan & Tamminga, 2021), rather than exploring service geography across cities or regions. The rapid development of shared micromobility has been largely driven by the private sector, requiring close partnerships between companies and local municipalities (Rane, 2022). For shared micromobility expansion to occur in underserved areas, transportation professionals, operators, and cities should understand what leads to inequality in system distribution and address gaps between service provision and local needs.

Despite numerous equality studies highlighting the impact of inequality in car or public transit access (Currie & Delbosc, 2010; Mattioli, 2021; Smart & Klein, 2020), the implications of unequal distribution in shared micromobility require further investigation. Shared micromobility is often lauded for bridging first/last-mile gaps for public transit, yet many conclusions are

speculative, based on the free-floating feature, travel distance, and bikeshare-transit station proximity (Shaheen & Chan, 2016a; Witzel, 2018). While GIS-based and stated preference studies have suggested that shared micromobility can connect with public transit (Kong et al., 2020; McQueen & Clifton, 2022; Oeschger et al., 2020, 2023), recent studies indicate that inferred transit-connecting trips may be inaccurately estimated (Yin et al., 2024). Also, these studies did not investigate how the distribution of shared micromobility services and trips led to where the connecting trips happened and who used shared micromobility for transit connections.

Additionally, recent studies have explored equity policies and requirements for shared micromobility (Brown & Howell, 2024; McNeil et al., 2019; Riggs et al., 2021), which aim to address equity issues by managing inequalities in shared micromobility systems. However, most shared micromobility programs do not establish a clear evaluation framework to examine the performance of these equity policies and requirements. Even though transportation equity scholars have discussed the fundamental equity principles (i.e., normative principles) (Banister, 2018; Martens, 2017; Pereira, 2018), a significant gap remains in translating these principles into specific frameworks for developing or evaluating transportation policies. Cross-cutting research between inequality and equity in shared micromobility is almost absent, and rare in other transportation fields. For instance, Golub and Martens (2014) applied the access poverty line to evaluate how two regional transportation plans addressed gaps between transit and automobile access. Singer et al (2023) developed the Accessibility Sufficiency Index to assess the equity performance of public transit job accessibility in U.S. metropolitan areas. These studies set clear standards for evaluating equity based on the principle of sufficientarianism, which can determine whether the current inequality in transportation is acceptable and whether the effects of equity policies and programs are desirable. Nevertheless, even though most shared micromobility

systems have incorporated equity policies or requirements (Brown & Howell, 2024; Riggs et al., 2021), the evaluation framework for these policies is absent. It is unclear how and to what extent these policies can impact the inequalities in shared micromobility and achieve equity goals.

In summary, most inequality studies explore the factors influencing the distribution of micromobility services and trips among demographic groups and communities, yet they neglect city-level service geography. Research on the positive and negative impacts of shared micromobility should delve into where and who benefits or suffers from different service distributions. Lastly, genuine cross-cutting shared micromobility research on inequality and equity should incorporate normative principles and develop feasible measures for evaluating equity performance rather than merely examining the inequalities in shared micromobility.

1.3. Research Aims and Scopes

To bridge the identified gaps in the literature, this dissertation aims to comprehend inequalities in current shared micromobility systems and investigate how equity policies and dockless shared micromobility address inequalities in the existing transportation system. Diverging from previous studies that focus on inequalities in micromobility at the community level, the first study examines the factors explaining *inequality in shared micromobility systems* across regions and cities by analyzing multi-source open data *at the global level*. Specifically, I used world city theories to identify the elements that have driven the establishment of shared micromobility companies in specific world cities, as well as their country-level expansion patterns. Additionally, I adopted mixed methods, qualitative analysis supplemented by quantitative analysis, to uncover the factors related to the unequal distribution of shared micromobility systems across cities in the world.

The national-level study is the *first study* evaluating the *effectiveness of shared micromobility equity policies and requirements* in managing *inequalities in shared micromobility* and achieving equity goals across 141 systems in the US. This study examines how policies rooted in two foundational principles—equalizing resources and equalizing opportunities—address inequalities in vehicle distribution and trips within shared micromobility systems. To achieve this, I utilized the General Bikeshare Feed Specification (GBFS) to develop a comprehensive database that recorded the geographic location data of vehicles at one-minute intervals over a month. From this database, I derived monthly data on vehicle and trip distribution and calculated city-level vehicle and trip inequality indexes. Equity requirement data was obtained from the U.S. micromobility equity requirements database for systems with available GBFS data. Finally, structural equation modeling was utilized to construct two latent policy variables—resource-equalizing and opportunity-equalizing policies—based on equity requirements and to analyze their direct and indirect effects on vehicle and trip inequalities.

The third study, at the local level, explores the effects of Chicago's 2019 dockless shared e-scooter pilot program on existing transportation modes within the transportation equity priority area designated by the city, where residents are facing elevated mobility barriers. This study treats the e-scooter pilot as a quasi-natural experiment, analyzing its influence on trips taken by other transportation modes, including docked bikeshare, railway, bus, ride-hailing, and taxi services. Notably, the e-scooter pilot required operators to redeploy e-scooters to transportation equity priority communities, ensuring an equal distribution of shared micromobility services within the operational area. This setup provided a valuable opportunity to investigate whether the shared e-scooter program facilitated, hindered, or complemented the shared micromobility system and other transportation services in the equity priority area. The comprehensive

examination of these heterogeneous effects provides policy insights into how shared e-scooters can address existing inequalities in the transportation system.

1.4. Structure of the Dissertation

This dissertation research proposal is organized into five sections. The first introductory section provides an introduction, detailing the research context, identifying gaps, defining the scope and objectives, and outlining the dissertation's overall structure. The next three sections describe each of the three studies in detail, including their respective research questions, theoretical or procedural frameworks, methodologies, results, discussions of findings, and conclusions. Finally, the last section summarizes the key findings and contributions of each study.

CHAPTER II

GLOBAL PERSPECTIVE: EXPLORING THE INEQUALITY IN SHARED MICROMOBILITY SYSTEMS ACROSS CITIES WORLDWIDE

2.1. Introduction

Shared micromobility has been gaining increasing attention in the past decade, due to its potential contribution to the sustainable multi-modal transportation system in cities worldwide. However, shared micromobility is nothing new, as its development has experienced the iteration of three generations (DeMaio, 2009). The first shared micromobility system was called the White Bicycle Plan, a dockless unlocked bikeshare system established by Provos in 1965. Abandoned bicycles were painted white and deployed in central Amsterdam for everyone to ride freely. The early attempt at free bike sharing failed quickly due to bicycle theft and vandalism issues, though the White Bicycle Plan may not have been intended to work but acted as a transformative action for rethinking urban transportation systems (O'Sullivan, 2022).

To address these challenges, many European cities launched the second generation of shared micromobility systems in the 1990s. The most well-known program was Bycyklen, Copenhagen's bikeshare system, which was the role model of the second generation of shared micromobility systems, characterized as: "(1) distinguishable bicycles (by special color and design); (b) designated docking stations where the shared bike can be locked, borrowed, and returned; and (c) small deposits to unlock the bikes (Shaheen, et al., 2010)." Based on the structure of the second generation, the third generation of shared micromobility incorporated new technologies, such as smartcard payment, digital locks, and on-board kiosks.

Many cities in different regions have launched shared micromobility systems with the

second or third generation as the prototype, operated by various organizations, including governments, transportation agencies (semi-government organizations), universities, non-profits, advertising companies, and for-profits (DeMaio, 2009). Yet it was not until 2014 that the shared micromobility started to proliferate worldwide, driven by the private sector. Ofo, founded at Peking University, Beijing, in 2014, was recognized as the first dockless shared bicycle system that applied information communication technologies (Zhao et al., 2018). One year later, another Chinese shared micromobility start-up company, Mobike, launched the first intelligent dockless shared micromobility system featuring a blue-tooth smart lock, inserted GPS, smartphone-based digital platform, and mobile payment. These two shared micromobility companies signified the advent of the new generation of shared micromobility, characterized by adopting new information communication technology and dockless parking (Sun & Ertz, 2021). Within three years, shared micromobility services had spread throughout Chinese cities. According to a report by China's Ministry of Transportation, approximately 70 companies were operating over 16 million bicycles in 2017, with the number of shared bicycle users exceeding 100 million. After 2017, dockless shared micromobility systems expanded rapidly in other continents. Specifically, the advent of shared electric scooters marked a major turning point for the shared micromobility industry. Start-up companies like Lime and Bird popularized e-scooters in the US during 2017-2018, with many European and Asian cities following suit. Nowadays, more than 2,000 shared micromobility systems[2] are operating worldwide, present in 1,590 cities across 92 countries on every continent, except for Antarctica (O'Brien et al., 2022).

The development of shared micromobility was a global phenomenon but shared

[2] In this study, a "system" means a shared micromobility program operated by a certain organization in a certain city. Therefore, a shared micromobility program in a big city can have several systems operated by different organizations.

micromobility systems were distributed unequally among cities in the world (O'Brien et al., 2022), and significant disparities in the number of systems exist among cities within a country as well as cities in different countries. Global- or regional-level studies on shared micromobility systems to date have either reviewed the history or development of shared micromobility (DeMaio, 2009; Fishman, 2016) or focused on the shared micromobility system performance (Médard de Chardon et al., 2017; Todd et al., 2021). Even fewer studies have investigated the variations of shared micromobility systems in social equity, travel changes, operations, accessibility, or public policies across regions, nations, and built environments (Shaheen et al., 2023). The first global-level study in this dissertation aims to understand what explains the unequal distribution of shared micromobility systems across cities worldwide. As mentioned in the introduction section of this dissertation, this study is an empirical transportation inequality study, focusing on the determinants of unequal distribution of shared micromobility systems at the city level. Thus, this study neither has any normative connotations nor claims that the absolute equal distribution of shared micromobility systems is either preferable or ideal. Instead, this study aims to reveal the barriers to implementing shared micromobility systems in places where a significant demand for shared micromobility exists. Specifically, this paper answers two research questions:

1) How were shared micromobility companies established and expanded at the global level?
2) What explains the unequal distribution of shared micromobility systems across cities worldwide?

Micromobility companies are headquartered in limited cities worldwide. To answer the first research question and understand why companies originated in these headquarters cities, and

the role such cities play in the unequal development of shared micromobility systems, I utilized world city theory to conduct the comparative qualitative analysis. The world city theory[3] aims to understand the significance of a few superstar cities of the world city hierarchy in the globalization process (Friedmann, 1986). The proliferation of the shared micromobility systems in the past decade related closely to the emergence of the digital economy, making world city theory a better framework to explain the establishment and expansion of micromobility at the global scale compared to traditional economic geography theories.

To answer the second research question, I employed qualitative analysis supplemented by quantitative analysis to examine the unequal distribution of shared micromobility systems across cities worldwide. I first interviewed employees from shared micromobility companies to confirm the applicability of factors identified by the literature and other factors impacting the implementation of shared micromobility. Then, I used multilevel Tobit regression to analyze how the number of shared micromobility regional offices[4] in a country and city-level characteristics relate to the number of shared micromobility programs in a city, including those without a shared micromobility system. Following the regression analysis, I interviewed city staff and scholars in local cities to understand the barriers to introducing shared micromobility systems that may explain unequal system distribution beyond factors that can be quantified. I combined interview data with studies on news reports, government documents, and public discourse data from social media platforms regarding the lack of shared micromobility, to fully understand why these cities are underserved by shared micromobility.

[3] The concept of "World City" was first put forward by Hall, and then mainly developed by Friedman and Wolf.
[4] The term "regional offices" in this paper means national or regional offices of shared micromobility companies, which are responsible for the business development, policy and communications, government or public relations, operations in a region or country.

2.2. Literature Review

In this literature review, I first review theories developed by geographic economists and identify the limitations of these theories for explaining global economic activities in the digital era. Then, I examine the world city theories and summarize the key features of different approaches to theorizing world cities. Lastly, I examine city-level facilitators for and barriers to implementing shared micromobility systems.

2.2.1. From Classical Foundations to New Economic Geography and Beyond

This study regarded the expansion of shared micromobility's service as the spread of the digital platform economy at the global level, so reviewing the theories of economic geography was intuitively a must-do. The study of economic geography—the location of production—was also not something new. Before the end of the Cold War, the landscape of economic geography was richly painted with theories that aimed to formalize the understanding of how economic activities are spatially distributed, such as Heinrich von Thune's (1826) pioneering model, Christelle's (1968) central place theory, Weber's (1922) location theory, Lösch's (1940) model, and Harold Hotelling's (1929) model of spatial competition.

These classical theories, emphasizing the static analysis of location advantages and resource allocation, paved the way for the New Economic Geography (NEG). Emerging in the late 20th century, predominantly through the work of Krugman (1991), NEG introduced a dynamic perspective by integrating microeconomic principles and models of industrial organization. It accentuated the role of economies of scale, transportation costs, and the mobility of labor and capital in the formation of economic agglomerations and the uneven distribution of industries across geographical spaces. Unlike its predecessors, the NEG examined how these factors interact in a self-reinforcing manner, leading to the concentration of economic activities

in certain areas, thus explaining the emergence of urban centers and regional disparities in a globalized economy. This shift towards a more nuanced understanding of economic geography underscored the importance of internal and external economies of scale and the strategic decisions of firms and workers within the global economic landscape.

While the NEG provided a framework primarily focused on explaining the spatial distribution of economic activities in terms of spatial equilibrium, it has been criticized for treating geography and history as exogenous variables naively (Garretsen & Martin, 2010). Scholars in geography, urban planning, sociology, and other disciplines tend to understand geographic economic activities by highlighting the networks of flows capturing various economic, social, political, and cultural factors. These interdependencies pin down the importance of geography and history as endogenous factors binding corporations, works, institutions, and organizations. Additionally, the NEG, as illustrated by Krugman (1991), was a model useful for explaining the economic activities of the traditional manufacturing sector in the "old world", for which the transportation cost, market size, and economics of scale were the paramount factors.

The spread of the digital platform economy at the global level introduces a new social dynamic, making NEG or geographic economics less helpful for explaining the emergence of shared micromobility. By contrast, theories developed by scholars in urban planning, geography, and sociology offer complementary perspectives that delve into the qualitative aspects of urban and regional development, especially in the globalization process. These disciplines, while acknowledging the economic dimensions of spatial development, incorporate a richer array of influences beyond the economic calculus emphasized in NEG. They provide insights into how global economic processes, technological advancements, cultural shifts, and policy decisions

influence urban form, social dynamics, and regional disparities. This approach allows for a nuanced understanding of economic concentration, addressing not only the where and why of economic activity distribution but also its implications for communities, governance, and the quality of urban life.

2.2.2. World City Theories

Theories of globalization developed by scholars in urban planning, geography, and sociology aimed to examine the hierarchical city system, with a focus on the role of a few superstar cities in the global economy. A wide range of relevant terms has been developed to describe the world city network, such as world cities, global cities, megacities, financial cities, industrial cities, ecological cities, primate cities, and imperial cities (Beaverstock et al., 1999). These terms shared a few consensuses on what contributes to the development of superstar cities, such as agglomeration effects, but the wide range of terminology fundamentally reflected the diversity of cities and ways of studying cities in the globalization process. An initial dichotomy of these ideas into two broad traditions, demographic and function traditions, can differentiate the focus of each tradition (Beaverstock et al., 1999). The demographic tradition, such as mega-city region, delved into the implications of population concentration on urban residents, the environment, and other sustainability issues (Fuchs, 1994), but it did not pay attention to the mechanisms of agglomeration, which are essential for understanding the economic activities. Agglomeration mechanisms encompass various factors such as economies of scale, knowledge spillovers, specialized labor markets, and infrastructure networks, all of which play crucial roles in shaping the globalization process. Therefore, I mainly focus on the literature of world cities with the function tradition.

The function tradition of world city theories can be traced back to Hall's (1966) *The*

World Cities, and developed by many other scholars in urban planning, geography, and sociology (Friedmann, 1995; Friedmann & Wolff, 1982). A shared objective of world city theories or hypotheses is to identify world cities at the top of the hierarchical structure of cities worldwide. Five distinct approaches have been established to define world cities: cosmopolitan characteristics, the new international division of labor, advanced producer service, financial centers, and city network (Beaverstock et al., 1999).

The first approach focused on the cosmopolitan characteristics of world cities, which was the key theme in early world city studies. World cities were examined in terms of their global power and influence in various aspects (Hall, 1966), and were specifically identified by analyzing the location decisions of multinational companies' headquarters (Hymer, 1982). This specific analytical method profoundly impacted how empirical studies on world cities were conducted in the last few decades. The second approach took a step further to explore how the new international division of labor relates to the formation of world cities (Cohen, 2018; Friedmann, 1986; Friedmann & Wolff, 1982). The new international division of labor was characterized by four transformations: the international spread of manufacturing, the international spread of corporate-related services, a system of international financial markets, and internalized systems of production and exchange (Cohen, 2018).

The concept of the global city developed by Sassen (1991) highlights the concentration of outsourced central corporate functions (i.e., advanced producer services), such as information technology consultancy, management consultancy, accounting, legal services, and advertising, which is the core of the third approach. A hypothesis of Sassen's global cities is that the greater the corporation headquarters can outsource their most complex and unstandardized functions, the freer they can opt for other non-global cities. Thus, many start-up companies can gain great

flexibility in choosing a headquarters location by outsourcing some functions to advanced service producers; as a result, these companies themselves do not have to be located in global cities. The fourth approach regards world cities as financial centers by examining the impact of financialization on global cities and proposing an extension of the world city hypothesis (Bassens & van Meeteren, 2015; Meyer, 2015; Reed, 1989).

Even though these four approaches of theorizing world cities are useful for understanding the formation of multinational companies and the location choice of their headquarters, examining the exchange process of goods and services and its implication for inequality in service geography requires a further investigation into how these headquarters are connected to the end market. Therefore, the last approach aims to examine the world city network to understand how corporations expand their goods and services globally. The seminal work of Taylor (2004) explored the intricate connections and hierarchies among globalizing cities, providing another perspective to examine the world city system. The prologue of this book clearly illustrates how the world city network differs from other world city studies. The world city literature conceptualized the hierarchical structure of world cities (Friedmann, 1986, 1995), but most theoretical and empirical works focused on identifying world cities or comparing world cities at the top tier without considering the inter-city relations among cities at various levels. Thus, Taylor (2004) called for exploring the "second nature" of cities, contrasting to the internal structure of cities conceptualized by Harris & Ullman's (1945) *The Nature of Cities*. Specifically, Taylor (2004, p. 2) advocated for relational analysis by examining "information on the connections, links, flows – in short, the relations – between cities." Many international business studies used the concentration of subsidiaries to indicate the corporations' country or region entry decisions (Arregle et al., 2009; Delios & Beamish, 2005), determined by the

centripetal and centrifugal forces of a particular region. For the individual cities, the presence and number of subsidiaries in their countries illustrated the connections between these individual cities and the world city hierarchy. Therefore, the companies' entry decisions and cities' connectivity with the world city hierarchy are the two sides of the same coin, which can be measured by the same indicator.

Many empirical studies have identified world cities by investigating companies' headquarters' locations, although the majority of studies focused on advanced producer service or financial sector and did not explore the relations in the world city hierarchy (Robinson, 2005). A recent study investigated world cities of ride-hailing to demonstrate how the ride-hailing industry connected with the world city network in terms of access to talent, knowledge spillover, and government policies (Brail, 2022). This study focused on how and why world cities of ride-hailing differ from "traditional" world cities in advanced producer services and discussed equity concerns regarding the concentration of high-skilled labor in these world cities of ride-hailing. Even though this paper touched on the inequality in ride-hailing services between countries (e.g., the lack of ride-hailing initiatives and services in African countries), formal analysis to reveal the process of global market entry was not possible due to the absence of data about secondary offices and cities with ride-hailing services.

2.2.3. Inequality in Shared Micromobility Service Geography among Cities

Although world city theories could explain why shared micromobility was *initiated* in certain world cities, as well as country-level variations in service geography, they can hardly explain the city-level variation in shared micromobility systems. The inequality was determined by firms' entry decisions at the local level, while limited studies examined the city entry decisions of transportation network companies in the globalization process. Existing literature

suggests that two major factors may largely impact shared mobility companies' entry decisions: demand and regulatory environment. Studies on ride-hailing city-level adoption suggested that the market potential or demand and regulatory environment or cost were the primary reasons for companies to choose cities to enter (Swofford, 2020; Troyslit, 2016). Only one study examined the spatial spread of dockless bicycle systems among Chinese cities, suggesting that companies assess cities "according to their weather conditions, topography, population size and demography, and government attitude towards dockless bike-sharing" (Han, 2020, p. 5). This sole study conducted the spatial analysis of the major three bikeshare companies' systems in China and analyzed the news and technical reports regarding these three companies to identify their city-level expansion strategies. Nevertheless, the city-level factors and local responses are absent in examining the spatial spread of dockless shared micromobility systems.

Even though very limited studies examined the inequality in shared micromobility's adoption across cities, some quantitative studies delved into various factors for predicting demand at the system or community level. These variables at the city level can be utilized by companies to analyze the demand for shared micromobility, determining whether a city is an important market for companies. A Chinse study explored how urban socioeconomic and demographic factors, system characteristics, and composite indicators affect the daily use and turnover rate of public bikeshare systems (Zhao et al., 2014). A global study sampling 75 bikeshare systems used system attributes, density, geographic factors, weather, and transportation infrastructure to predict the utilization rate (Médard de Chardon et al., 2017). Additionally, a recent global study focused on system-level performance by cluster analysis based on population, topography, precipitation, and bicycling infrastructure (Todd et al., 2021). Most studies on demand for shared micromobility were conducted at the community or

individual level. Review studies have summarized the primary determinants of shared micromobility demand, including weather conditions, built environment and land use, public transportation facilitates, socio-demographic factors, station-level attributes, and temporal factors (Eren & Uz, 2020; Guo et al., 2022; Mitropoulos et al., 2023). In sum, most empirical studies showed that high population, dense and mixed land use, economically developed areas, moderate weather conditions, flat terrain, and well-developed transportation infrastructure increased the demand for shared micromobility, which are the facilitators for implementing shared micromobility systems.

Varied regulatory responses—such as the lack of regulatory framework, strict regulatory framework, and complete ban—can create different levels of barriers to the implementation of shared micromobility. Most studies on the regulatory environment have examined policy practices in cities *with* shared micromobility programs or pilots (Fearnley, 2020; Herrman, 2019; Rayaprolu et al., 2020; Shaheen & Cohen, 2021). Common policies regulating shared micromobility providers and users include application processes, device caps, service area limitations, parking requirements, rules on usage, fees and fines, education and communications, and data sharing and compliance. However, these studies have not examined the regulatory environment for shared micromobility in cities *without* a shared micromobility system, which may significantly deter the implementation of shared micromobility systems.

Additionally, understanding the motivations and perceptions of governments is crucial, as these factors largely determine whether the regulatory environment facilitates or deters micromobility's entry into a city. Few studies have examined the governments' or public concerns over shared micromobility, which can result in an unfriendly regulatory environment for launching shared micromobility systems (Bretones et al., 2023; Fuller et al., 2021; Gössling,

2020). The public and government's concerns included safety hazards, conflicts with other road users, misparking and cluttering, and vandalism. Nevertheless, none of these studies investigated whether or how regulatory barriers or governments' perceptions of shared micromobility can bar or discourage micromobility from entering certain markets entirely.

My study addresses these gaps by investigating the demand-related factors, regulatory environment, motivations behind regulatory decisions, and impacts of these demand factors, regulatory framework, and perceptions on the adoption of shared micromobility. Specifically, by examining the perceptions and concerns of governments and the public, my research aims to provide a deeper understanding of the factors that influence the regulatory environment and its implications for implementing shared micromobility programs.

2.3. Methods

2.3.1. Study Design

The overarching objective of this study is to understand what explains the unequal distribution of shared micromobility systems across cities worldwide. To address the research gaps in the literature, the first research question aims to examine how the world city network explains the creation of multinational shared micromobility corporations in certain cities and then the diffusion of this new transportation innovation across countries. The second research question seeks to understand why certain cities are underserved by shared micromobility mainly based on qualitative analysis and supplemented by quantitative analysis.

Since the analysis unit is the city, I first needed to define and map all the cities in the world. Given that different countries had different definitions for cities, it was necessary to adopt a consistent definition to map cities in different countries. Thus, I obtained the boundary of cities

from the Global Human Settlement Urban Centre Database (GHS-UCDB) (Moreno-Monroy et al., 2021), in which a 1km x 1km grid was defined as an urban center area containing 50,000 people or more, composed of contiguous cells, each with at least 1,500 people. The GHS-UCDB utilized this definition to identify cities across different countries and regions, which was used by previous global studies on shared micromobility's system-level performance (Todd et al., 2021). In total, the GHS-UCDB identified 13,135 cities in the world.

Figure 2-1 shows the procedural framework that illustrates the data and analysis methods in this study. For the first research question, I conducted a case-oriented comparative qualitative analysis by contrasting world cities of shared micromobility with other types of world cities in the literature, to understand the necessary conditions for the establishment of shared micromobility companies in these cities. I also examined the world city network of shared micromobility (i.e., the connections between headquarters and regional offices) to understand how shared micromobility companies expanded their service geographies globally. The number of regional offices within the world city network in a country can represent companies' current country entry decisions, which accounts for country-level variations in shared micromobility systems.

For the second research question, I first interviewed the employees from multinational shared micromobility companies to understand the major factors determining city-level entry decisions. The analysis of interviews with companies' employees confirmed the applicability of the factors identified by the literature regarding city entry decisions. Second, I conducted the regression model to analyze how the number of regional offices in a country (i.e., the proxy variable for companies' country entry decisions) and city-level characteristics (i.e., the proxy variables for the demand of a city for shared micromobility) relate to the number of shared

micromobility systems in a city. The regression analysis aimed to identify the cities underserved by shared micromobility, where the actual number of systems was lower than the predicted number by the regression model.

Last, I relied on qualitative analyses to understand how the regulatory framework deterred the development of shared micromobility systems and what led to the unfriendly regulatory environment in cities without or underserved by shared micromobility systems. I collected qualitative data from interviews with city staff and scholars in local cities, studies on new reports regarding the perception of shared micromobility, and public discourse on the development of shared micromobility systems. I used a hybrid approach (i.e., both deductive process and inductive process) to understand how the regulatory environment and other barriers hindered the implementation of shared micromobility.

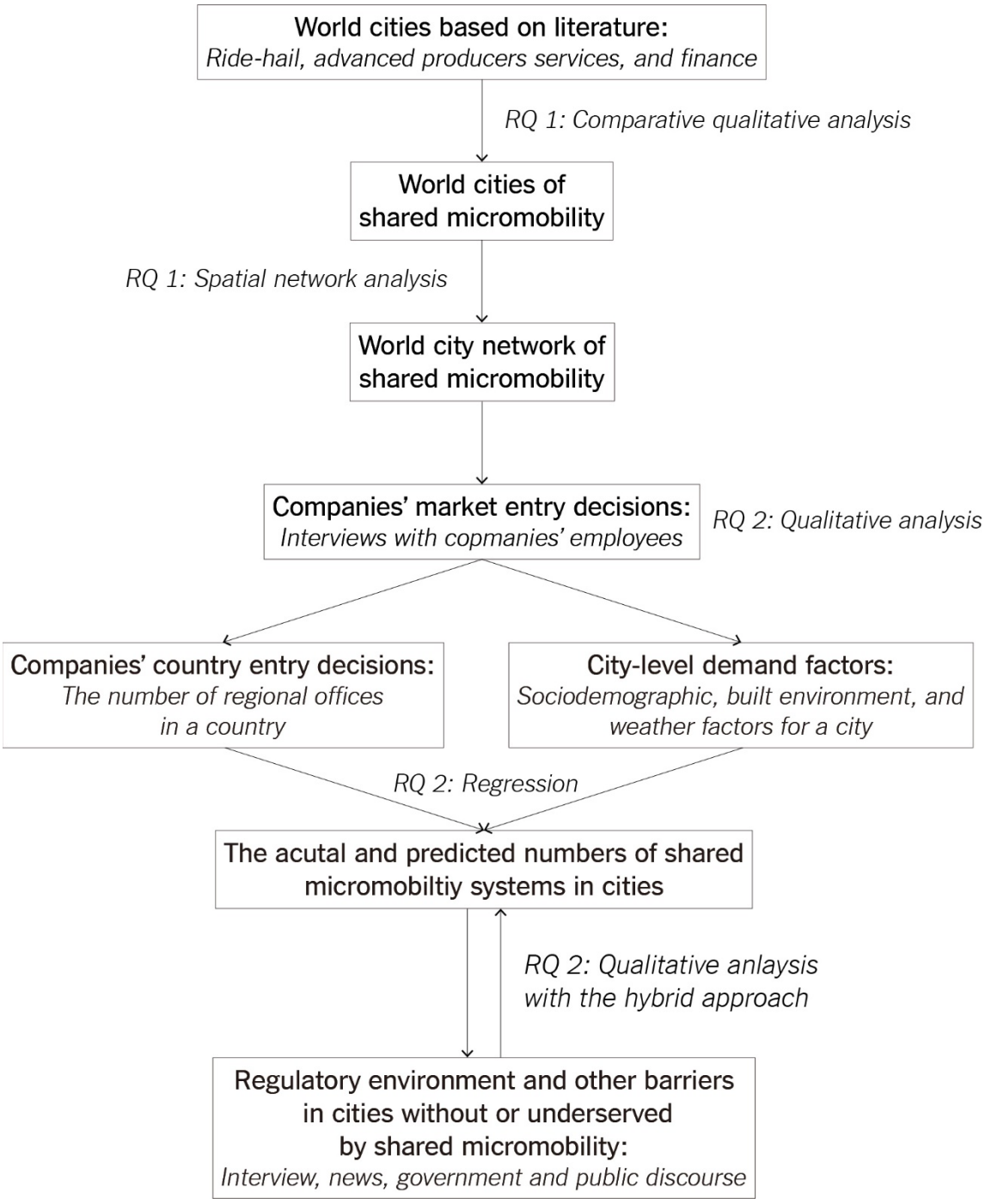


Figure 2-1. Procedural framework

2.3.2. Data Collection and Qualitative Analysis for World Cities of Shared Micromobility

To address the first research question about the world city of shared micromobility, I collected system- and firm-level data on shared micromobility (Table 2-1). The system-level

shared micromobility data were obtained from the bike-sharing world map[5] (BWM) (O'Brien et al., 2022), which collected system-level information from micromobility databases, news, and other publicly available sources. The system-level variable used in this study included the system location, operators, start year, and fleet size. For operators publishing the locations of their operating systems, such as Yonganxing and BCycle, I utilized this publicly available location information to refine the dataset.

Table 2-1. Descriptions of variables for world city analysis.

Variables	Description	Source
System-level		
System location	The country and city of a shared micromobility system operating in 2024	BWM
Operators	The operator of a shared micromobility system in 2024	BWM
Start year	The year when the shared micromobility system was implemented	BWM
Fleet size	The number of vehicles in operation for the shared micromobility system in 2024	BWM
Firm-level		
Headquarters	The cities where the headquarters of major shared micromobility operators are located in 2024	Official website, TianYanCha, and LinkedIn
Regional offices	The cities where the national or regional offices of major shared micromobility operators in 2024	Official website, TianYanCha, and LinkedIn

Regarding the firm-level data, I acquired the headquarters information of the top 30 shared micromobility companies in the world in terms of the number of systems in the database (Table 2-2), accounting for almost 80% of the total vehicles worldwide. The other companies are operating shared micromobility systems in limited cities in the sole country, which did not significantly shape the distribution of shared micromobility systems at the global level. To construct the world city hierarchy of shared micromobility, I also needed to collect the location

[5] This dataset includes the location and system-level information of all types of shared micromobility systems (e.g., shared e-scooter, dockless shared bicycles, and docked bikeshare), though the name of this dataset suggests only bikeshare systems were recorded.

data of regional offices of these top 30 shared micromobility companies. Nevertheless, these location data are difficult to access, so very limited world city literature examined the world city network by identifying both headquarters and regional offices. To address this research gap, I utilized multi-source data, including official websites, LinkedIn, and Tianyancha[6], to map the regional offices of shared micromobility companies. Many companies' official websites and LinkedIn webpages show current and prospective employees' working locations. A city was identified as a place for regional offices if jobs related to regional management, operation, and/or market development were in this city. It should be noted that a regional city does not necessarily need to have a physical workplace for the employees, as companies provide many remote jobs in both world and regional cities. Thus, it is very interesting to observe that many online teams were responsible for regional business development.

Since mergers and acquisitions among micromobility start-up companies were common in the past decade, the acquired company was regarded as a secondary office of the acquiring companies. For instance, Bird acquired Spin in 2023, so Spin's headquarters was regarded as the secondary office of Bird in the dataset.

Table 2-2. The top 30 shared micromobility companies.

Operators	Headquarters' locations	Home countries	Number of systems
Yonganxing	Shanghai	China	215
Lime	San Francisco	United States	207
Nextbike	Leipzig	Germany	167
Tier	Berlin	Germany	92
Donkey Republic	Copenhagen	Denmark	61
Meituan	Beijing	China	54
Hellobike	Shanghai	China	39
BicinCittà	Turin	Italy	34
Bolt	Tallinn	Estonia	30
DiDi Qingju	Beijing	China	26

[6] Tianyancha is a data technology company providing corporate information.

Hello Cycling	Tokyo	Japan	25
Docomo Bike Share	Tokyo	Japan	21
JCDecaux	Paris	France	21
ROOVEE	Warsaw	Poland	21
Beryl	London	United Kingdom	19
BCycle	Waterloo	United States	18
PiPPA	Kyoto	Japan	16
Veo	Los Angeles	United States	15
Dott	Amsterdam	Netherlands	14
EasyBike	Athens	Greece	14
Tembici	São Paulo	Brazil	14
YouBike	Taichung	China	14
Bird	Los Angeles	United States	11
Lyft	San Francisco	United States	11
RideMovi	Milan	Italy	11
Velospot	Bern	Switzerland	11
Cyclopolis	Athens	Greece	9
Fifteen	Paris	France	9
Neuron	Singapore	Singapore	9
Yulu	Bangalore	India	9

To analyze the system- and firm-level data, I first identified the cities where the headquarters of shared micromobility companies were located as world cities of shared micromobility. Similar to ride-hailing, a limited number of multinational shared micromobility companies in world cities dominate the global market. Thus, I conducted a case-oriented comparative analysis to investigate the mechanism of generating world cities of shared micromobility. I contrasted world cities of shared micromobility with world cities of ride-hailing, advanced producer services, and startups and venture capital investments to understand the role of the new international division of labor, advanced producer services, and financial capital in shaping the economic geography of shared micromobility startups. Last, I examined the locations of regional offices of shared micromobility companies to understand firms' country-entry strategies.

2.3.3. Qualitative Data and Analysis for Exploring Barriers to Introducing Shared Micromobility

I collected qualitative data related to the market entry for shared micromobility companies and barriers to implementing shared micromobility in the cities, including interviews, local municipalities' responses, news reports, and public comments on social media platforms (Table 2-3). I conducted semi-structured interviews with 18 mobility company staff, city planners, and academic researchers in March and April 2024. All interviews were conducted online (e.g., Zoom and Tencent Meeting) and lasted 30 to 60 minutes. Informed consent was obtained from all participants before the interviews. Participants were assured of confidentiality, and data was anonymized to protect their identities. Ethical approval for the study was obtained from the relevant institutional review board. Interviews were recorded with the participants' permission using digital audio recording tools. The recordings were transcribed verbatim using transcription software (e.g., Microsoft Office) and reviewed for accuracy.

I first interviewed four employees from two multinational shared micromobility companies, who were responsible for business development at the global or local level. The aim of interviewing shared micromobility companies was to understand how companies expanded services to certain countries and cities and the perceived barriers to implementing shared micromobility. Interviews with employees from companies can also validate whether and to what extent the two factors identified by the literature, demand and regulatory environment, matter for business development. The key themes of these semi-structured interview questions are centered around understanding the strategic, operational, and contextual factors that influence the expansion of shared micromobility systems into new markets (Appendix B).

I utilized convenient and purposive sampling to interview planners, city staff members, and planning scholars in 14 cities underserved by or without shared micromobility systems. The

purpose of the interviews was to understand the regulatory barriers to implementing shared micromobility in these cities and factors resulting in unfriendly regulatory environments; therefore, I sought interviewees familiar with transportation planning and local knowledge of the urban context, transportation system, and people's perceptions and travel behaviors. Fourteen participants in cities were identified through professional networks, referrals, and relevant industry contacts. To ensure a diverse range of perspectives, I included planners, city staff members, and planning scholars with varying levels of experience and from different geographic locations. The semi-structured interviews were guided by a set of core questions focused on key topics such as the existing transportation infrastructure, perceived barriers to implementing shared micromobility, regulatory and policy challenges, and community attitudes toward shared micromobility (Appendix A).

Table 2-3. Descriptions of qualitative data in this study.

Qualitative Data	Descriptions	Data Sources
Interview with people from local municipalities	I interviewed planners and scholars who are familiar with the local context in 14 cities in Bangladesh, China, Japan, and the United States. The semi-structured interview questions focused on the perceptions of shared micromobility and barriers to implementing shared micromobility.	Interview
Interview with people from shared micromobility firms	I interviewed four employees from multinational shared micromobility firms. The semi-structured interview questions focused on the global and local market development	Interview
Public discourse	The public opinions regarding the absence of shared micromobility development in cities were collected from social media platforms, such as Baidu Tieba, Reddit, Facebook, Hupu, and Zhihu since 2016	Major social media platforms
Government's responses	The Chinese cities' Q&As on the absence of shared micromobility	Official websites
Studies on news reports	The studies on news reports about the attitudes, perceptions, and concerns related to the absence of shared micromobility since 2016	Google Scholar

Also, the analysis of qualitative data went further by exploring the causes of specific regulatory environments. Therefore, this study aims to investigate various barriers (i.e., the impacts of the regulatory environment, governmental perceptions, and public attitudes) to implementing shared micromobility in cities underserved by or without shared micromobility systems. I utilized the hybrid approach to analyze the qualitative text data to understand the barriers to introducing shared micromobility in these cities. I started with a deductive approach by using the common themes identified in the literature (Bretones et al., 2023; Fuller et al., 2021; Gössling, 2020) (Table 2-4). Since previous studies have only examined the regulatory framework and specific policies in cities with shared micromobility systems, the common themes derived from these studies cannot fully reveal what led to the exclusion of shared micromobility systems in cities without shared micromobility systems. Therefore, after the deductive process, I used an inductive analysis to uncover additional insights and validate the initial assumptions.

Table 2-4. Themes and potential codes of barriers to introducing shared micromobility.

Themes	Potential Codes
Infrastructure	Lack of infrastructure, Incompatible urban design, infrastructure development
Parking	Lack of parking space, clutter, blocking sidewalks
Regulatory framework	permit complexity, burdensome requirements and rules, compliance issues
Safety	Safety incidents, safety regulations, safety measures
Cost and funding	Budget constraints, funding sources, cost-effectiveness
Security	Theft and vandalism, and reservations about secure and appropriate public parking
Vehicle design	Limited capacities for carrying people, limited capacities for carrying goods, adaptive vehicles

2.3.4. Quantitative Data and Analysis for Explaining Inequality in Systems Across Cities

The literature suggests that sociodemographic factors, land use and built environment, transportation facilitates, and weather conditions are associated with the demand for shared

micromobility. The GHS-UCDB contained a wide range of city-level factors, and I selected eight city-level variables that are associated with these four categories of determinants of demand (Table 2-5). For the sociodemographic variables in this study, night light emission is a proxy of the intensity of economic activity (Doll et al., 2006; Mellander et al., 2015). The economically developed and populated areas are expected to have greater demand for shared micromobility (Eren & Uz, 2020), and therefore more shared micromobility systems. Built-up area per capita measured the land use density, while the shared of non-built-up area and land use efficiency represents the cross-sectional and longitudinal compactness of urban form. Most empirical studies suggest that compact and high-density environment predicts high demand for bicycling (Fraser & Lock, 2011; Wang et al., 2016; Yang et al., 2019). The association between weather conditions and demand for shared micromobility is frequently examined but results are mixed. Evidence does show, however, that extreme weather conditions (e.g., scorching heat and heavy rain) are negatively associated with demand for shared micromobility (Eren & Uz, 2020). In this study, I included the average temperature and precipitation for cities in the quantitative analysis, which are the most common weather variables for predicting demand for bicycling. It should be noted that the two weather variables may oversimplify weather impacts, missing short-term variations, extreme events, and local differences; instead, they can only represent the general climate trends and typical weather conditions of a city, providing a broad overview of its environmental context. Last, since the data on transportation facilities (e.g., bike lanes) are unavailable in cities in many developing and least-developed countries, I did not incorporate transportation facility data.

Another important variable of interest was the number of regional offices in a country representing the firms' country entry decisions. Cities located in countries with a higher

concentration of regional offices are more inclined to establish partnerships with shared micromobility firms and implement shared micromobility systems compared to cities with similar characteristics in countries with fewer regional offices. The city-level variables are effective in explaining variations in shared micromobility among cities but cannot account for between-country variations, given that the cities are nested in the country. Country entry decisions of shared micromobility companies largely determined the between-country variation of shared micromobility systems. Last, country-level covariates were acquired from the World Bank (Table 2-5).

Additionally, the qualitative analysis was supplemented by the quantitative model. I used the regression model to predict the number of systems for all the cities. A city is defined as underserved by shared micromobility if the actual number of systems in this city is below the predicted value. Except for noises, other factors not included in the model may lead to the discrepancy between the actual values and the predicted values, such as the regulatory environment highlighted in the literature.

Table 2-5. Descriptions of variables for the regression analysis.

Variables	Description	Source
City-level		
Population	The total population in 2015 calculated within the spatial domain of the Urban Centre of 2015	GHS-UCDB
Built-up area	Total built-up area in 2015 calculated within the spatial domain of the Urban Centre of 2015 (square kilometers)	GHS-UCDB
Built-up area per capita	Amount of the built-up area per person in 2015 calculated within the spatial domain of the Urban Centre (square meters per person)	GHS-UCDB
Share of non-built-up area	Percentage of the non-built-up surfaces and high green surfaces within the area of the Urban Centre in 2015	GHS-UCDB
Land use efficiency	land use efficiency, the ratio of land consumption growth rate to population growth rate, between 1990 and 2015,	GHS-UCDB

	estimated for the area of the Urban Centre	
Night Light	Mean nighttime light emission calculated within the Urban Centre spatial domain (nano-watt per steradian per square centimeters).	GHS-UCDB
Temperature	Average temperature calculated from annual average estimates for time interval centered on the year 2015 (the interval spans from 2012 to 2015) within the spatial domain of the Urban Center (°C)	GHS-UCDB
Precipitation	Average precipitation calculated from annual average estimates for time interval centered on the year 2015 (the interval spans from 2012 to 2015) within the spatial domain of the Urban Center (mm)	GHS-UCDB
Country-level		
Regional offices	The number of national/regional offices in a country	
Population	Total population in 2022 in a specific country	World bank
GDP	The gross domestic product for a country in current US$	World bank
GDP per capita	The gross domestic product per capita for a country in current US$	World bank
Urban Population	The percentage of the urban population	World bank
Electricity	The percentage of people with access to electricity	World bank
Internet	The percentage of individuals using the Internet	World bank

I conducted multilevel Tobit regression to examine how the world city network and city-level characteristics relate to the number of shared micromobility systems in a city. The independent variables were the number of regional offices in a country, city-level characteristics, and country-level covariates (Table 2-5). The number of regional offices in a country was the proxy variable for country entry decisions of shared micromobility companies, and city-level characteristics were the proxy variables measuring the demand for shared micromobility. To ensure the comparability of coefficients, the independent variables for the regression models were standardized. Additionally, I calculated variance inflation factors (VIF) for the independent variables, and the results (not shown) indicated that the VIFs were below 10, indicating that potential concerns of multicollinearity were adequately addressed.

In a multilevel Tobit regression, some values in the dependent variable are censored, typically due to measurement constraints or data recording practices. In this study, the number of shared micromobility systems is censored at a lower threshold (zero) because the city cannot have a negative number of systems. The observed dependent variable, y_{ij}^{*}, represent censored versions of y_{ij} for city i within county j. Therefore, the dependent variable is defined as:

$$y_{ij}^{*} = \begin{cases} y_{ij} & if\ y_{ij} > 0 \\ 0 & if\ y_{ij} = 0 \end{cases} \quad (2.1)$$

Where 0 is the low-censoring limit, and there is no upper-censoring limit. The expectation of the dependent variable y_{ij} could be modeled by the following:

$$E\left(y_{ij} \mid x_{ij}, \mu_j\right) = \beta_0 + \left\{\beta_1^C x_{1ij}^C + \cdots + \beta_c^C x_{cij}^C\right\} + \left\{\beta_1^T x_{1ij}^T + \cdots + \beta_t^T x_{tij}^T\right\} + \mu_j + \varepsilon_{ij} \quad (2.2)$$

Where $x_{ij} = \left[\left(x_{1ij}^C + \cdots + x_{cij}^C\right), \left(x_{1ij}^T + \cdots + x_{tij}^T\right)\right]'$ is a vector including c city-level characteristics, the number of regional offices x_{1ij}^T, and $t-1$ country-level covariates. $\mu_j$and ε_{ij} are normally distributed random intercept and random error, respectively.

2.4. World Cities of Shared Micromobility

2.4.1. The Headquarters of Top 30 Shared Micromobility Companies

Figure 2-2 (a) shows that the headquarters of the top 30 shared micromobility companies are concentrated in cities in the global north, specifically in Europe, Eastern Asia, and the US. The comparisons between world cities of shared micromobility and the other three types of world cities explained why these Top 30 shared micromobility companies were established in these specific cities. First, 64% of world cities of ride-hailing were also world cities of shared micromobility. The development of ride-hailing and shared micromobility both benefited from the development of information communication technology, such as wireless networks, GPS,

smartphone applications, and online payment systems. Brail (2022) divided the world cities of ride-hailing (Figure 2-2 (a)) into three categories: world cities for technology startups (San Francisco, Beijing, Singapore) (Adler et al., 2019), cities with national policies for innovation (Bangalore, Singapore, Tel Aviv, and Tallinn) (Crescenzi et al., 2019), and gateway cities that are influential in certain countries and/or regions (Bangalore, Beijing, Dubai, Jakarta, Madrid, São Paolo, and Singapore) (Taylor et al., 2002). Since most shared micromobility start-ups are also technology and innovation-oriented, it is clear that they also take advantage of locating in these three types of cities.

World cities of shared micromobility are more consistent with world cities of startups and venture capital investments than world cities of global services (Figure 2-3 (a)). Shared micromobility companies often require substantial capital to scale their operations, develop technology, and expand into new markets. Venture capital investments provide the necessary funding for these companies to rapidly expand, allowing them to establish a strong presence in multiple cities and countries, especially in the early stage of their development. For world cities of shared micromobility distant from venture capital investments, national-, regional- and local-level policies contributed to the establishment and development of multinational companies. For instance, Bolt's rapid development in Europe and Africa benefited from Estonia's regulations, e-government services, and policies for attracting technology-oriented startups (Brail, 2022).

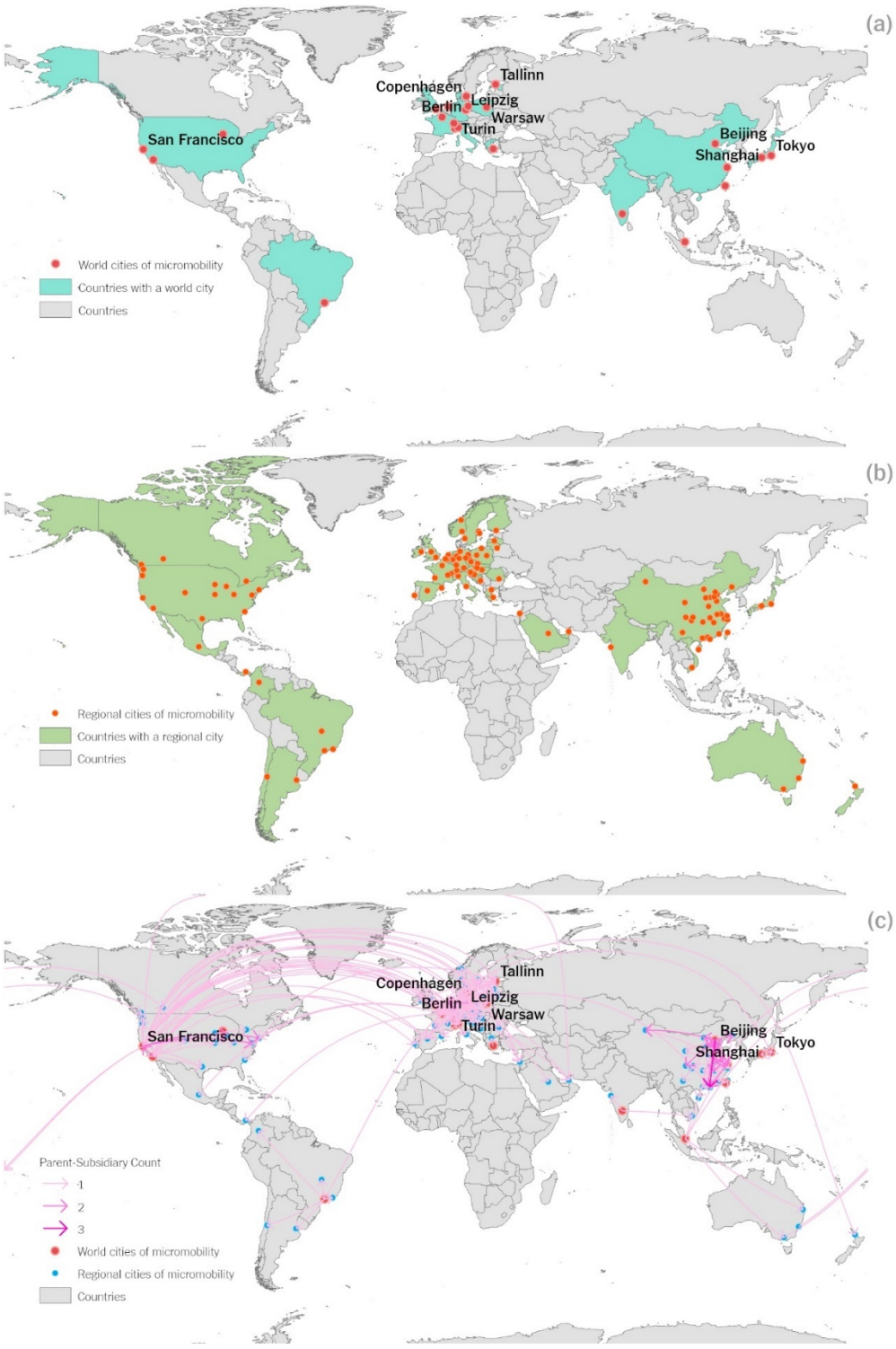


Figure 2-2. The world cities of shared micromobility (a), regional cities (b), and world city network (c).

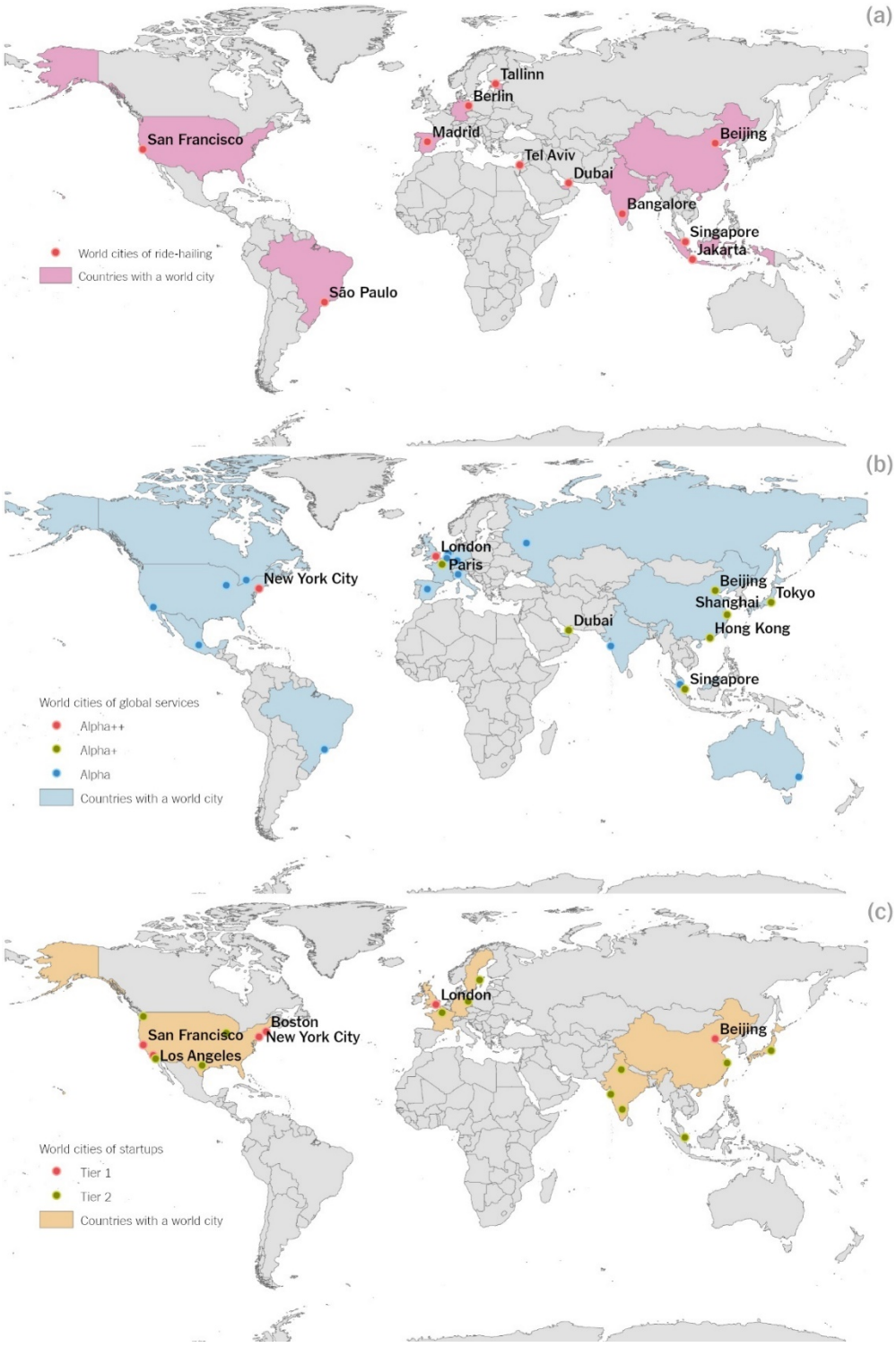


Figure 2-3. The world cities of (a) ride-hailing, (b) global advanced producer services, and (c) startups and venture capital.

More importantly, shared micromobility startups can directly derive benefit from the knowledge spillover from ride-hailing unicorns due to the geographic proximity, through labor mobility, collaboration, and partnerships (Autant-Bernard, 2001; Breschi & Lissoni, 2009; Montoro-Sánchez et al., 2011). Many founders and executives of shared micromobility companies were previous employees from ride-hail companies, which carried knowledge and expertise in operating digital-platform transportation services, leading to spillovers. For instance, the founders of Meituan Bike and Bird, the trailblazers of shared micromobility in China and the US, were both from the executive team of ride-hailing unicorns, Didi and Uber. Ride-hailing companies, such as Lyft, Grab, and Boldt, also developed their micromobility services by themselves or by acquisition. Collaborations and partnerships between shared micromobility and ride-hailing companies also facilitated the growth and success of shared micromobility businesses. San Francisco-based companies Uber and Lime started a partnership in 2018, which enabled Uber users to rent a Lime scooter through their Uber app (Salinas, 2018). In 2020, Uber also led a direct investment in Lime, which helped Lime acquire its competitor and expand its service geography (Lime, 2020).

The cities of the top 10 shared micromobility unicorns (labeled cities in Figure 2-2 (a)) deviated from Alpha++ or Alpha+ world cities of global advanced producer services[7] (labeled cities in Figure 2-3 (b)) (Derudder & Taylor, 2016). Only four world Alpha++ or Alpha+ cities of global services, Beijing, Shanghai, Tokyo, and Singapore, had the top 10 shared

[7] The explanations of Alpha++ or Alpha+ world cities of global advanced producer services were quoted from the official website, The World According to GaWC: “Cities are assessed in terms of their advanced producer services using the interlocking network model. Indirect measures of flows are derived to compute a city's network connectivity. The connectivity measures are used to classify cities into levels of world city network integration. These levels are interpreted as follows: alpha++ cities In all analyses, London and New York stand out as clearly more integrated than all other cities and constitute their own high level of integration; alpha+ cities Other highly integrated cities that complement London and New York, largely filling in advanced service needs for the Pacific Asia.”

micromobility companies. Many cities of the top 30 shared micromobility companies are not even classified as the Alpha world cities of global services, such as Athens, Tallinn, Copenhagen, Warsaw, Leipzig, Bangalore, and Taipei. This phenomenon is consistent with the implication of Sassen's (1991, 2005) global city theory: the concentration of global advanced producer services, such as consultancy, accounting, legal services, and advertising, enabled multinational corporations to locate their headquarters in non-world cities of advanced producers service if the corporations can outsource the most complex and unstandardized functions.

When examining the organizational structure of these shared micromobility companies, I found that many advanced producer services were outsourced, and the headquarters' locations were less subject to agglomeration economies. For example, even the top 10 shared micromobility companies generally do not have their own accounting and advertising teams. Relatively small shared micromobility companies have limited resources and may lack the capacity to handle certain advanced producer services internally, so outsourcing can be particularly attractive for these small companies. If a relatively small company outsourced these advanced producer services and focused on other core business functions, such as engineering and operation, this company would not need to locate in world cities of advanced producer services to recruit people specialized in accounting, advertising, legal, and consultancy services.

In sum, the initiation of multinational shared micromobility companies was not a random process but closely associated with the agglomeration effects of world cities. The concentration of highly skilled talents, technological innovations, outsourceable global services, and startups and venture capital investments, together with the government policies determined where the shared micromobility companies were established and developed. Without these shared micromobility startups, it is impossible to witness the rapid expansion of shared micromobility

globally in the past decades. The next section devolved into how shared micromobility companies expanded across countries.

2.4.2. World City Network of Shared Micromobility

The comparison between Figure 2-2 (a) and (b) reveals that many regional cities were in countries comprising world cities of shared micromobility. Specifically, 38% of regional offices of a shared micromobility were situated in the country where the headquarters of this firm was based; 81% of regional offices were located in the continent where the headquarters of this firm was based; and 63% of regional offices were situated in countries containing any world cities of shared micromobility (Figure 2-4). The distribution pattern of regional cities reflected the "home bias" of country entry—setting up more regional offices in the home country and neighboring countries than countries with established shared micromobility businesses than other countries.

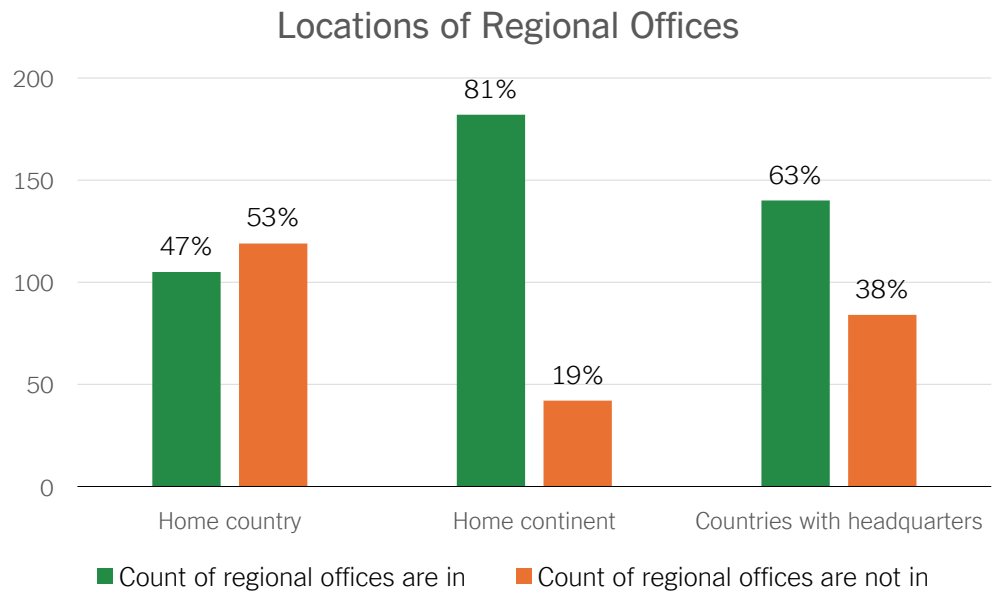


Figure 2-4. Locations of regional offices of shared micromobility.

The world city theory has limited capacity to explain the international development of multinational shared micromobility companies due to its focus on the headquarters, so I opted to

utilize theories in international business to explain the home bias of country entry decisions. The international market entry process has been studied by various approaches in the field of international business, such as the Euclidean approach (Vahlne & Wiedersheim-Paul, 1973), cultural perspective (Kogut & Singh, 1988), evolutionary approach (Mutinelli & Piscitello, 1998), institutional approach (Berry et al., 2010), and network approach (Coviello & Munro, 1997; Johanson & Vahlne, 2009). Except for the network approach, others focused on the barriers and costs of entering a foreign market. The concept of liability of foreignness can largely explain the additional cost faced by multinational companies for market entry, including cultural differences, regulatory barriers, institutional differences, and political risks. My interviews with employees from shared micromobility companies suggested that the market development relied on public-private partnerships (PPP) and collaboration with stakeholders in communities. Thus, it is not surprising that companies first expand services in home countries and neighboring countries or countries with well-developed shared micromobility systems and then to other foreign countries, which can mitigate the liability of foreignness while building a robust foundation for future expansions into more distant and diverse foreign markets.

For instance, the dockless bikeshare company, Ofo, developed the first dockless bikeshare program at Peking University in China. Then, Ofo launched several bikeshare programs at other universities where this campus-based business model can be easily duplicated. Once receiving venture funding, Ofo started to implement bikeshare systems in various Chinese cities and then cities in foreign countries. Many shared micromobility companies adopted this home-based piecemeal approach for business development due to the liability of foreignness.

The location of existing regional offices reflected the firms' market entry choices with the consideration of culture, regulatory barriers, and institutions. Individual cities in countries

with regional offices are connected to the world city hierarchy of shared micromobility. By contrast, cities in countries without subsidiaries face more barriers to connecting with these shared micromobility companies, as a country entry can be regarded as a significant capital cost for operating services in any city in this country.

2.5. The Inequality in Shared Micromobility Systems

The three maps in Figure 2-5 illustrate the inequality in service geography across countries with three indicators: 1) the number of shared micromobility systems per city (i.e., the average of cities' shared micromobility systems), 2) the number of shared micromobility systems per capita (i.e., the sum of shared micromobility systems in a country divided by this country's population), and 3) the number of vehicles per capita (i.e., the sum of shared micromobility vehicles in a country divided by this country's population). Even though there are some variations across these three maps, it is clear that the shared micromobility services were concentrated in the northern hemisphere, specifically in western and northern Europe and eastern Asia. Australia and Colombia have more shared micromobility services compared to other countries in the southern hemisphere. The distribution pattern of shared micromobility systems among countries can manifest the impact of the world city network of shared micromobility on country-level service distribution and suggest whether country-level variations should be controlled in the regression analysis. The country-level descriptive analysis is the bridge connecting the qualitative analysis of world cities with the mixed method analysis of inequality in shared micromobility systems among cities.

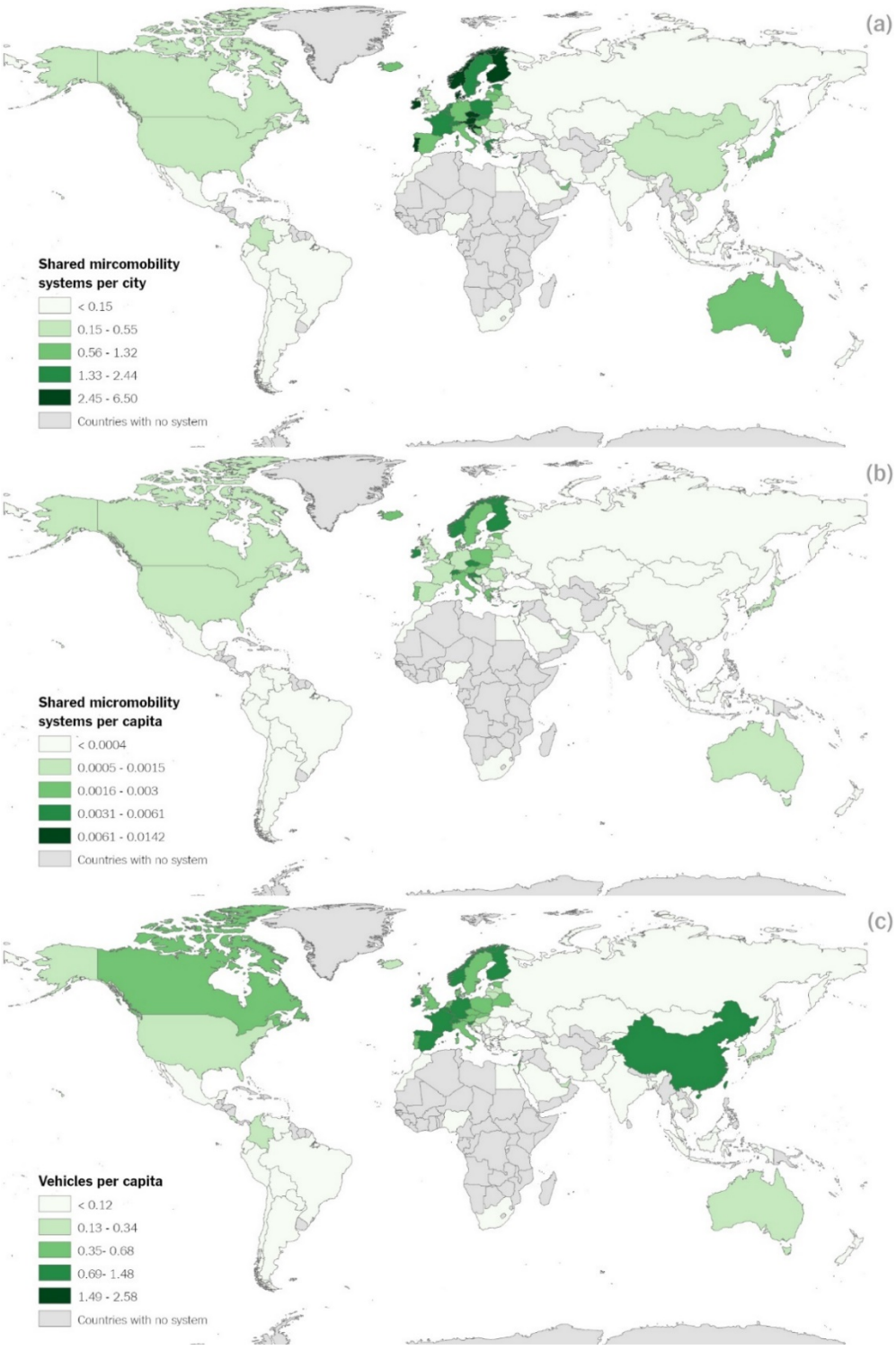


Figure 2-5. The distribution of shared micromobility by county: (a) the number of systems per city, (b) the number of systems per capita, and (c) the number of vehicles per capita.

Specifically, almost 93% of cities defined by GHS-UCDB do not have shared micromobility systems (Figure 2-6). For cities with shared micromobility, most (80%) have only one system. Figure 2-7 illustrates cities with at least one shared micromobility are significantly different from cities without a shared micromobility in terms of socioeconomics, built environment, and weather conditions. Cities with at least one shared micromobility system tend to be populated, economically developed, dense, compact, and characterized by high temperatures and low precipitation. Additionally, the number of systems in cities with headquarters (Mean = 5.05, Std = 3.51) and regional offices (Mean = 3.28, Std = 2.79) are significantly higher than that in other cities (p = 0.000).

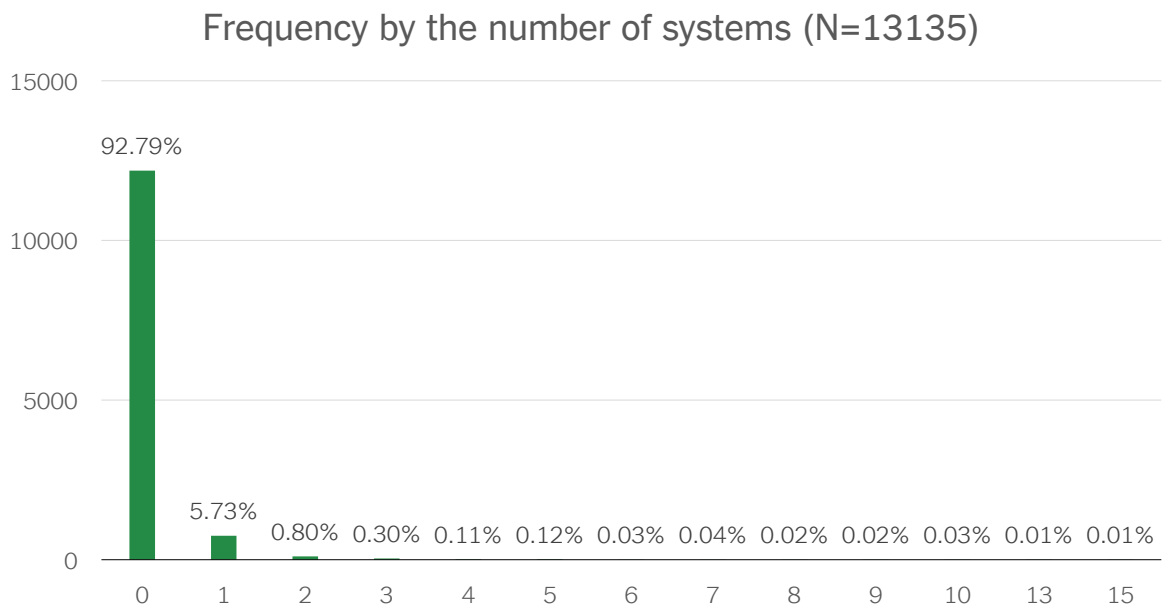
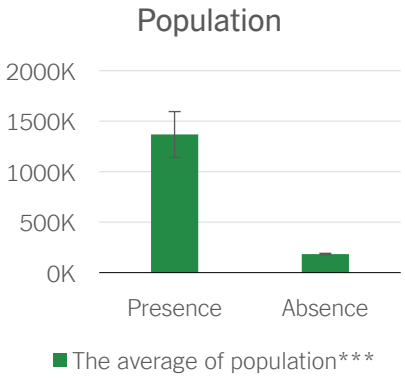
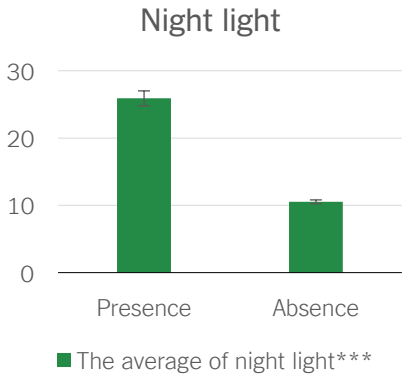
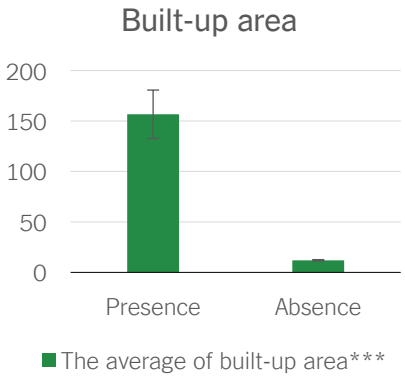
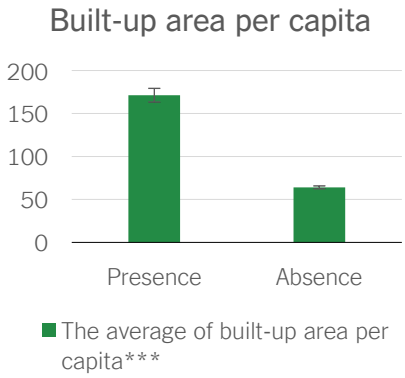


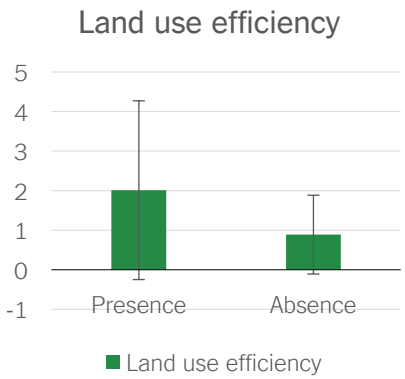
Figure 2-6. The frequency by the number of systems for cities worldwide.

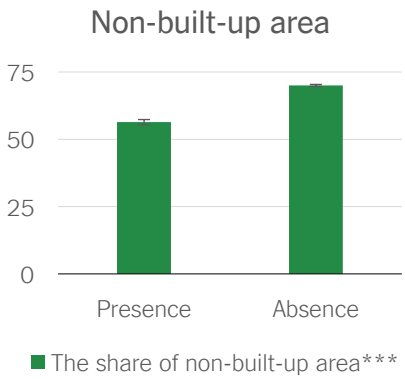

Population
2000K
1500K
1000K
500K
0K
Presence
Absence
The average of population***

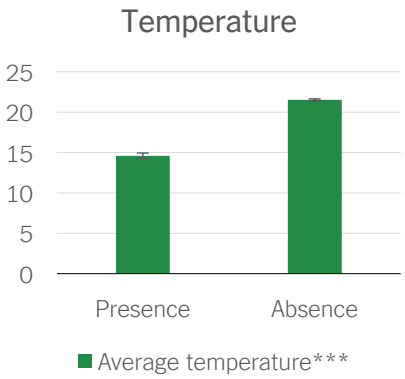

Night light
30
20
10
0
Presence
Absence
The average of night light***


Built-up area
200
150
100
50
0
Presence
Absence
The average of built-up area***


Built-up area per capita
200
150
100
50
0
Presence
Absence
The average of built-up area per capita***


Land use efficiency
5
4
3
2
1
0
-1
Presence
Absence
Land use efficiency


Non-built-up area
75
50
25
0
Presence
Absence
The share of non-built-up area***


Temperature
25
20
15
10
5
0
Presence
Absence
Average temperature***

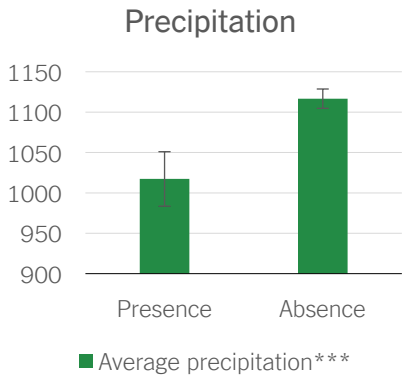

Precipitation
1150
1100
1050
1000
950
900
Presence
Absence
Average precipitation***

Figure 2-7. City-level characteristics by the presence of a shared micromobility system.

*Note: the number of asterisks denotes the significant level: *p ≤ 0.1, **p ≤ 0.05, ***p ≤ 0.01.*

2.6. Factors Impacting the Unequal Distribution of Shared Micromobility Systems across Cities

This section shows the factors that may, directly and indirectly, impact the implementation of shared micromobility systems in cities. The two important direct influencing factors identified by the literature are the local regulatory environment and the demand for shared micromobility. The interviews with employees from shared micromobility companies largely confirmed the importance of these two major factors. All shared micromobility employees mentioned a wide range of factors, highlighting the complex, variable, and context-specific decision-making process for market entry. A uniform point included the perceived demand for shared micromobility in a city and some specific indicators related to density. For example, an employee used a metaphor to illustrate the importance of demand:

> *Why do people rob banks? Because that's where the money is. Why do people bring products into certain markets? Because that's where the people are. So, places that have a density of population, places that have a density of destinations. Great places where people want to go, places where there is safe infrastructure is really important.*

Another important factor can be generally described as the regulatory framework. Almost all of the interviewed employees mentioned the role of government, local regulations, and laws in shaping the decision of market entry. An experienced global market development manager explicitly talked about this point:

> *Government and regulations are a big factor, right? So, you know, does the city want us to be there? Right. That's really important because you know that just makes it easier to*

run your business there, right? That's really important.

These in-depth interviews resonate with the findings from the literature. In the next two sections, I examine how demand-related factors and local regulatory framework can impact the local market entry of shared micromobility systems. Also, I harness the qualitative data to understand what leads to unfriendly regulatory environments and the deep-rooted reasons for cities' decisions to exclude shared micromobility systems, including the concerns regarding clutter, parking non-compliance, safety, insufficient infrastructure, the coalition between groups with opposite interests against shared micromobility, and the absence of active transportation in long-term planning.

2.6.1. Demand-related Factors

The demand-related factors were examined by both quantitative and qualitative analyses. Table 2-6 shows the results of multilevel Tobit regression analysis. Except for land use efficiency and population, all other city-level characteristics are significantly related to the number of shared micromobility systems, so these proxy variables may be able to predict the demand for shared micromobility perceived by shared micromobility companies.

Specifically, as expected, the population and night light emission (i.e., the proxy variable of economic activity) are positively related to the number of shared micromobility systems. The built-up area per capita, the opposite of population density, is the negative predictor, which is consistent with the literature (Eren & Uz, 2020; Y. Yang et al., 2019). The negative association between the share of non-built-up area, measuring urban compactness, and the number of systems implies that compact urban forms tend to accommodate a greater number of systems. Low average temperature and high precipitation are related to the increased number of shared micromobility systems, which reflects that shared micromobility systems tend to be located in

habitable places. For instance, the Great Basin in the US and the Northwestern Arid Region in China are both characterized by their arid climate with hot summers and extremely low precipitation. Shared micromobility systems are rare in these two regions compared to other regions in these two countries.

Also, among all the variables of interest, the absolute value of the coefficient of regional offices in a country is significantly greater than those of other variables. This suggests a firm's country-level entry decision largely determined the number of systems in a city by accounting for between-country variation, all else equal.

Table 2-6. Factors associated with the number of shared micromobility systems in a city, multilevel Tobit regression analysis results.

Variables	**Std. coef.**	**Std. err.**	**z-value**	**p**
Country-level				
The number of regional offices	1.487***	0.485	3.07	0.002
City-level				
Buit-up area	0.210***	0.029	7.35	0.000
Population	0.305***	0.029	10.62	0.000
Buit-up per capita	-0.114*	0.066	-1.73	0.084
Night light	0.352***	0.049	7.25	0.000
Precipitation	0.391***	0.064	6.07	0.000
Temperature	-0.295***	0.073	-4.03	0.000
Non-built-up	-0.478***	0.056	-8.48	0.000
Land use efficiency	0.054	0.043	1.24	0.215
Country-level Covariates				
Population	-0.342	0.514	-0.66	0.506
GDP	-0.717**	0.295	-2.43	0.015
GDP per capita	0.650***	0.106	6.12	0.000
Internet	0.539**	0.239	2.25	0.024
Electricity	0.626**	0.310	2.02	0.044
Urban population	-0.328*	0.189	-1.72	0.085
Constant	-4.143***	0.338	-12.27	0.000
Model summary				
N	8892	Uncensored	947	
Lef-censored	7945	Right-censored	0	
Number of groups	258	Prob > chi2	0.000	
Log-likelihood	-3203.68	Wald chi	945.05	

*p ≤ 0.1, **p ≤ 0.05, ***p ≤ 0.01

The qualitative analysis suggests that perceived low demand for shared micromobility is a common concern among many interviewees in cities without a shared micromobility system. The reasons for forming this perception vary significantly, including the absence of bicycle infrastructure, the competitive transportation mode, and the unbikeable land use and built environment. First, it is uncontroversial that bicycle infrastructure is significantly positively related to the demand for bicycling and shared micromobility (Eren & Uz, 2020; Yang et al., 2019). A transportation planner in a Bangladeshi city thought the disconnected bike lane may lower the demand for bicycling, undermining the feasibility of running a shared micromobility system in this city.

> *[Certain areas] have a dedicated lane for the bicycle, but the problem is that this is only for some kilometer or some road. They are providing the dedicated lane but this is not a network. If you have only a lane for the bicycle in some segment, this will not actually work because you cannot do all the thing you have to do by the bicycle. If you can have your infrastructure to introduce the shared mode of transport in [city's name], you can do that. But without this, this will be failed.*

Second, other two-wheeled transportation modes (e.g., private moped, motorcycle, two-wheeled ride-hailing) are prevalent in many cities. These travel modes have their advantages (e.g., carrying people and goods) that are absent in the mainstream shared micromobility systems (e.g., shared bicycles and e-scooters). If shared micromobility companies and cities cannot develop adaptive vehicles and services to serve local needs, many interviewees do not regard shared micromobility as a viable transportation alternative. A city staff member in a small county-level city in China introduced the advantages of other popular micromobility in Chinese cities:

> *People here have a low demand for shared bicycles, as most people choose to use*

motorcycles and e-mopeds for commuting. Motorcycles and e-mopeds can carry goods and other people, so they serve the needs of families here better than shared bicycles. [shared bicycles are] suitable for riding alone.

Most shared micromobility vehicles are not equipped with passenger seats, while shared e-scooters and some shared bicycles are not fitted with baskets. Studies have shown that the inconvenience of carrying people and goods is one of the major deterrents to shared micromobility, and cargo bikes can fill in this strategic gap (Pimentel & Lowry, 2020; Riggs, 2016). Additionally, in many South Asian cities, the local ride-hailing platforms not only provide car-based services but also incorporate two-wheeled services (e.g., hailing motorcycles and e-mopeds). Given the weather conditions (i.e., hot and humid tropical climate) and low labor cost in these cities, these existing two-wheeled transportation services may be more attractive to local residents and tourists.

Lastly, land use and built environment also impact the perceived demand for micromobility. As illustrated in the literature review, the high-density environment, mixed land use, and compact and connected urban form are generally associated with increased demand for bicycling. By comparison, the low-density environment, single land use, and urban sprawl may deter active transportation and limit the travel scenario of shared micromobility. A planner in a small college town in the US mentioned:

[This city] is a car-dependent place, so shared e-scooters may only be useful within the campus.

In sum, the perceptions of low demand for transportation derive from interviewees' local knowledge of the urban transportation system, infrastructure, and built environment. Nevertheless, the problems of demand analysis based on observing existing travel behaviors are

well-established in transportation equity studies (Martens, 2016). None of these cities have investigated people's latent demand for shared micromobility, and people in these cities may need shared micromobility. For instance, in many dense cities in Asia, various destinations are within the bikeable distance. If the city can create a well-connected bicycle network, shared micromobility can serve as a viable transportation alternative for the locals.

2.6.2. Regulatory Environment

As summarized by the literature and analysis of interviews with companies' employees, the regulatory environment is another primary factor determining companies' entry decisions at the local level (Han, 2020; Swofford, 2020; Troyslit, 2016). The regulatory environment is generally not hospitable in these cities, as only interviewees in four cities were enthusiastic about shared micromobility. However, the higher-level (e.g., state or national level) regulatory framework can act as a deterrent to implementing shared micromobility. A planner in a large US city elaborated on the goal of incorporating shared micromobility into the city's transportation system:

> *[Y]ou want everyone to be able to bike, walk, or scooter to fresh fruits and groceries to any essential means within 15 minutes where you want to be lowering the cost of transportation for everyone.*

Despite the city's enthusiasm, dockless shared e-scooters have been banned by the state legislature, effectively barring scooters from operating locally. The city was authorized by the state legislature to run a two-year shared e-scooter pilot program. This program developed detailed policies with stakeholders to ensure safety, equity, and compliant parking, but it concludes with an indefinite pause in shared e-scooter operations now. The statewide ban demonstrates how higher-level government regulations can bar market entry even where local

demand exists. In addition to state or broader government-level support, local regulatory frameworks are important for shared micromobility to enter a market. The other two small cities in China and the US also saw the potential benefits of introducing shared micromobility for the cities, such as revitalizing relatively high-density (e.g., downtown) districts, providing alternative transportation options, riding shared micromobility for fun and public health, and attracting tourists. However, these cities generally had no experience in planning for and managing shared micromobility and therefore lacked regulatory frameworks. The absence of pre-existing regulations on shared micromobility is not attractive for shared micromobility companies, as an employee specialized in market development from a shared micromobility company mentioned:

> *Well, there's nothing here. So, we have to build it from scratch, so it's one of those situations where you're not just showing up and it's like well then things are already in place…And so these are all challenges.*

Another company's blog explicitly mentioned how the absence of the regulatory framework led to the withdrawal from small cities (Bird, 2022):

> *[W]e have conducted a thorough review of our portfolio of cities to determine whether or not they possess the regulatory framework necessary to facilitate the development of an innovative, competitive, self-sustaining micromobility industry. It has become clear that some markets lack such a framework...Therefore, taking into account both the economic viability of markets and the regulatory environment, we have had to make the difficult decision to wind down operations in several dozen, primarily small to mid-sized cities across the U.S.*

A clear regulatory framework denotes a stable business environment for the operators, while smaller cities without regulations may therefore struggle to attract or retain shared

micromobility operators. Overly strict regulations, too, may also significantly slow down the development of shared micromobility, even if the regulatory framework is clear and explicit. For example, an urban planning PhD candidate in Japan explained how the strict regulations resulted in the slow growth in shared micromobility:

> *...It is also illegal to leave an abandoned bicycle in public space, so you need to go through a process to dispose of your bicycle. All these regulations will increase the cost of running a shared bicycle system. Riding a shared bicycle is even more expensive than taking a taxi for the same trip if you have a partner to share the taxi fee, not to mention the public transit. So, I am wondering how shared bicycles can scale up here.*

Compared to cities with positive perceptions of shared micromobility, other cities expressed more concerns about its potential impacts on cities. Thus, these cities either banned or maintained negative attitudes towards shared micromobility, resulting in an inhospitable regulatory environment. The following sections delve into the specific barriers that result in an unfriendly regulatory environment.

2.6.3. Clutter, Parking Non-compliance, Safety Concerns, and Insufficient Infrastructure

Similar to previous literature, this study finds that cluttering public right-of-ways, non-compliant parking, safety concerns, and insufficient infrastructure, were the major concerns identified by interviewees about shared micromobility services. Even though these concerns can only be directly observed after the implementation of shared micromobility, many interviewees share these common concerns with their general perceptions of shared micromobility. These four types of common concerns are interconnected. For instance, a recent study shows that the public tends to use pedestrian accessibility (i.e., whether the e-scooters clutter the pedestrian right-of-way) to assess parking compliance (Klein et al., 2023). The public holds an intuitive

understanding that blocking the right-of-way is wrong, but they also think that scooters that they deem as visual clutter (not parked tidily) are also parked incorrectly. The perception based on visual preference is not often true based on city parking requirements. Therefore, planners and city officials in cities without shared micromobility systems and regulatory frameworks may also tend to lump the concerns about cluttering, misparking, and riding together. A planner in a big city in China said:

> *[T]he government is worried about the three types of potential chaos resulting from implementing shared micromobility: chaotic deployment, chaotic riding, and chaotic parking.*

Studies in multiple cities worldwide have shown that the frequency of improper parking is quite low in commercial areas (Brown, 2021; Fang et al., 2018; Klein et al., 2023), and car drivers are more likely to mispark their vehicles than scooter riders (Brown et al., 2021). However, many news reports tended to expose the negative impacts of this new transportation mode, raising public concerns (Gössling, 2020). These misconceptions of shared micromobility may largely result from the dockless feature of many new shared micromobility systems (Gauquelin, 2019). Another planner in a tier-3 Chinese city mentioned:

> *Compared to the docked public bikeshare, the dockless bicycles are convenient for the citizens to use, but this mode led to more frequent misparking and cluttering public space. From the perspective of urban management, it generates more challenges than opportunities for the city.*

Even though the perceptions of cluttering and non-compliant parking may derive from the availability bias, the rapid development of shared micromobility fueled by venture capital investments in the past decade may lead to valid concerns (Shaheen & Cohen, 2021). For

instance, even though many Chinese cities have connected bicycle infrastructure, some cities are concerned that the existing bicycling infrastructure cannot accommodate the influx of shared micromobility, which could result in disordered riding and parking. Another city staff member from a populated tier-3 city in China explained this point based on the informal analysis of urban form:

> *Main roads in the urban core are very narrow with no dedicated bike lanes. After placing shared bikes or e-bikes, [I] anticipate the situation where cars and shared bikes are sharing the lanes will rise sharply. Also, the building setback is very limited, so it is hard to meet the demand for deploying shared bicycles. [Anticipated] misuse and misparking of shared bicycles will seriously impede public order and cause traffic congestion.*

Safety issues were less mentioned in the Chinese context than in the Western context, according to interviews and news text mining studies (Gössling, 2020; Wu & Lei, 2019). The distinct perceptions of safety issues may originate from the difference in major transportation modes for daily travel. In China, the mode share of bicycling and motorcycling is notably high, whereas in many US cities, the mode share of bicycling remains around 1% (McKenzie, 2014). When shared micromobility vehicles appear in the street, the potential conflicts between shared micromobility users and other road users will raise safety concerns. For example, even though many advocacy groups for shared micromobility in the city with the state-level ban on shared e-scooter seek to legalize e-scooters at the level, the legislation was strongly opposed by the disability and aging organizations due to safety concerns. For example, a statement from a local organization said:

> *Residents throughout [this city] who are disabled, elderly, have real mobility needs, and are in search of real mobility solutions have long raised concerns about scooters and*

their prioritization in the city's transportation policy.

The concerns of cluttering public right-of-ways, non-compliant parking, safety, and insufficient bicycle infrastructure are widely held by interviewees from cities across the world. Nevertheless, cities can implement various policies and requirements to build bicycle infrastructure and address the negative impacts of introducing shared micromobility systems. Recent studies show that providing sufficient virtual or physical parking corrals, implementing a lock-to policy, and designating parking areas can significantly lower the non-compliant parking rate and then contribute to addressing the clutter issue (Klein et al., 2023; Meng, Brown, Klein, et al., 2024; Nivel, 2023). Other easy-to-implement requirements, such as designated operating zones, speed limits, and assembled helmets for vehicles, can also address safety concerns. Therefore, the concerns of cluttering, misparking, and safety may not be the primary deterrents to developing shared micromobility, as the studies discussed above, and the regulations and policies developed by other municipalities have provided effective solutions to these problems. The following sections will delve into specific concerns of cities without shared micromobility systems, which create additional barriers to implementing shared micromobility systems.

2.6.4. The Coalition between Groups with Opposite Interests against Shared Micromobility

As previously discussed, existing studies and interviewees suggest that planners, community organizations, and the public are concerned about the negative impacts of shared micromobility on cities and public interests. However, this opposition may be supported by both "Bootleggers and Baptists."[8] The interest group that can benefit from the ban on shared

[8] The theory of Bootleggers and Baptists was first issued by Yandle (1983). Yandle (1999) provided a formal definition of the Bootleggers and Baptists theory in a retrospective paper: "Durable social regulation evolves when it is demanded by both of two distinctly different groups." Yandle (1999) also highlighted the different roles of bootleggers and Baptists: "It is worth noting that it is the details of a regulation that usually win the endorsement of bootleggers, not just the broader principle that may matter most to Baptists." Thus, even if a shared micromobility is implemented in a city, how the system operates may largely be subject to "bootleggers" rather than "Baptists."

micromobility may also be antagonistic toward the implementation of shared micromobility. In the Bangladeshi city, the vehicle mode share of rickshaws[9] was around 50%, while that of bicycles was around 2%. The group of rickshaw drivers is connected to the local business groups and politicians, and the planner in this city mentioned the barriers to introducing shared micromobility created by this ecosystem:

> *The ecosystem [rickshaw drivers, businesspeople, politicians] I already told about you that businessmen or the political people who are who are getting the advantages of rickshaw in the road, they will not welcome [shared micromobility] in the road.*

Many surveys and studies have shown that shared micromobility can replace taxi and ride-hail trips (Wang et al., 2023), so introducing shared micromobility may pose a threat to these interest groups, especially in small cities where shared micromobility is more likely to replace taxi and ride-hail trips due to the overlapped accessibility patterns. The anecdotal evidence from the social media platform illustrates the barriers set up by the local interest group. A comment to a post discussing the absence of shared micromobility in a small city stated:

> *To summarize, there are only two points: more troubles and less returns. Shared bicycles impact bus, taxi, and ride-hail. If [shared micromobility companies] act like taxi companies who give enough money, [the government] will take care of everything.*

In the case of banning shared micromobility, planners and some social groups— "Baptists" —took the moral high ground and endorsed the ban of shared micromobility for public interests. In contrast, the taxi and rickshaw groups— "Bootleggers" —expected to prevent their profits from the implementation of shared micromobility, supporting the ban for personal interests.

[9] Rickshaw is a two- or three-wheeled non-motorized cart, pulled by one person.

2.6.5. The Absence of Active Transportation in Long-term Planning

The interviews ended with questions on the role of shared micromobility in future transportation planning. Cities in China and Bangladesh developed long-term transportation master plans, which specify the goals of transportation development, the major transportation projects, and the capital investments. Active transportation projects and programs are generally not prioritized or even absent in these long-term transportation plans; instead, the focuses include regional railway and highway transportation networks, green and intelligent transportation, and freight transportation. Most planners did not recognize the role of shared micromobility in constructing multi-modal transportation systems:

> *The shared micromobility is good, but the thing is that we need to develop our bus transit…, elevated expressway…, and traffic management.*

Transportation planners still hold the mindset that pursues mobility, motorization, control, and technology. Additionally, this mindset is reinforced by the recent development of electric and autonomous vehicles, which are subsidized by various levels of government. a planner in a medium-sized Chinese city mentioned the underlying principles for future transportation planning.

> *The two fundamental principles for constructing the transportation system are to utilize new and clean energy and develop smart and intelligent transportation.*

These mega transportation projects and the electric and autonomous vehicle industry are regarded as the stimulus to boost economic growth, while the economic benefits of introducing shared micromobility are not obvious for cities.

2.7. Conclusions

Previous studies on inequalities in shared micromobility have predominantly focused on intracity service or trip inequality among communities, and limited intercity studies on shared micromobility only examined the system-level performance, such as utilization or turnover rate. In this study, I explored the location choices of multinational shared micromobility firms' headquarters and national-level market entry under the perspective of world city theories. Also, I utilized mixed methods to explain the unequal service geography of shared micromobility across cities worldwide. I found that the headquarters of shared micromobility are concentrated in a small number of cities primarily in developed regions—world cities of shared micromobility. Resonating with the studies on world cities of ride-hailing (Brail, 2022), the world cities of shared micromobility reinforced a shift from traditional world cities to world cities in the digital economy. Cities in Asia, Eastern Europe, and South America are shaping the geography of digital platform-based transportation services, but very limited world cities of shared micromobility are situated in the global south. The locations of world cities of shared micromobility are associated with the spillover effects of ride-hailing companies, the outsourceable advanced producer services, and the access to venture capital investments.

The country-level entries by shared micromobility companies, measured by the location of regional offices, reflect the home bias. The successful operation of shared micromobility requires mutual trust in public-private partnerships, so expanding service to foreign markets with different cultures, regulatory environments, institutions, and political ecosystems is very risky for shared micromobility companies. Locating regional offices more in the home and neighboring countries can mitigate the liability of foreignness, which also suggests that the global shared micromobility development is still at the initial stage. The regression analysis shows that the

number of regional offices in a country is the most significant predictor for the number of shared micromobility systems in a city, mainly accounting for between-country variations. Therefore, the location choices of headquarters, regional offices, and local operations are deeply connected.

Besides the concerns discussed in previous literature, this study found four new major barriers to implementing shared micromobility: the strict or lax regulatory framework, the perceived low demand for shared micromobility, the coalition by two distinctly different groups for banning shared micromobility, and the absence of active transportation in the long-term transportation planning. First, regulatory frameworks can either be too restrictive or too lax to implement shared micromobility systems, and both extremes present different sets of problems. The onerous regulations would increase the cost of operations, limit flexibility, and stifle potential innovations, while the absent regulatory framework may also increase the cost of entering a city, raise concerns about safety and parking, and lead to an unstable market environment. Effective regulation needs to involve collaboration between micromobility companies and local governments. Second, the city's perceived low demand for shared micromobility deters the implementation of shared micromobility. This perception resulted from the interviewees' local knowledge of transportation systems, built environments, and land use patterns. By contrast, controlling the country-level variables, the regression results suggest that populated, economically developed, high-density, compact, and climate-habitable cities tend to have a larger number of shared micromobility systems.

Third, barriers identified in previous studies, such as safety hazards, misparking, and insufficient infrastructure, also appeared in this study. They may be real concerns for those who care about public interests, but they can also be the cover for those whose private interests may be undermined due to the introduction of shared micromobility systems. The "coalition" between

groups with distinct intentions may make it very difficult to expand shared micromobility services, even in places with high demand. Last, active transportation is not typically a high priority in comprehensive or long-range transportation planning, which currently highlights the intelligent and electrified development of motorized modes. Transportation professionals have a deep-rooted preference for motorized transportation systems in many municipalities across the world, which has been shaped by a set of ideas embedded in the transportation practice, such as mobility, speed, control, and technology. To integrate shared micromobility into our cities, transportation professionals need to embrace the paradigm shifts from planning for motorized transportation to planning for multi-modal transportation systems.

This study acknowledged limitations that warrant consideration. First, despite utilizing a diverse range of shared micromobility data sources, the dataset of shared micromobility systems is not comprehensive. This exclusion arises due to the unavailability of system information for many shared micromobility programs in small municipalities, which might not be accessible online in English. Thus, I may leave out a few major shared micromobility operators in the world city analysis. Second, the identification of regional offices may not be 100% accurate. Even though I utilized multiple data sources (e.g., official website, LinkedIn, and company directory websites), the location information of some regional offices may not be available online. Third, the regression analysis is subject to several limitations. The regression only examined city-level characteristics related to the demand for shared micromobility, so it may have omitted important variables that led to incorrect inferences about the relationships between variables. Using the number of systems in a city as the dependent variable may not correctly reflect the availability of shared micromobility services for this city, as the fleet size information of the systems was not complete. For instance, one system with abundant shared micromobility vehicles can provide

more extensive service geographies than several systems with limited vehicles. Also, the data for the regression analysis is cross-sectional, which cannot account for the dynamic nature of many variables. Last, the sampling of the interview is not a random process, undermining the generalizability of interview findings.

CHAPTER III

NATIONAL PERSPECTIVE: EXAMINING THE EFFECTS OF EQUITY POLICIES ON INEQUALITIES IN SHARED MICROMOBILITY

3.1. Introduction

In the United States, shared micromobility ridership witnessed an approximately fourfold increase between 2017 and 2019 due to the advent of dockless shared micromobility systems, notably shared e-scooters and bicycles (Figure 3-1). Despite the COVID-19 pandemic's negative impact on travel patterns, micromobility ridership nearly rebounded to pre-pandemic levels by 2022, and it is anticipated to surpass 2019 levels in 2023 (NACTO, 2023). As previously mentioned, shared micromobility has the potential to enhance sustainable transportation systems by addressing numerous issues associated with car dependency (Abduljabbar et al., 2021; McQueen et al., 2021; Şengül & Mostofi, 2021). However, the rapid expansion of shared micromobility introduces significant regulatory challenges for municipalities, including traffic accidents, vandalism, improper parking, and inadequate bicycle infrastructure (Latinopoulos et al., 2021; Ma et al., 2021).

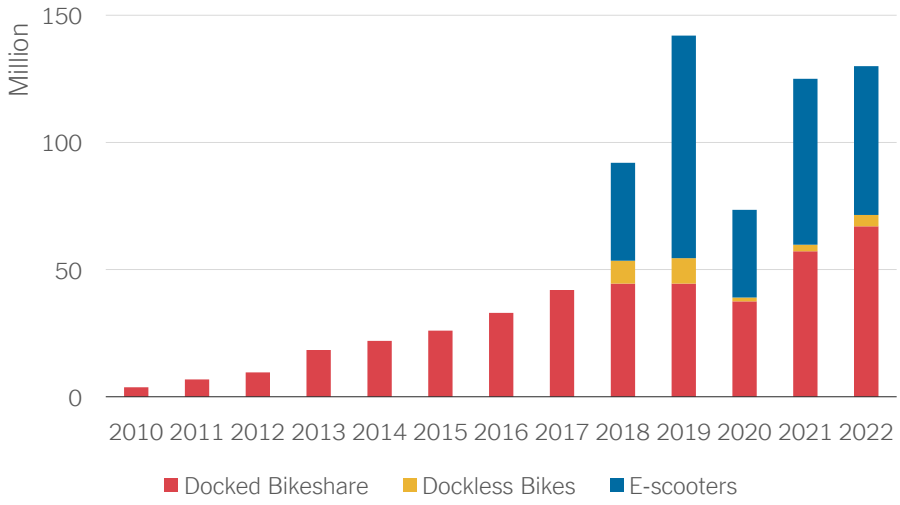


Figure 3-1. Shared micromobility ridership in the U.S. and Canada, 2010-2022.

Note: drawn by the author using data acquired from NACTO (2023)

Furthermore, shared micromobility also faced intracity equity-related challenges, which limited usage among vulnerable populations (Bai & Jiao, 2021). For instance, shared micromobility services were not equally distributed across communities in US cities, potentially leaving underserved communities further marginalized by transportation services (Barajas, 2018; Meng & Brown, 2021). Studies have shown that shared micromobility services were predominantly concentrated in affluent and white communities, whereas access to shared micromobility services was significantly lower among low-income and minority communities (Dill & McNeil, 2021). Additionally, the cost of using shared micromobility could be a significant barrier for lower-income individuals. Many shared micromobility systems utilized monolingual smartphone applications for reservations and payments, necessitating bank accounts, which could also exclude non-native-language speakers, non-smartphone users, unbanked, and less tech-savvy people (Abduljabbar et al., 2021).

To address these equity concerns in shared micromobility systems, many cities have established equitable policies and requirements for shared micromobility operators. For instance, shared micromobility operators were required to expand service geographies to areas historically underserved by transportation, where shared micromobility could satisfy short and medium-distance travel and serve as a valuable solution for last-mile connectivity (CDOT, 2020; PBOT, 2019). A technical report outlined equitable service standards and programs addressing these concerns, including affordability for low-income individuals, digital access, neighborhood service coverage, education and outreach, and access for people with disabilities (Shaheen & Cohen, 2019). A national scan of docked bikeshare systems showed that almost three-quarters of

bikeshare systems have equity programs, and small systems without receiving funding through the Better Bike Share Partnership were less likely to implement equity programs (McNeil et al., 2019). These bikeshare systems mainly tackled equity through various approaches, including service area designation, payment and fees, education or facilitation programs, marketing, mixed fleet options, internal operations, and transit integration. Another evaluation of e-scooter policies revealed that 56% of 61 surveyed municipalities identified equity requirements for operators, with 5% of municipalities in the process of developing such policies (Riggs et al., 2021). Typical equity requirements included payment plans for low-income users, distribution mandates, vehicle limits, and incentives. A recent comprehensive national-level examination of equity policies for shared micromobility systems indicated that 62% of the 230 programs surveyed had developed equity requirements (Brown & Howell, 2024). Equity requirements, strategies, evaluations, and implementation varied significantly across programs and cities and requirements generally fall within the following categories: reduced fares, multilingual services, cash payment compatibility, non-smartphone access, adaptive vehicles for users with disabilities, mandated geographic service areas, and targeted marketing and outreach.

Given that existing literature primarily summarized equity policies and relied on qualitative feedback to gauge equity performance, these reports suggested a need for developing a data-driven mechanism to examine the efficacy of equity requirements to achieve equitable outcomes. This nation-level study therefore aims to explore if and how equity-based policies and requirements for shared micromobility systems achieve equitable outcomes under the perspectives of strict and luck egalitarianism in the US. Policies developed based on strict egalitarianism or resource-equalizing principle aim to equalize transportation resources for everyone, while policies based on luck egalitarianism or opportunity-equalizing principle aim to

compensate the transportation disadvantaged to ensure equal opportunities for using transportation services.[10] These two equity principles can effectively categorize the current equity policies and requirements in shared micromobility, which enables the establishment of a suitable evaluative framework. Specifically, the following specific research questions will be addressed:

1. How are the inequalities in shared micromobility vehicle distribution associated with inequalities in shared micromobility trips?
2. How do equity policies based on strict egalitarianism relate to the inequalities in shared micromobility vehicle availability?
3. How do equity policies based on luck egalitarianism relate to the inequalities in shared micromobility trips?

In this study, I employed a recently published dataset that contains shared micromobility equity requirements (Howell et al., 2023) and structural equation modeling to investigate the direct and indirect relationships among these two types of equity policies, inequalities in shared micromobility, and equity outcomes of shared micromobility programs. This research reveals the overall equity landscape of shared micromobility in the US and establishes a framework for evaluating the impact of equity policies and requirements on shared micromobility based on the standardized format of open data. Furthermore, this theoretical framework is applicable to evaluate the effects of various equity requirements on reducing the inequalities in benefits and burdens of other transportation modes.

[10] Strict egalitarianism and resource-equalizing are used interchangeably, and luck egalitarianism and opportunity-equalizing are identical in this study. However, given the direct connotations of these terms, I used the terms "strict and luck egalitarianism" in the literature review and theoretical sections and the terms "resource- and opportunity-equalizing" in the analysis and discussion sections more frequently than in other sections.

3.2. Literature Review

3.2.1. Equity as Distributive Justice

Equity has various connotations in different fields. Therefore, clarifying the concept of equity is paramount in this research to preclude misconceptions. The emergence of perspectives on equity in urban and transportation planning dates back to the 1960s with the formulation of advocacy planning (Davidoff, 1965). Norman Krumholz, recognized as the father of equity planning, embraced the theory of advocacy planning and argued that equity planners should more properly serve the needs of their cities' poor and working-class residents (Krumholtz, 1986; Krumholz, 1982). Over the past several decades, equity planning has evolved; nowadays, equity planning seeks to expand options for those with limited choices and redistribute resources, political power, and participation to disadvantaged, lower-income residents of their cities (Krumholz & Hexter, 2022).

The goals and practices of equity planning highlighted the distribution and redistribution of planning outcomes toward disadvantaged people in cities, thus, at its core, equity planning embodies *distributive justice:* "how a society or group should allocate its scarce resources or product among individuals with competing needs or claims (Roemer, 1996) ." However, neither advocacy planning theory nor equity planning practices addressed the fundamental normative questions about distributive justice (i.e., "equity" in the planning context) principles for achieving equitable outcomes (Krumholz & Hexter, 2022). Principles of distributive justice offer moral guidance for the political processes and structures, which profoundly shaped and reshaped planning frameworks (Lamont & Favor, 2017). When planning for the disadvantaged, planners may adopt different frameworks within different institutions, planning processes, and policy goals, resulting in distinct distribution patterns of planning benefits and burdens. For example,

the strict egalitarian principle pursues the equal distribution of planning outcomes, while Rawlsian principles highlight the highest absolute gains for disadvantaged people regardless of the relative proportion. Numerous principles align with the overarching goal of equity planning, yet they may yield nuanced or contrasting implications for policies, so it is important to examine different distributive justice principles.

3.2.2. Equity Principles in Transportation Planning

Principles of distributive justice derive from broader theories of justice. For instance, the utility-based principle, which seeks to maximize happiness/utility for the greatest number, was the core of Jeremy Bentham and John Stuart Mill's utilitarianism theory (Driver, 2022); the difference principle was a key component of John Rawls's theory of justice as fairness (Rawls, 2001); libertarian principles originated from John Locke's labor theory and Kant's categorical imperatives and advanced by Robert Nozick (Lamont & Favor, 2017). Similarly, equity principles in transportation planning have been developed based on these overarching principles of distributive justice (Martens, 2016; Pereira et al., 2017; Pereira & Karner, 2021). Two principles, utilitarianism and egalitarianism, have been prominent in the evolution of the transportation planning process (Lewis et al., 2021).

Utilitarianism in the transportation planning and policy-making process was merely a reflection of simplistic aggregative consequentialism, so the general principle is to maximize the aggregated benefits and minimize the aggregated burdens for the people. However, this principle faces twofold problems: specification and implementation. Similar to the diverse theories of justice, utilitarianism encompasses a broad spectrum of claims, such as ideal utilitarianism, act and rule utilitarianism, preference utilitarianism, and negative utilitarianism, which were sometimes related but more often conflicted (Sinnott-Armstrong, 2023). Thus, policies directed

by different utilitarianism principles would have distinct practical outcomes. For instance, policymakers adhering to preference utilitarianism might support costly transportation projects that serve few, if any, or other misinformed, horrendous, or trivial policies that are morally acceptable if they satisfy people's preferences. Conversely, proponents of hedonistic utilitarianism will reject this project since it does not effectively contribute to increasing pleasure for people. Due to the lack of discussion on the specification of utilitarianism in the transportation field, this also renders the implementation process untenable. For instance, many transportation engineers utilize the monetary value of saved time as an important indicator for directing and distributing transportation investments, as the derived utility is measured by people's willingness to pay (Martens, 2016; Pereira et al., 2017). This specific construct of utility together with a revealed preference for predicting future travel needs inevitably leads to a distribution of more transportation resources to people conducting highly profitable activities and ignoring disadvantaged people's needs (Levine, 2013). Conducting intrapersonal comparisons is challenging by claiming that the marginal utility of a trip for luxury activities for an affluent person is larger than that of a trip for basic needs for a disadvantaged person. Also, utilitarianism, a teleological moral theory, contrasts significantly with deontological theories, which have vastly different practical implications, such as Kant's theory of justice.

As transportation equity issues raised concerns, partly because of the utility-based transportation planning and policies, researchers and policymakers in transportation have increasingly incorporated egalitarianism as the primary equity principle implicitly (Lewis et al., 2021). Like utilitarianism has various branches, egalitarianism is likewise an umbrella concept encompassing various specific principles. Transportation equity analyses often adopt egalitarianism as the fundamental equity principle without a clear explanation, so egalitarianism

can denote strict egalitarianism, prioritarianism, formal equality, and proportional equity (Lewis et al., 2021). In transportation practices, strict egalitarianism or rough proportionality is often regarded as the default principle for equity planning, as it has the clearest definition that is intuitively acceptable (Forkenbrock & Schweitzer, 1999; Kolm, 2002; Lamont & Favor, 2017). Nevertheless, a study of transportation plans developed by metropolitan planning organizations (MPOs) suggests that most MPOs failed to develop explicit equity principles and used equity standards in a "haphazard" and "opportunistic" way (Martens & Golub, 2021). Based on the literature and review of transportation policies, I argue two egalitarianism principles, strict and luck egalitarianism, have been frequently adopted in transportation research and practice as the guiding equity principle, which could incorporate variations of egalitarianism principles.

3.2.3. Strict Egalitarianism versus Luck Egalitarianism

Strict egalitarianism is one of the simplest principles of distributive justice (Lamont & Favor, 2017), emphasizing the equal distribution of materials and resources among individuals. Previous studies have found that many local municipalities implicitly regard strict egalitarian distribution as their guiding equity principle (Karner et al., 2020; Martens et al., 2019, 2022), as it has the most direct and clear policy implications. Moreover, because aggregated utilitarian principles lead to unequal distribution in transportation services, strict egalitarianism could address this trend non-controversially. Equitable transportation planning and policies based on strict egalitarian principles can be directly translated into resource-equalizing policies. Given the clear policy goals of resource-equalizing policies, the implied equity requirements aim to fill in gaps in the transportation system by providing increased transportation goods and services for underserved areas and people, as an immediate remedy for historically inequitable transportation practices.

Luck egalitarianism, centered on equality of opportunity, seeks to ensure equal access to opportunities despite the unequal distribution of materials and resources, widely accepted in disciplines such as education and healthcare (Daniels, 2017; Shields et al., 2023). Luck egalitarianism is a response to Rawls' challenge on the returns to luck rather than factors for which people are responsible, which was primarily developed by Ronald Dworkin, Cohen, and John Roemer (Arneson, 2004). Ronald Dworkin's theory differs from Rawls' difference principle in two key aspects (Dworkin, 1981). First, Dworkin proposes that people should have equal start points (i.e., the "level-the-playing-field" metaphor) by compensating for variations in endowment. Given that transportation goods and services hold unique social significance by enabling mobility for achieving various ends, they should be allocated differently (i.e., outside the market system) (Martens, 2012; Martens et al., 2012). Accordingly, transportation policies should guarantee a sufficient or comparable level of resources for everyone, akin to the insurance model in Dworkin's thought experiment. For example, it is justified to offer additional services and facilities for people with disabilities to ensure their ability to travel on par with others. Second, individuals ought to be accountable for their choices when provided with equal starting points. Therefore, if a person decides to invest a little in utilizing transportation services, transportation policies should not distribute excessive resources to this person for equalized accessibility and travel outcomes. For example, if two people with similar backgrounds are neighbors, but they have different preferences on acceptable walking distance for accessing public transit. If a transit stop is within one person's acceptable walking buffer but outside another person's acceptable buffer, transportation policies should not compensate for the latter's preference by relocating the transit stop closer to them or other approaches.

3.3. Theoretical Framework

Roemer (1993, 1996, 2002) formalized the luck egalitarianism for equalizing opportunities as follows:

$$O = f(\varphi,\ e,\ C) \qquad (3.1)$$

Where O is the individual outcome; φ is the policy developed by planners; e represents the individual's effort; C denotes the individual's circumstances. Also, the value of the individual's C can define this person's type. To further explore this function, Roemer first assumes that the whole population has a limited number of types, and the continuum of people in each type exists. He uses t to represent types $1, 2, 3, \ldots, \tau$. Also, the set of types is denoted by T, and the set of potential policies is represented by Φ. Furthermore, Roemer assumes that given any introduced policy φ, one can expect that a distribution of effort in each specific circumstance (i.e., type), represented by F_{φ}^{t}, defined as a probability measure over the set of non-negative real numbers, representing the range of possible efforts. An additional related assumption is followed: effort is represented by a one-dimensional variable. Given that **P** represents the set of all probability distributions over $\mathbb{R}_{+}$, the mapping $F : T \times \Phi \rightarrow \mathbf{P}$ are initial elements of the theoretical model. Then, the indirect outcome function can be derived as:

$$o^{t} = f(\varphi, \pi) \qquad (3.2)$$

Where o^{t} is the level of O for individuals of type t at the πth quantile of the effort distribution for F_{φ}^{t}; π can be any quantile in the interval [0,1]. Assuming π is held constant (i.e., equal opportunities can be directly translated to equal outcomes), selecting the policy that can result in equal outcomes across types at π implies the argument of maximizing the minimum value of the individual outcome. However, $\{\varphi^{\pi} \mid \pi \in (0,1)\}$ is a continuum of policies, so a

compromise function is the objective function of each quantile of the population. Because each quantile has an equal number of people, the equal opportunity policy can be defined as:

$$\varphi^{EOp} = \underset{\varphi}{\text{Arg Max}} \int_0^1 \underset{t}{\text{Min}}\, o^t(\pi, \varphi)\, d\pi \qquad (3.3)$$

Figure 3-2 is a simplified illustration of this optimization problem by assuming that only three types of individual circumstance exist, which show three graphs of the functions o^t of π under different policy scenarios. The optimal policy for equality of opportunity maximizes the shaded area. Notably, necessary restrictions should be applied to determining alternative policies in Φ. For instance, the quantity of resources that planners are committed to distributing is equal to the available resources that can be distributed (Roemer, 2000). Otherwise, it is hard to determine which policy is preferred when the quantity of resources the policies can distribute varies significantly.

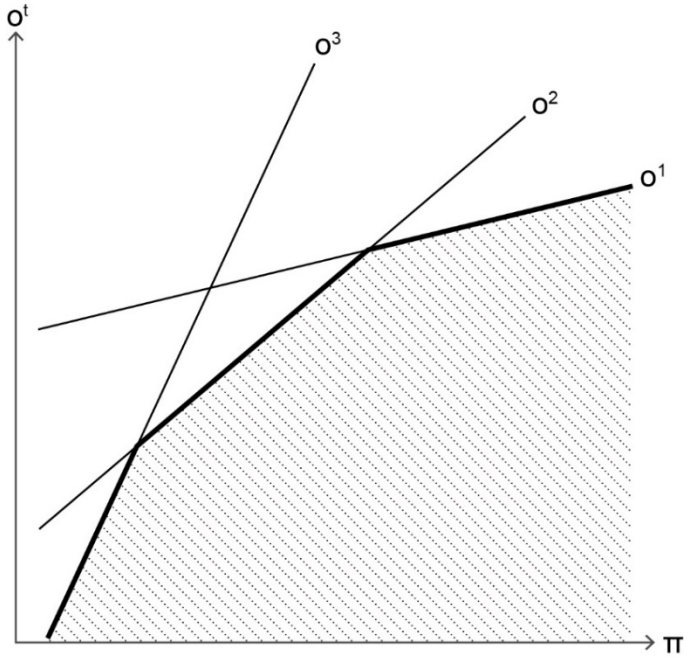


Figure 3-2. The illustration of luck egalitarian objectives with two policy scenarios.

To understand the relationship between and effects of equity policies in shared micromobility based on strict egalitarianism and luck egalitarianism, I assume only two types of people exist (transportation advantaged vs. transportation disadvantaged people) and φ is a one-dimensional variable representing the proportion of limited transportation resources distributed to the disadvantaged people. Then, let hold π fixed and, the objective function can be defined as:

$$\varphi^{\pi} = \underset{\varphi}{\text{Arg Max}} \underset{t}{\text{Min}}\, v^{t}(\pi, \varphi) \qquad (3.4)$$

Figure 3-3 illustrates this optimization problem by holding π constant, showing two graphs of the functions o^a and o^d of φ. When $\varphi = 0.5$, the policies are based on strict egalitarianism, and d represents the difference between transportation outcomes between the advantaged and disadvantaged, which results from the difference between individual circumstances. When $\varphi = \varphi^{\pi}$, more resources have been distributed to the disadvantaged for compensating the gaps in individual circumstances, so $o^a = o^d$. When $\varphi > \varphi^{\pi}$, excessive resources have been allocated to the disadvantaged, resulting in inequalities again, which is not preferable. Figure 3-3 also illustrates the dynamic relationship between resource-equalizing policies and opportunity-equalizing policies, which is influenced by the gap in outcomes, the total quantity of resources, and the proportions of resources that have been distributed to different groups. If $\varphi < 0.5$, these two policies are inherently consistent with each other, so resource-equalizing policies can be regarded as opportunity-equalizing policies. However, if $\varphi > 0.5 \; and \; \varphi < \varphi^{\pi}$, resource-equalizing policies are contradicted by opportunity-equalizing policies.

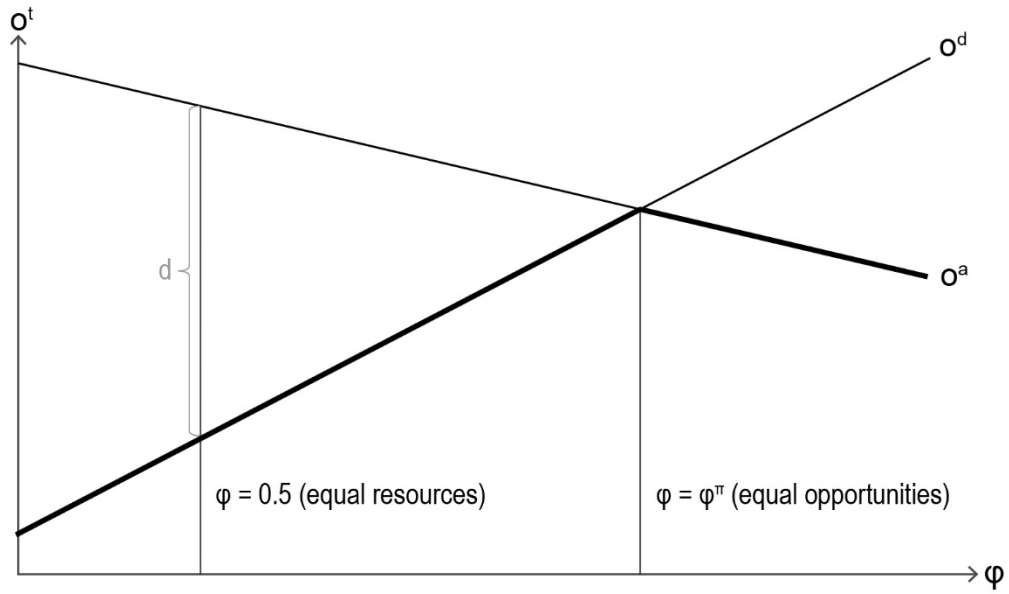


Figure 3-3. The illustration of luck egalitarian objectives with the effort of constant.

Building on the formalization of luck egalitarian principles, I have developed a framework and path diagram to examine the association between equity requirements for shared micromobility systems and inequalities in vehicle distribution and trips (Figure 3-4). Shared micromobility policies can be categorized into two types: those based on strict egalitarianism for equal resources, and those based on luck egalitarianism for equal opportunities. Examples of policies for equal resources as the equity principle included service area designation, rebalancing, rate discount, and infrastructure development and land use interventions. These policies aim to equalize transportation and planning resources across the population without targeting specific groups. Specifically, such resource-equalizing policies in shared micromobility focus on the distribution of vehicles, namely bikes and e-scooters. Policies that embody the principle of equal opportunities include low-income plans, cash payment options, and smartphone alternatives. These policies are designed to compensate transportation-disadvantaged

individuals by allocating additional resources to them, thus mitigating inequalities in travel outcomes by unequal distribution of resources (i.e., trips in this study).

Given that shared micromobility is characterized by non-private ownership, there exists a feedback loop where vehicle availability and usage mutually influence one another (RQ1, Figure 3-4). Assuming all else is equal, individuals with higher financial means may frequently use shared micromobility services, consequently "relocating" vehicles to more affluent areas. On the other hand, the deployment of vehicles determines their availability for use. The impact of these policies on inequality outcomes, such as disparities in micromobility trips, depends on the allocation of resources, prevailing policies, and existing inequalities. Considering the significant inequalities in current US shared micromobility systems, as demonstrated by empirical studies (Barajas, 2018; Meng & Brown, 2021), I developed two hypotheses for the last two research questions (RQs 2 and 3, Figure 3-4).:

Hypothesis 1: Resource-equalizing policies directly reduce vehicle distribution inequality and indirectly lessen trip inequality.

Hypothesis 2: opportunity-equalizing policies directly decrease trip inequality and indirectly mitigate the inequality in vehicle distribution.

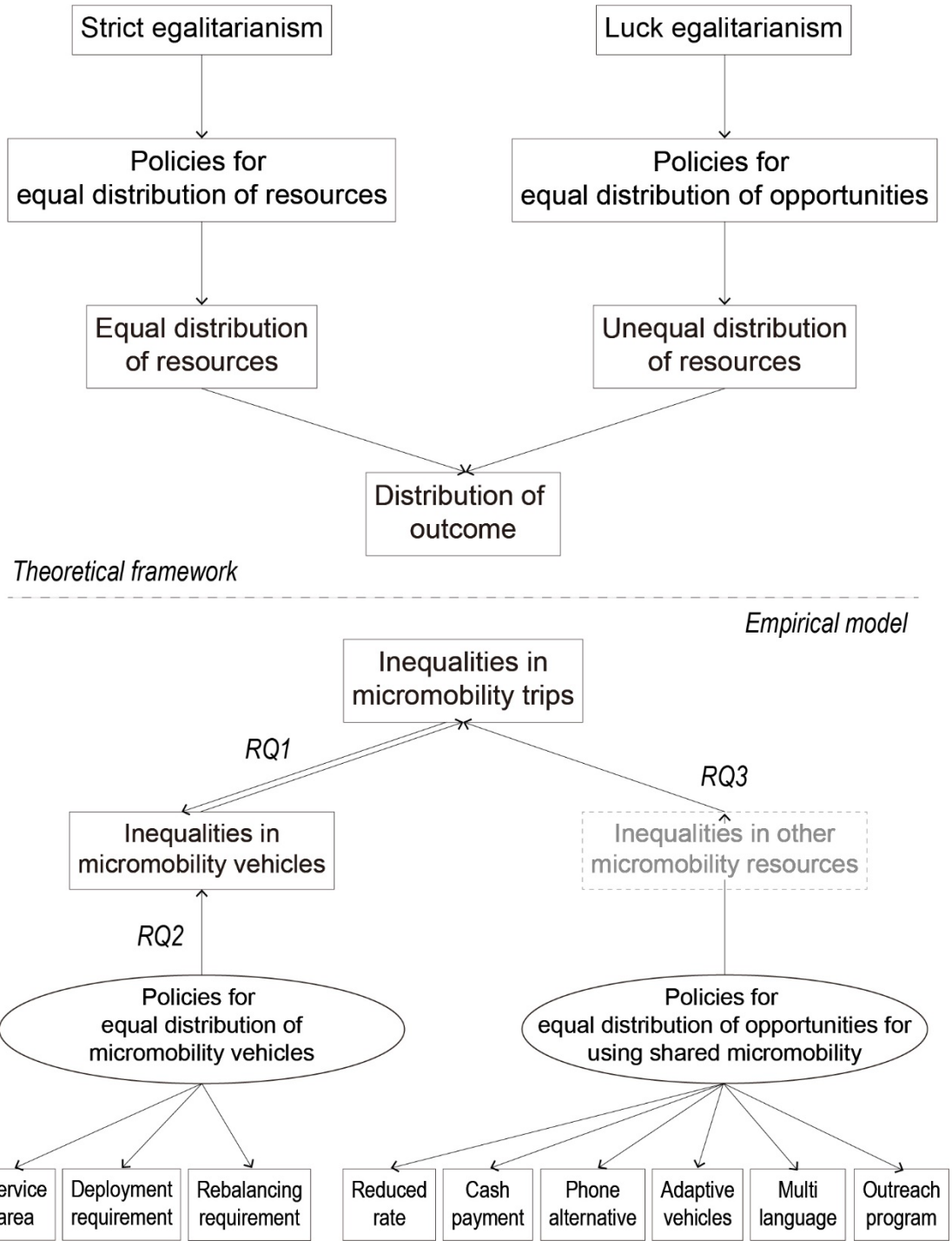


Figure 3-4. The illustration of the theoretical framework and empirical model for the structural equation analysis.

Note: the dashed line denotes the variable that was not measured in this study.

The distribution of allocated shared micromobility resources is the direct measure of the policy impacts, so the first hypothesis aims to examine the direct policy outcome of resource-equalizing policies of shared micromobility, focusing on the distribution of vehicles across neighborhoods and populations. The second hypothesis focuses on the indirect effects of opportunity-equalizing policies on trip distribution, acknowledging challenges in quantifying other shared micromobility resources (e.g., discounts, adaptive equipment, community outreach) across different social groups.

This empirical model evaluates the performance of equity policies for shared micromobility, exclusively with equalizing opportunities for using shared micromobility as the outcome. In other words, pursuing alternative outcomes, such as overall transportation equity, may lead to other empirical models. For instance, suppose the final outcome is to equalize overall transportation opportunities, then the unequal distribution of shared micromobility opportunities (i.e., providing more services for those underserved by the existing transportation modes) might be deemed equitable to better serve those underserved by existing transportation systems. Nevertheless, as the selection of theoretical framework is an ethical question, the selection of outcome is normative. While the choice of theoretical framework and outcome selection is normative, this study does not claim the *ethical superiority* of this framework but selects it based on the review of current equity policies' potential outcomes, the state of inequalities in shared micromobility, and the clarity of equity goals.

3.4. Methods

3.4.1. Study Area

This study conducted a comprehensive national-level analysis of all shared micromobility

systems in the US, encompassing docked bikeshare, dockless e-scooters, and dockless bicycles. The General Bikeshare Feed Specification (GBFS) was utilized to obtain a list of programs offering real-time vehicle location data, excluding systems lacking publicly available datasets (GBFS, 2024). Overall, the study encompassed 141 programs across 91 municipalities. Notably, the average population of cities with excluded systems (average = 337,341) was significantly lower than in cities with systems included in the GBFS dataset (average = 722,302), while there was no significant difference in the number of equity requirements between included and excluded systems. This discrepancy reveals a study limitation concerning the representativeness of programs without GBFS in smaller cities, suggesting the findings may not comprehensively reflect the effectiveness of shared micromobility equity programs. Figure 3-5 illustrates the geographic distribution of sampled cities.

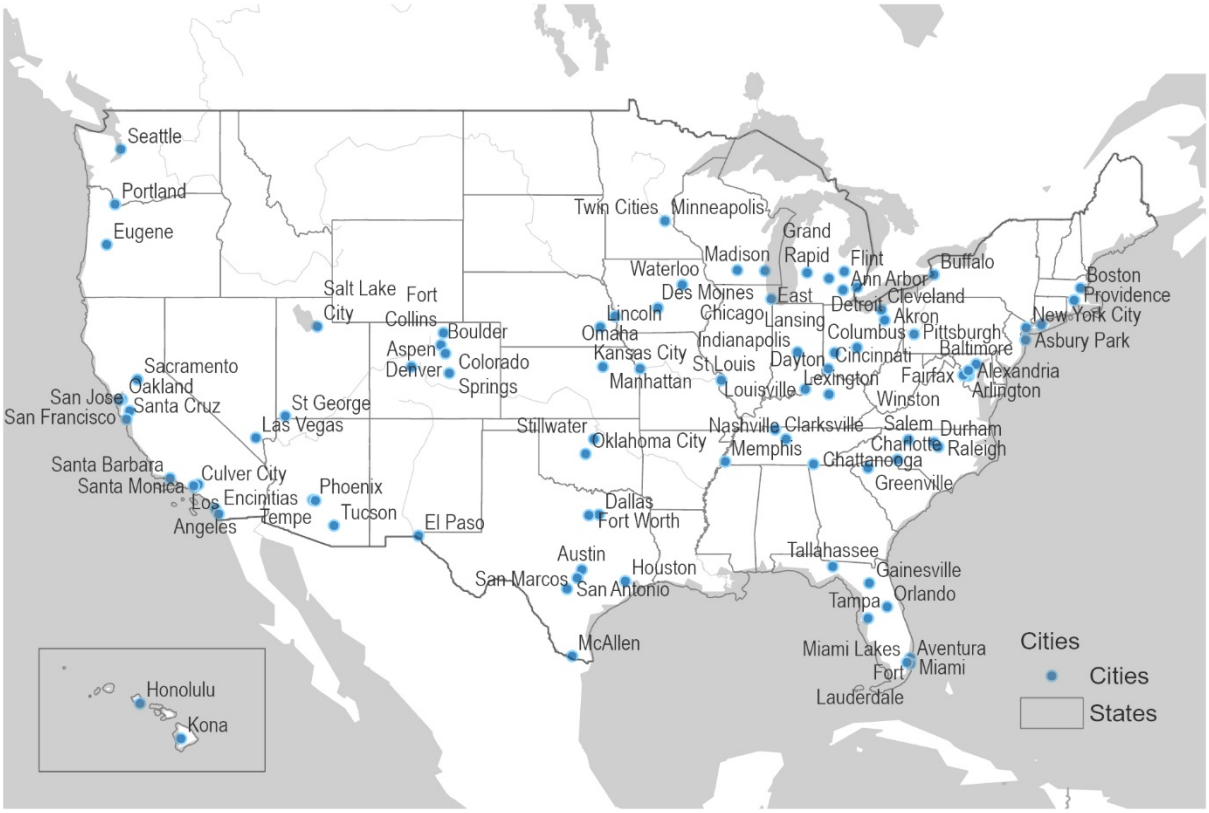


Figure 3-5. Cities with general bikeshare feed specification.

3.4.2. Data Collection

Table 3-1 summarizes the data used in this study. For shared micromobility data, a Python script was developed to automatically gather vehicle location information from dockless systems and the count of available vehicles at docked system stations at one-minute intervals. The script was run from October 1 to 31, 2023, a period identified as the peak ridership season for shared micromobility annually (Ride Report, 2023). Additionally, another script was programmed to acquire the starting and ending locations of trips by eliminating duplicate vehicle location data over consecutive periods. For example, if a vehicle's presence is recorded in the dataset from time point x to x+10 minutes, it indicates that the vehicle was parked at location y at time x and was taken away 10 minutes later. Given the unchanged location information over ten minutes, it can be inferred that two trips occurred: one ending at x and another starting at x+10 minutes. Subsequently, the counts of available vehicles and trips were aggregated by census block group to represent the distribution of micromobility vehicles and trips. For instance, Figure 3-6 uses the census block group of the University of Oregon to demonstrate this algorithm. Here, the average number of available vehicles calculated is 8.125, derived from the sum of parked vehicles in each period (9, 11, 8, 8, 9, 6, 6) divided by the number of periods (8). The total number of trips aggregated is 15, calculated from the sum of trips that occurred in each period (0, 2, 3, 0, 4, 3, 3, 0) at the University of Oregon.

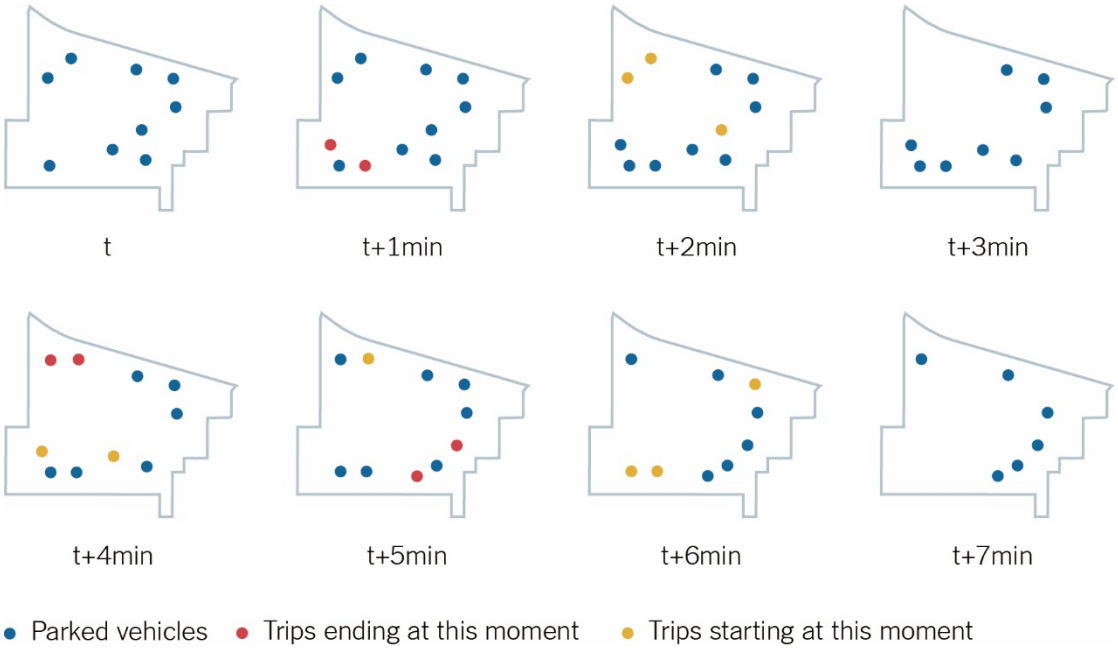


Figure 3-6. The illustration of the algorithm calculating aggregated vehicles and trips.

Equity policies for shared micromobility systems were acquired from the database developed by Howell et al. (2023). This dataset includes binary variables that indicate the presence of various equity requirements, including general geographic requirements, expansion of service area, rebalancing activities, reduced fares, multilingual services, cash payment compatibility, non-smartphone access, adaptive vehicles for users with disabilities, and targeted marketing and outreach.

Table 3-1. The description of data applied in this study.

Data	Description	Source
Shared micromobility location data		
Real-time shared micromobility data	The location data of dockless shared micromobility vehicles	GBFS
Docked bikeshare station location data	The location data of docked micromobility stations	GBFS
Equity policies		
Shared micromobility equitable policies	The presence of equity requirements for shared	Howell et al. (2023)

	micromobility programs in the US	
Community-level factors		
Census block	The geographic boundaries of census blocks in the US	2020 TIGER/Line® Shapefiles
Population	The number of residents in the census block group	2022 ACS 5-year estimates
Employment	The number of jobs in the census block group	2021 Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics
Race/ethnicity	The number of white, Asian, Black, and Hispanic people for each census block in the US, used for calculating the residential segregation	2020 Census data
System-level factors		
System type	Dockless or docked	GBFS
Fleet size	The total number of available micromobility vehicles	GBFS
City-level factors		
Population	The number of residents in the census place	2022 ACS 5-year estimates
Income inequality	Gini index	2022 ACS 5-year estimates

3.4.3. Structural Equation Modeling

Given the theoretical framework involves two dependent variables, a feedback loop between them, and both direct and indirect effects of independent variables, Structural Equation Modeling (SEM) emerges as the ideal tool for analyzing these complex relationships. SEM stands out for its capacity to test complex models with multiple equations simultaneously, capturing the intricate interactions between endogenous (response) and exogenous (predictor) variables. Endogenous variables are influenced within the model, whereas exogenous variables, determined outside the model, serve as predictors. This approach facilitates a nuanced analysis of direct and indirect effects, along with mediation and moderation among variables, offering a

comprehensive insight into the underlying theoretical constructs.

SEM analysis involves comparing the observed data covariance matrix to the model's predicted covariance matrix. This comparison is crucial for evaluating the model's fit, with a closer alignment indicating a more accurate representation of the data structure. A key step in this process involves contrasting the proposed model against a fully saturated model—one in which all possible connections between variables are permitted—to identify any missing links or model misspecification. These diagnostic evaluations are crucial for refining the model to more accurately capture data complexities, ensuring a robust and reliable analysis.

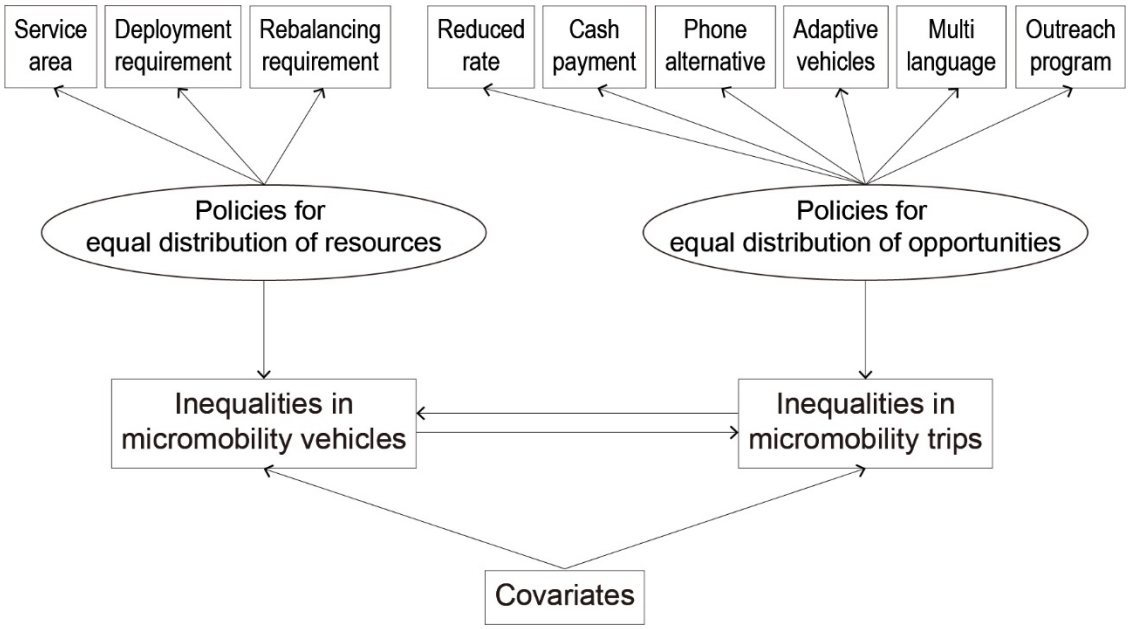


Figure 3-7. Path diagram for the structural equation modeling.

Note: the correlation connections between variables for the factor analysis and the error terms were left out in this path diagram.

The conceptual path diagram is presented in Figure 3-7. The endogenous variables are the inequalities in shared micromobility vehicles and trips. The measurements of inequalities in transportation are primarily based on metrics used in other social science disciplines, such as the

Lorenz Curve/Gini index (Gastwirth, 1972), Atkinson index (Atkinson, 1970), and Theil T and L indices (Theil, 1967). All these indicators denote perfect equality by values of 0. Gini index and Atkinson index range from 0 to 1 (perfect inequality), while Theil T's maximum value is ln(n), and Theil L has no upper limit value. The Atkinson index incorporates an inequality aversion parameter, ε, to consider the equity principles to determine the degree of inequality. Many transportation inequality studies have adopted the Lorenz Curve/Gini index to measure the formal inequality of transportation facilities across geographic space or population (Delbosc & Currie, 2011; Meng & Brown, 2021). I applied the Gini index to demonstrate the inequality metric, which is measured as:

$$G = 1 - \sum_{k=1}^{n} (X_k - X_{k-1})(Y_k + Y_{k-1}) \quad (3.5)$$

Where k represents the census block group in a city; X_k is the cumulated percentage of the population of census block group k in a city, with $X_0 = 0$ and $X_n = 1$; and Y_k is the cumulated proportion of per-capita shared micromobility vehicles or trips, with $Y_0 = 0$ and $Y_n = 1$. I utilized the census block group as the basic unit for calculating Gini indices due to the trade-offs between granularity and accuracy. If using the census block, vehicles in a block may be mistakenly and frequently allocated to adjacent blocks due to the relatively small area of the census block and GPS drifts of vehicles. Utilizing census tract can significantly prevent these misallocations, but calculating Gini indices at this coarse level will fail to capture within-tract variations in trips and vehicles. The Gini index reveals the overall inequality of spatial access in a city, but it cannot capture the between-groups inequality (e.g., high-income versus low-income). Nevertheless, examining the effects of policies based on luck egalitarianism does not require analyzing outcomes by groups, so the Gini index is an applicable indicator.

To define exogenous variables of equity policies, I categorized equity requirements into two groups, forming two latent variables: one for policies aimed at equal distribution of resources and another for policies promoting equal distribution of opportunities. These two latent variables represent the extent of implementation of the two types of equity policies by each city or agency, although their binary nature may not fully capture the nuances of these efforts. Additionally, the correlations between variables for the factor analysis were considered in this SEM.

Urban income inequality and residential segregation, as city-level covariates in the model, influence the adoption of various equitable policies and the extent of inequalities in micromobility. Residential segregation is associated with the service geography of micromobility service, as many empirical studies have shown that bikeshare stations and vehicles are predominantly located in white communities (Barajas, 2018; Dill & McNeil, 2021; Hosford & Winters, 2018). Given that shared micromobility users are more likely to earn high incomes (Barbour et al., 2019; Dill & McNeil, 2021; Shaheen et al., 2013), high urban income inequality implies that many disadvantaged people may have limited ability to pay for the shared micromobility services. Additionally, urban income inequalities and residential segregation undermine the equity lens for agenda setting, as the economic elites can exert their influence to keep equity policies from receiving government attention (Epp & Borghetto, 2021; Stubager, 2015). I used the Gini coefficient of income for a city as the indicator of urban income inequality, a widely utilized metric in urban economics (Glaeser et al., 2009, 2011). Residential segregation is represented by the Theil Index, calculated using the R package “segregation” and 2020 block-level population and race/ethnicity data (Elbers, 2023; Elbers & Gruijters, 2024).

Additionally, dockless shared micromobility can technically expand the service area of shared micromobility to a great extent (Meng & Brown, 2021; Mooney et al., 2019; Qian et al., 2020), which is a specific form of equity policies for equal distribution of transportation resources. However, the dockless feature does not translate to equal vehicle availability and opportunities directly. Compared to the docked systems, for which limited vehicles can be parked and used in certain areas due to the limitation of docks, dockless systems may aggravate the inequalities in micromobility systems if vehicles are disproportionately used in certain areas. Also, operators can deploy more vehicles easily without building bikeshare stations in high-profit areas if no geographic equity requirements are implemented. Consequently, the type of micromobility system—dockless vs. docked—is examined as a system-level covariate in the model.

Last, almost all cities in the US implemented fleet caps for shared micromobility systems as a must or natural rule (Gauquelin, 2019), in order to regulate the shared micromobility vehicles in the street. However, fleet caps may have unintended inequitable consequences that reduce the supply of vehicles and service areas (Shaheen et al., 2022). Moreover, limiting the supply will increase the price of the service, resulting in affordability issues. Given the significant association between per-capita fleet size and resource-equalizing requirements, per-capita fleet size (vehicles per capita) is included as a system-level covariate for analyzing trip inequality.

3.5. Results

3.5.1. The Characteristics of Shared Micromobility Equity Policies in the US

Among shared micromobility systems with available General Bikeshare Feed

Specification (GBFS) data, approximately 25% lack any form of equity requirements (Figure 3-8). Except for the deployment requirement, less than 50% of systems adopt other equity requirements. Specifically, only a small proportion of systems offer adaptive vehicles (16%) and multilingual services (31%) to promote equal opportunities, with the majority lacking such features.

Figure 3-9 depicts the frequency of systems by the number of equity requirements across three different policy categories: all policies, policies for equal distribution of opportunities, and policies for equal distribution of resources. As the number of equity requirements increases, the number of systems that meet these requirements generally decreases across all categories. Notably, 40% of systems fail to offer any equity requirements concerning the equal distribution of micromobility vehicles; in contrast, 30% of systems do not have any equity requirements concerning the equal distribution of opportunities, and 20% of systems lack policies for either equal distribution of resources or opportunities.

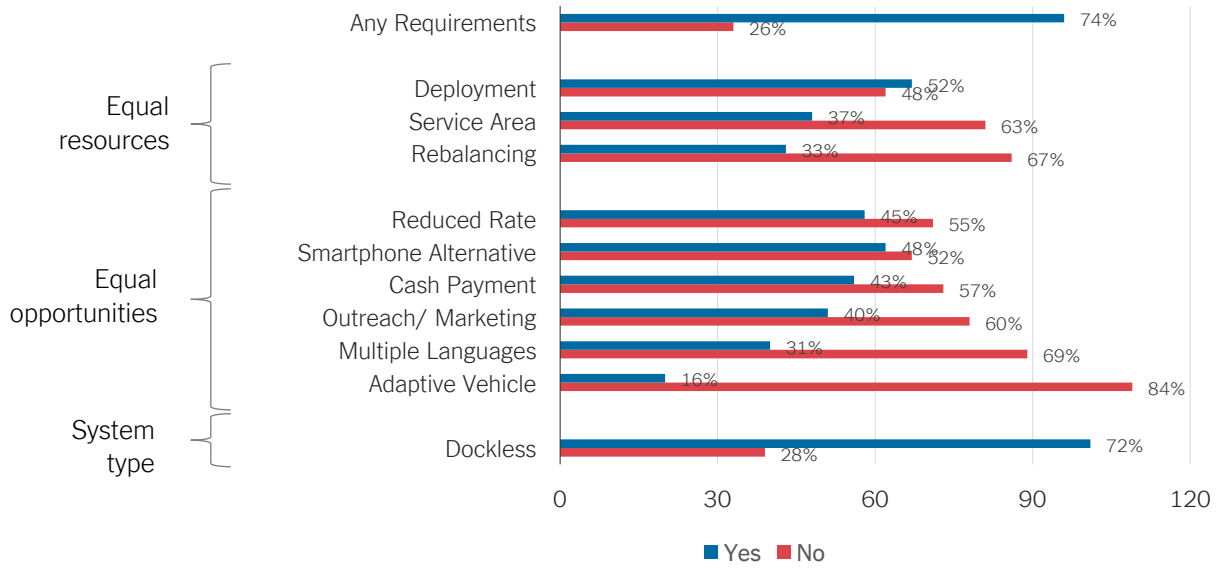


Figure 3-8. Availability of equity requirements and types for micromobility programs.

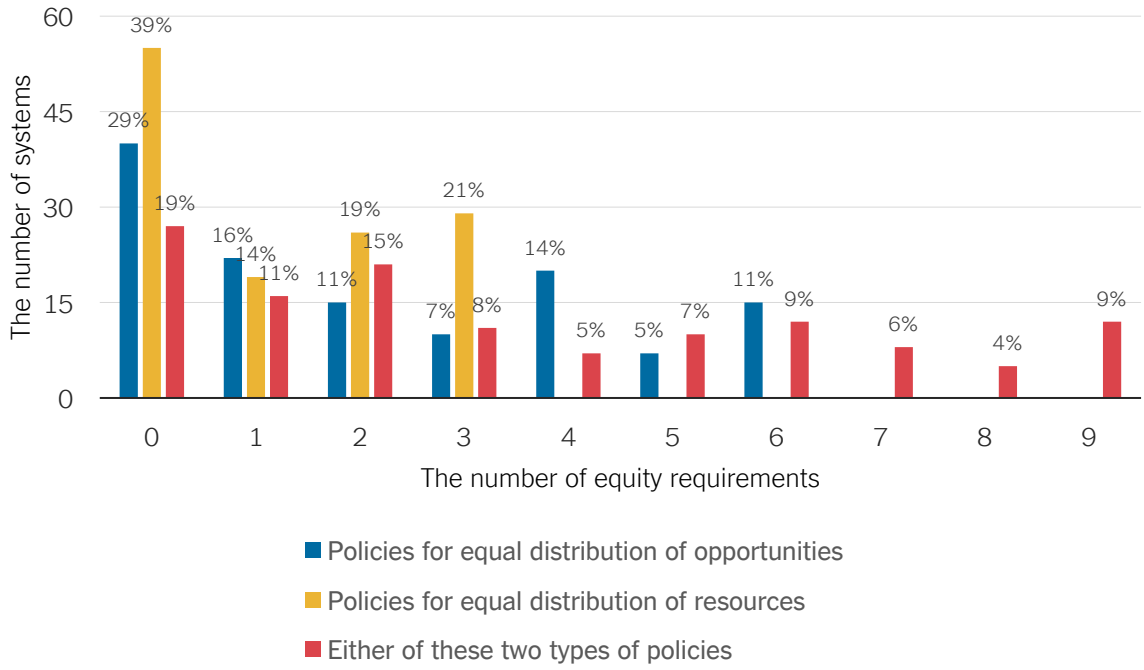


Figure 3-9. Program counts by the number of equity requirements across different policy types.

3.5.2. The Inequalities in Shared Micromobility Systems in the US

The descriptive statistics, as detailed in Table 3-2, reveal that the distributions of shared micromobility vehicles and trips exhibit extreme inequality, with Gini coefficients exceeding 0.5. The Gini index of vehicle distribution is significantly lower than that of trips ($p < 0.001$), and they are strongly correlated with each other ($r = 0.918$, $p < 0.001$) (Figure 3-10). Descriptive statistics for continuous covariates are presented in Table 3-2.

Table 3-2. The descriptives of Gini coefficients of vehicles and trips and covariates.

Variable	Obs	Mean	Std. Dev.	Min	Max
Endogenous Variables					
Gini (vehicles)	140	0.743	0.192	0.056	1
Gini (trips)	140	0.829	0.15	0.073	1
Covariates					
Vehicles per capita	140	9230	2753	8	30743
Population	140	878917	1545543	6952	8622467
Segregation	140	0.282	0.111	0.043	0.54
Gini (income)	139	0.495	0.037	0.391	0.61

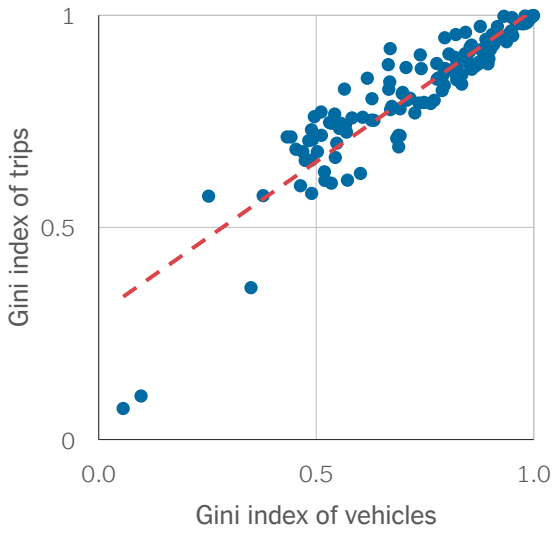
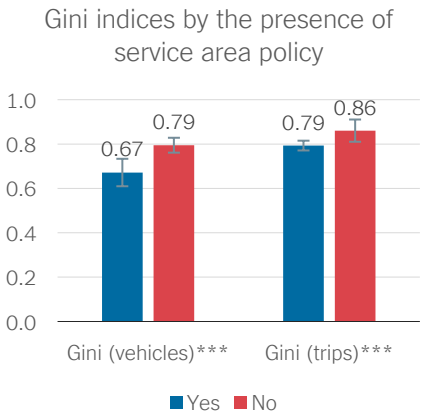
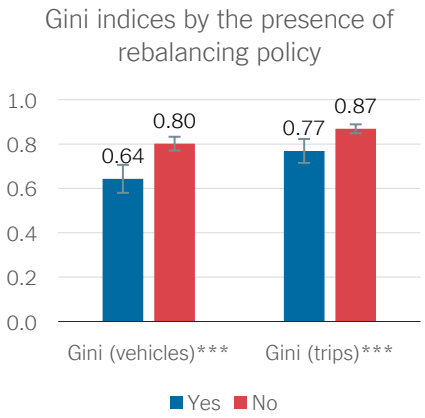
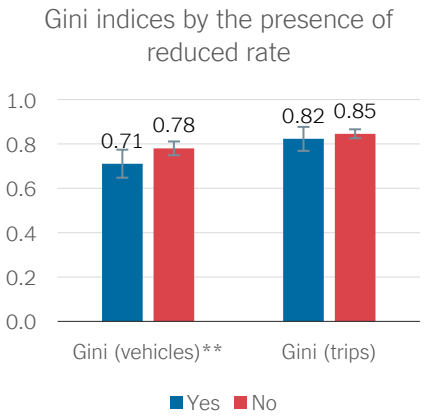


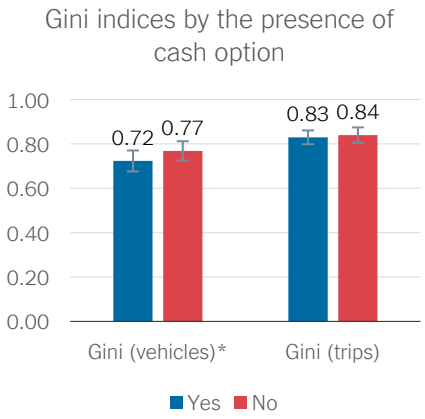
Figure 3-10. The scatter plot between Gini coefficients of micromobility vehicles and trips.

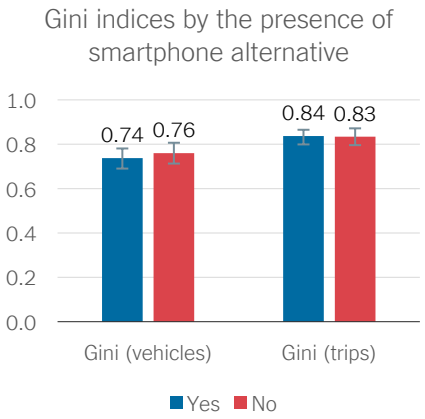
Figure 3-11 suggests an association between the implementation of equity requirements in shared micromobility systems and reduced inequalities in the distribution of both vehicles and trips. Specifically, the difference in vehicle distribution inequality—as measured by Gini coefficients—between systems with and without resource-equalizing policies is significant and exceeds the difference observed between systems with and without opportunity-equalizing policies.

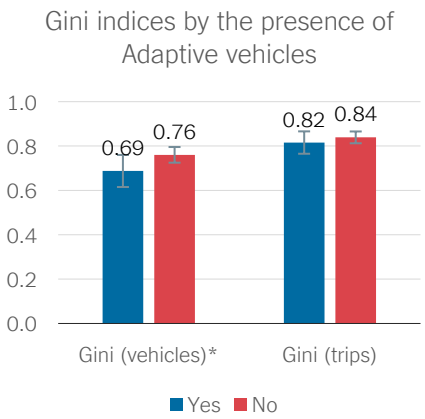

Gini indices by the presence of service area policy
1.0
0.8
0.6
0.4
0.2
0.0
0.67
0.79
0.79
0.86
Gini (vehicles)***
Gini (trips)***
Yes
No

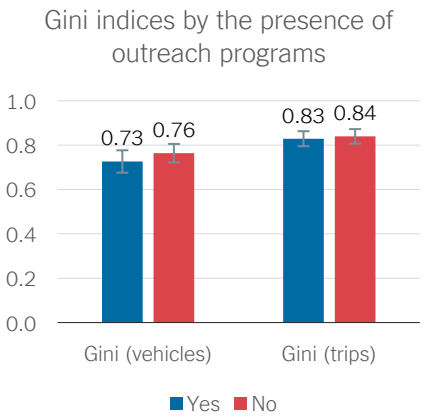

Gini indices by the presence of rebalancing policy
1.0
0.8
0.6
0.4
0.2
0.0
0.64
0.80
0.77
0.87
Gini (vehicles)***
Gini (trips)***
Yes
No


Gini indices by the presence of reduced rate
1.0
0.8
0.6
0.4
0.2
0.0
0.71
0.78
0.82
0.85
Gini (vehicles)**
Gini (trips)
Yes
No


Gini indices by the presence of cash option
1.00
0.80
0.60
0.40
0.20
0.00
0.72
0.77
0.83
0.84
Gini (vehicles)*
Gini (trips)
Yes
No


Gini indices by the presence of smartphone alternative
1.0
0.8
0.6
0.4
0.2
0.0
0.74
0.76
0.84
0.83
Gini (vehicles)
Gini (trips)
Yes
No


Gini indices by the presence of Adaptive vehicles
1.0
0.8
0.6
0.4
0.2
0.0
0.69
0.76
0.82
0.84
Gini (vehicles)*
Gini (trips)
Yes
No


Gini indices by the presence of outreach programs
1.0
0.8
0.6
0.4
0.2
0.0
0.73
0.76
0.83
0.84
Gini (vehicles)
Gini (trips)
Yes
No

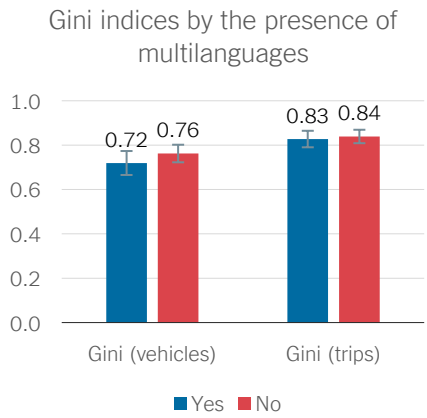

Gini indices by the presence of multilanguages
1.0
0.8
0.6
0.4
0.2
0.0
0.72
0.76
0.83
0.84
Gini (vehicles)
Gini (trips)
Yes
No

Figure 3-11. Inequalities in micromobility systems by the presence of equity requirements

*Note: the number of asterisks in the x-axis titles denotes the significant level: *p ≤ 0.1, **p ≤ 0.05, ***p ≤ 0.01.*

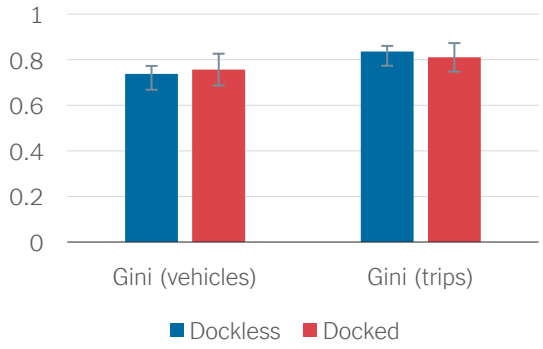


Figure 3-12. Inequalities in micromobility systems by system types.

Figure 3-12 reveals that the average Gini coefficients for vehicle distribution and trips in dockless systems are not statistically different from those in docked systems. Furthermore, Figure 3-13 illustrates the correlations between inequalities in micromobility systems and various continuous covariates. The number of micromobility vehicles per capita within a shared micromobility system exhibits a strong negative correlation with inequalities in both vehicle distribution ($r = -0.572$, $p < 0.001$) and trip distribution ($r = -0.671$, $p < 0.001$). Residential segregation demonstrates a positive correlation with the Gini coefficients for the vehicle ($r = 0.225$, $p = 0.008$) and trip distributions ($r = 0.215$, $p = 0.011$). Conversely, the Gini index of income shows no significant correlation with vehicle distribution inequalities and a negative correlation with trip distribution inequalities ($r = -0.227$, $p = 0.007$).

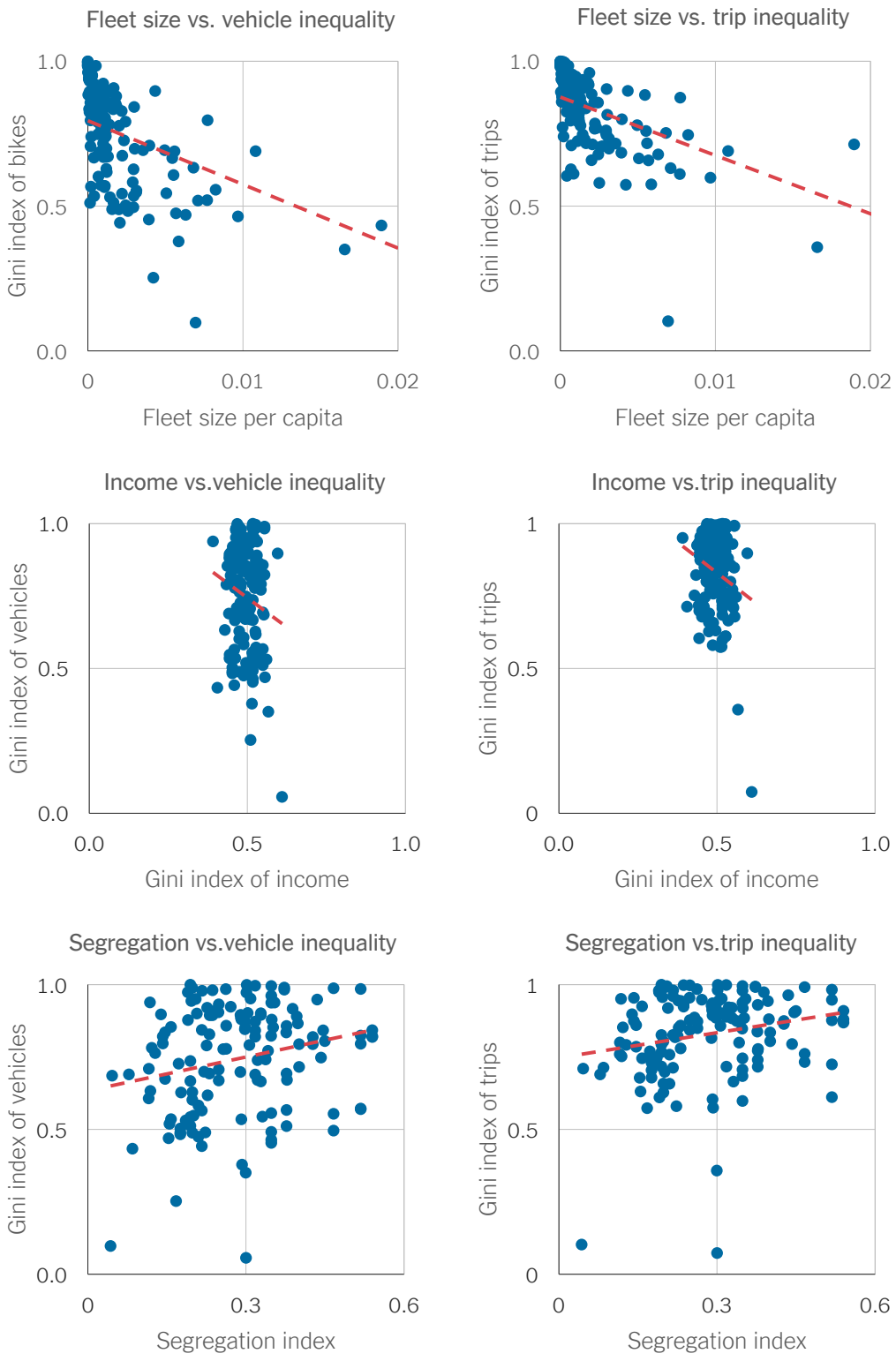


Figure 3-13. The scatter plot between Gini coefficients and covariates.

3.5.3. The Associations between Equity Policies for Shared Micromobility and Inequalities

The fit indices of the constructed model fall within the acceptable range (Hooper et al., 2008), indicating a good overall model fit (Table 3-3). Figure 3-14 displays the results of structural equation modeling, with numbers representing the standardized coefficients for direct effects. Detailed relationships among all model variables, including measurement items for latent variables, are provided in Appendix C.

Table 3-3. Model fit indices.

	χ^2/df	RMSEA	SRMR	CFI	NFI	IFI
Fitted model	2.52	0.109	0.082	0.9	0.85	0.904
Acceptable range	2-5	<0.1	<0.08	>0.9	>0.8	>0.9

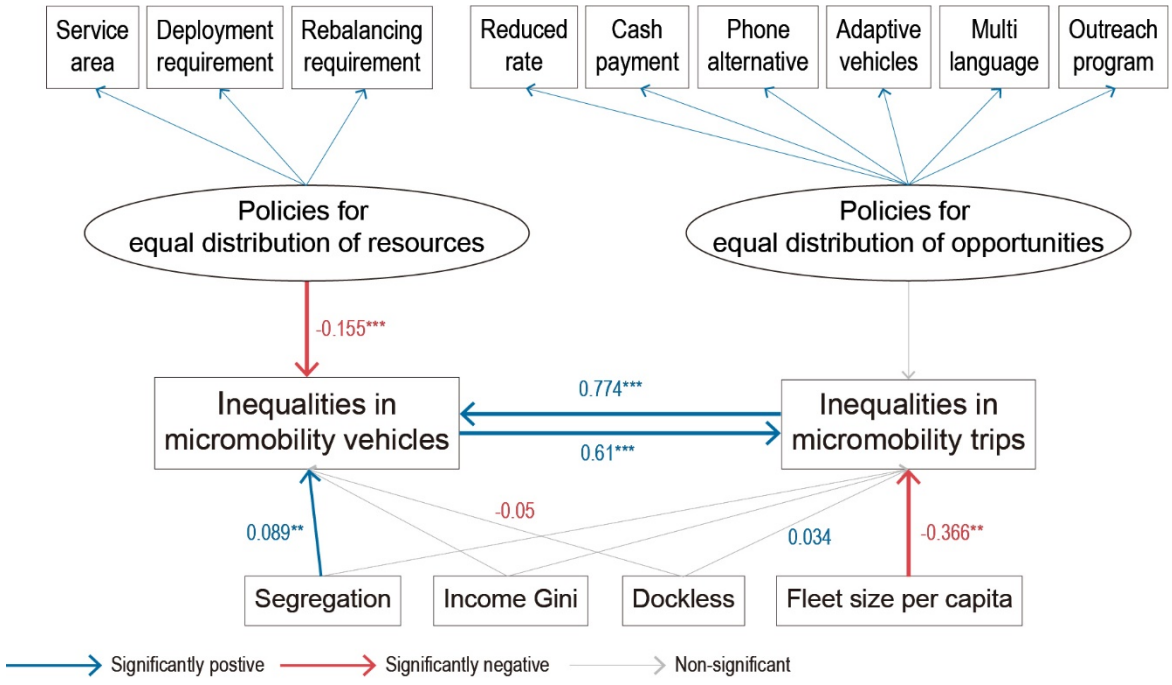


Figure 3-14. Results of the structural equation modeling.

*Note: *** p<0.01, ** p<0.05, * p<0.1.*

A strong positive correlation between the two endogenous variables—inequality in micromobility vehicles and trips—confirms the presence of a feedback loop (Table 3-4). Thus,

exogenous variables and covariables have associations with these two endogenous variables in the same direction. Consequently, policies for equal distribution of resources exhibit a significant negative association with inequalities in micromobility vehicle distribution directly (β = -0.155, p = 0.000) and inequality in micromobility trips indirectly (β = -0.09, p = 0.032). In contrast, policies for equal distribution of opportunities show a non-significant relationship with inequalities in micromobility trip distribution and vehicle availability, deviating from the expected direction.

Among the model's covariates, programs in more segregated cities are associated with higher vehicle distribution inequalities (β = 0.089, p = 0.018). However, trip inequality does not show a significant association with residential segregation. Per-capita fleet size significantly negatively correlates with trip inequality (β = -0.336, p = 0.007), Moreover, the dockless shared micromobility feature is weakly associated with reduced vehicle inequalities (β = -0.05, p = 0.142) and heightened trip inequalities (β = -0.034, p = 0.155), though indirect relationships demonstrate opposite effects (Table 3-4). Interestingly, the direct negative impact of the dockless feature on vehicle inequalities counterbalances its indirect positive effects, and vice versa for trip inequalities. Consequently, the dockless feature exhibits no net effect on these two indices of inequality.

Table 3-4. The estimated parameters of the structural equation model.

Endogenous	Op	Exogenous	Est	S.E.	z	p	Std.all
Direct *(~: Regression)*							
Gini (vehicles)	~	Policy (resources)	-0.08	0.02	-3.83	0.000	-0.15
Gini (vehicles)	~	Gini (trips)	1.04	0.07	15.06	0.000	0.77
Gini (vehicles)	~	Gini (income)	-0.09	0.20	-0.46	0.647	-0.02
Gini (vehicles)	~	Segregation	0.15	0.07	2.37	0.018	0.09

Gini (vehicles)	~	Dockless	-0.02	0.01	-1.47	0.142	-0.05
Gini (trips)	~	Policy (opportunities)	0.01	0.02	0.23	0.817	0.01
Gini (trips)	~	Gini (vehicles)	0.45	0.18	2.46	0.014	0.61
Gini (trips)	~	Gini (income)	-0.11	0.14	-0.79	0.429	-0.03
Gini (trips)	~	Segregation	0.00	0.07	0.02	0.985	0.00
Gini (trips)	~	Dockless	0.01	0.01	1.14	0.155	0.03
Gini (trips)	~	Fleet	-10.36	3.85	-2.69	0.007	-0.37
Indirect *(:= new combinations of coefficients)*							
Gini (trips)	:=	Policy (resources)*Gini (vehicles)	-0.03	0.02	-2.15	0.032	-0.09
Gini (vehicles)	:=	Policy (opportunities)*Gini (trips)	0.01	0.02	0.23	0.817	0.01
Gini (trips)	:=	Dockless*Gini (vehicles)	-0.01	0.01	-1.26	0.207	-0.03
Gini (vehicles)	:=	Dockless*Gini (trips)	0.01	0.01	1.14	0.256	0.03
Gini (trips)	:=	Fleet*Gini (vehicles)	-4.68	0.44	-10.72	0.000	-0.22
Total *(:= new combinations of coefficients)*							
Gini (trips)	:=	Dockless*Gini (vehicles)+Dockless	0.00	0.01	0.14	0.885	0.00
Gini (vehicles)	:=	Dockless*Gini (trips)+Dockless	-0.01	0.02	-0.61	0.542	-0.02

3.6. Discussion and Policy Implications

The extreme inequalities in micromobility systems align with findings from previous empirical studies on the location of bikeshare stations, shared e-scooters, and micromobility trips at the community level (Dill & McNeil, 2021), which shows that micromobility services and trips are disproportionately concentrated in certain communities. The inequality in vehicle availability is lower than that in trip distribution, indicating the effectiveness of resource-equalizing policies. However, the average Gini coefficient for measuring vehicle distribution inequality is significantly higher than for the coefficient measuring the inequality in service areas (Meng & Brown, 2021), which once more reveals that vehicles are not even equally distributed within designated service areas. The strong correlation between the two indices of inequality

underscores an inherent feature of shared micromobility: vehicle distribution determines where people can find and use micromobility services, while the micromobility trips reshape the geographic distribution of vehicles. The trip inequality index is greater than the vehicle inequality index, suggesting the existence of vehicles may not frequently translate to the usage of shared micromobility, imagining the case where many vehicles are located but no person uses them. By contrast, greater trip frequency largely means greater vehicle availability, except for situations where the vehicle utilization rate is high. The difference in coefficients for the feedback loop reveals that the former scenario happens more than the latter.

This study verifies the effectiveness of resource-equalizing policies in addressing inequality in vehicle distribution, and how the unequal distribution of transportation services acts as a primary barrier to sufficient accessibility (Banister, 2018). Based on the formalization of luck egalitarianism principles (Figure 3-2), the current resource-equalizing policies can be regarded as a part of opportunity-equalizing policies, given the extreme inequalities in shared micromobility systems (Barajas, 2018; Dill & McNeil, 2021; Meng & Brown, 2021). The indirect negative effects of resource-equalizing policies on trip inequality clearly illustrate the consistency between resource-equalizing and opportunity-equalizing policies. By contrast, if the inequalities in transportation are very low at certain stages of the society (i.e., more resources are distributed to the disadvantaged, $\varphi > 0.5$ in Figure 3-2), conducting resource-equalizing will indirectly increase trip inequality. Then, these two types of policies may contradict one another. For instance, suppose there is one advantaged community and another disadvantaged community with the same population. Residents in the advantaged community are more likely to use shared micromobility services than those in the disadvantaged community. If more vehicles are currently distributed to the disadvantaged community to better serve the needs of disadvantaged

people by providing more reliable and accessible services, then pursuing the equal distribution of resources will decrease the inequality in vehicle distribution but may increase trip inequality.

The current extreme vehicle inequality also indicates limited vehicle availability in numerous communities, so current resource-equalizing policies mainly aim to ensure everyone can access the shared micromobility services. When many people have no access in their communities or around their workplaces, it is not hard to argue that the marginal benefits of current resource-equalizing requirements (e.g., deployment and rebalancing requirements) should be higher than current opportunity-equalizing policies targeting specific social groups in terms of achieving equal opportunities. For instance, providing low-income plans, smartphone alternatives, and multi-language options have almost no effect on people if vehicles are not accessible. Additionally, the factor analysis suggests that the more exhaustive requirements are developed, the more significantly inequalities in vehicle distribution and trips are addressed. Except for the designation of service areas and deployment requirements, other resource-equalizing requirements, such as increasing deployment frequency and evaluating vehicle distribution, can also be implemented to ensure efficacy.

The lack of a significant correlation between equal opportunity policies and trip inequality highlights the limited impact of specific measures. Many cities suggest that operators should develop specific plans (e.g., low-income plans, cash options, and smartphone alternatives) for the disadvantaged, but these requirements are not well-developed and based on community needs assessment (Brown et al., 2022). Thus, it is unknown whether these opportunities-equalizing requirements are the most effective ones for removing barriers for the disadvantaged. It is also unclear whether and to what extent shared micromobility operators implemented these required policies. Only a limited number of systems publish evaluation reports (Brown et al.,

2022), and cities' reports on the evaluation of these programs show that many operators failed to fulfill equity requirements (CDOT, 2020). Additionally, as discussed above, if the equal distribution of vehicles is not realized, opportunity-equalizing policies may be less productive.

Many studies have illustrated the disparities in micromobility services by race/ethnicity (Barajas, 2018; Dill & McNeil, 2021; Hosford & Winters, 2018), so it is not surprising that residential segregation is related to inequalities in vehicle distribution. While these findings align with existing research illustrating inequities in service provision across different communities, they do not offer insight into whether inequalities mirror racial or ethnic patterns within cities. It is plausible that the observed disparities align with broader patterns of inequality, but further research is necessary to explicitly connect these findings with the racial or ethnic makeup of serviced neighborhoods.

Previous single-city studies suggest that dockless systems can address equity concerns about docked systems by expanding micromobility services to communities of concern (Mooney et al., 2019; Qian et al., 2020). Nevertheless, this study shows that the dockless feature of shared micromobility does not contribute to addressing inequalities in vehicle distribution or trips. Examining the number of equity requirements by system type, I find that the dockless feature of a shared micromobility system is significantly associated with the increased number of requirements (Figure 3-15). It is also not hard to claim that dockless systems are more likely to be regulated, as the public is concerned with the negative impacts (e.g., safety concerns and improper parking) related to the free-floating feature (Duran-Rodas et al., 2020; Lipovsky, 2021). Therefore, these single-case studies' conclusions that dockless systems can improve equity may largely result from the equity policies for dockless systems rather than the free-floating feature, as many of these studies used cities with many equity requirements for dockless

shared micromobility as examples, such as Seattle (Mooney et al., 2019), Washington DC (Su et al., 2024), San Francisco (Qian et al., 2020). Furthermore, the dockless feature itself is more likely to aggravate inequalities. For instance, with no equity requirements, operators can freely deploy more vehicles to profitable areas, and people with greater ability to pay can use micromobility more frequently without the limitation of docks.

Lastly, a higher per-capita fleet size significantly correlates with reduced trip inequality. Limiting the supply is the origin of many issues in urban planning, such as inequalities in other transportation modes and the housing crisis (Glaeser & Gyourko, 2018; Levine, 2013). When planning a shared micromobility system, cities considered competing goals, such as ensuring safety, enhancing efficiency, reducing misparking, and improving equity. While cities impose caps on the fleet size to mitigate safety and parking concerns, these supply restrictions may introduce additional problems (Gauquelin, 2019; Shaheen et al., 2022), like increased trip inequality manifested in this study. My other study shows that introducing ride-hail services without a cap has addressed inequalities in taxi services that are highly regulated (Meng, Brown, & Barajas, 2024). The finding of this study further illustrates the association between supply restrictions and equity issues, so cities should comprehensively evaluate how a specific requirement impacts achieving different goals of implementing a shared micromobility system.

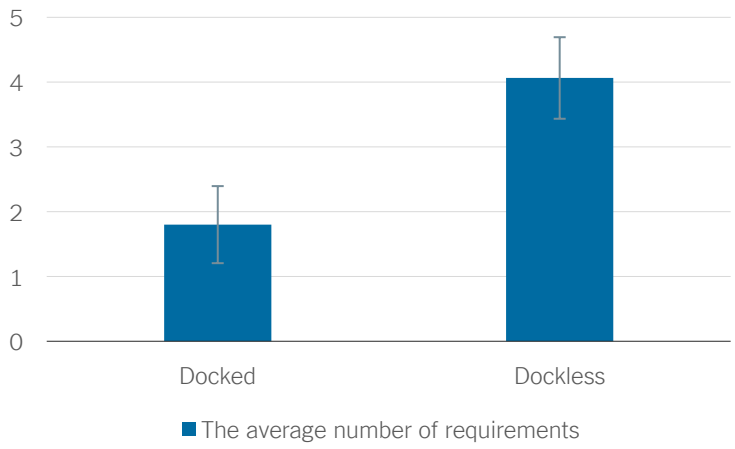


Figure 3-15. the number of equity requirements by system type.

These findings inform several policy recommendations for fostering equitable shared micromobility systems. First, policies for equal distribution of micromobility vehicles, such as service area expansion and deployment requirements, should be specified and implemented across micromobility systems given the extreme inequalities in vehicle distribution and trips. Nearly 40% of the systems evaluated lack any policies for equitable vehicle distribution. Evidence suggests that resource-equalizing policies can enhance equity in shared micromobility systems, with multiple specific requirements (e.g., service area expansion plus targeted deployment) being more effective than a single approach. On the other hand, prioritizing opportunity-equalizing policies is essential after implementing resource-equalizing policies, which aim to ensure equal accessibility levels, per se. When shared micromobility vehicles are equally distributed across the population, the disparity in individual circumstances is the major barrier for people with limited resources to use this transportation service. Then, policymakers should distribute more resources to the transportation disadvantaged, such as low-income plans, adaptive vehicles, and smartphone alternatives.

Second, if the equity goal is to ensure equal opportunity, policymakers should conduct community needs assessments and increase resources committed to hand out for equal distribution of opportunities in shared micromobility. Current policies, although well-intentioned, fall short of practice. Conducting thorough community needs assessments can identify barriers faced by disadvantaged groups and inform the development of impactful equity requirements. Also, this study reveals that trip inequality has the most significant impact on inequality in vehicle distribution, merely implementing policies based on strict egalitarianism cannot even ensure the equal distribution of micromobility services.

Third, introducing dockless systems, without integrating equal opportunity policies, does not guarantee more equitable outcomes, compared to docked systems. Both docked and dockless systems have pros and cons in terms of addressing transportation equity concerns. Even though the distribution of docked stations determines who can access shared micromobility services, the parking limitations of docked stations can ensure vehicles are not disproportionately distributed to certain areas. By comparison, dockless systems can expand the service geography without building docked stations. However, if no policies are implemented for equal opportunities for using micromobility, micromobility vehicles may be distributed to certain areas by operational strategies or users' trips without limitations. Dockless systems may have net negative impacts on shared micromobility equity compared to docked systems under this circumstance. Additionally, when considering the fleet-size limitation on the shared micromobility system, policymakers should also take the equity implications into account; otherwise, restrictions on fleet size would attend to one thing and lose sight of another.

Last, principles based on opportunity-equalizing principles should also be highlighted in other transportation planning processes considering equity goals. Transportation goods have

distinct social meanings and direct impacts on access to job opportunities, education resources, healthy food, and other basic goods, and the uneven distribution of transportation goods and services in the past transportation planning practice increased the disparity in accessibility. Thus, policymakers should bear these facts and opportunity-equalizing principles in mind to plan the future transportation system. For instance, many countries are subsidizing the electric and autonomous vehicle industry substantially, but almost all forms of subsidies, such as tax exemptions, are merely based on resource-equalizing principles, which cannot alleviate the inequality in transportation opportunities. Policies based on opportunity-equalizing principles would focus on technological adoption to address these disparities, such as accessible autonomous vehicle services for people with disabilities and public electric and autonomous shuttles in historically underserved areas.

Despite the comprehensive examination of equity requirements for shared micromobility programs in the US, several limitations are acknowledged. First, the collection and processing of GBFS data could overestimate the number of available vehicles and trips. Some vehicles, despite being non-operational due to mechanical failures or other issues, may still appear as available in the dataset. Additionally, accidental non-user activities, such as relocating improperly parked e-scooters, may inadvertently alter vehicle locations, thereby inflating trip calculations. Second, the aggregated trip data do not reveal the rider identities, affecting the accuracy of the inequality index calculated at the census block group level. For instance, it is conceivable that certain individuals within a census block group might not utilize shared micromobility, but the aggregated trip data cannot capture the distribution of trips within a census block group. Third, although the shared micromobility equity program dataset meticulously records the core equity requirements across US cities (i.e., the detailed descriptions), this study coded these requirements

as binary variables, which does not encapsulate the full spectrum of program nuances. For instance, some cities require all shared micromobility vehicles to offer seating, whereas others only require a small proportion of adaptive vehicles. Therefore, observed non-significant relationships between equity policies and inequalities could stem from the diverse ways these requirements are articulated. Capturing the details requires additional coding to reflect the nuances. Fourth, this study does not measure how resources and trips are distributed under the opportunity-equalizing principles among demographic groups, so the analysis cannot delve into the equity implications of equity policies for a certain disadvantaged group. Last, to ensure that policies take effect, I collected vehicle and trip data of shared micromobility systems roughly one year following the compilation of the equity policy dataset. Even though most programs update program policies yearly, it is still possible some equity requirements may be changed within this interval.

3.7. Conclusions

Shared micromobility systems in the US have extreme inequalities in vehicle distribution and trips, which are intrinsically linked. Policies grounded in strict egalitarianism, aimed at equalizing service availability, are directly associated with decreased inequality in vehicle distribution and indirectly related to decreased trip inequality. Conversely, policies rooted in luck egalitarianism, intended to ensure equal opportunities, have not demonstrated significant associations with yielding equitable outcomes. Additionally, the dockless nature of shared micromobility systems does not inherently address inequalities, and reduced per-capita fleet size is significantly associated with increased trip inequality.

CHAPTER IV

LOCAL PERSPECTIVE: THE IMPACTS OF IMPLEMENTING SHARED E-SCOOTERS ON TRIPS BY EXISTING TRANSPORTATION MODES IN THE EQUITY PRIORITY AREA IN CHICAGO

4.1. Introduction

Transportation services, including public bikeshare, transit, ride-hail, and taxis, are unequally distributed across space and population groups (Dill & McNeil, 2020; Griffin & Sener, 2016). In practice, gaps in service create both transportation deserts (Jiao & Dillivan, 2013) and divergent mobility and access, particularly for low-income and carless households (King et al., 2019; Nolan, 2010). Introducing dockless shared micromobility offers an opportunity to increase access to existing travel modes through its integration into the existing transportation system. For example, one initial aim of developing dockless shared micromobility is to solve the first/last mile problem by expanding public transit access (Shaheen & Chan, 2016), which could increase trips by transit in underserved areas. On the other hand, implementing dockless micromobility may also be able to alleviate inequalities in transportation by competing with the existing transportation modes. For instance, taxi and ride-hailing trips are disproportionately concentrated in the advantaged areas in Chicago (Meng, Brown, & Barajas, 2024), and the survey for an e-scooter pilot suggests that e-scooters primarily replace ride-hail trips (City of Chicago, 2020); if shared micromobility substitutes for trips made by for-hire vehicles in advantaged communities, the competition may motivate taxi and ride-hail drivers to serve previously underserved areas. Additionally, shared micromobility can also complement the urban transportation system by providing access to areas underserved by the existing transportation modes.

Except for the direct interactions between the shared micromobility and existing transportation modes, shared micromobility can also indirectly impact the use of these modes. Studies have shown that shared micromobility systems are effective in promoting bicycling (Doğru et al., 2021; Teixeira et al., 2021), so the newly introduced program may facilitate the use of the existing shared micromobility program. I, therefore, hypothesize that shared micromobility has the potential to alleviate existing inequalities in the transportation system through *direct and indirect interactions* with existing transportation modes. Most studies on the relationship between dockless micromobility and existing transportation, however, focus on how micromobility may interact with other modes, rather than exploring how the interactions can address inequalities in transportation services. Therefore, the central question guiding this research is: How did introducing shared e-scooters affect trips by existing transportation modes in the equity priority area (EPA) in Chicago? This research examines the heterogenous effects of shared e-scooters on bikeshare and other transportation modes between the EPA and non-EPA, then reveals how gaps in trips between these two areas change after the introduction of the shared e-scooter pilot program in Chicago.

To address this research question, I utilized Chicago's first e-scooter pilot program in 2019 as a quasi-natural experiment by employing the difference in difference (DID) models based on propensity score matching (PSM). Specifically, I conducted the heterogenous examination by sampling analysis units in the EPA and non-EPA, which revealed how shared e-scooters affected trips by the existing transportation modes in the EPA.

4.2. Literature Review

I review the interactions between shared e-scooters and other transportation modes, including

bikeshare, public transit (bus and rail), taxi, and ride-hail services. I first summarize the findings of the survey and GIS-based studies and then specify quasi-experimental studies examining the net impact of shared micromobility on other transportation modes. For each section, I start with studies on the interactions among different forms of shared micromobility (e.g., docked bikeshare vs. dockless e-scooters); then, I review the relationship between shared micromobility and public transit; last, I present evidence on how shared micromobility affects the use of for-hire motorized mobility (i.e., taxi and ride-hail services).

4.2.1. Surveys

Conducting a survey is the most direct method to examine how shared e-scooters affect other transportation modes, and a recent review found that most studies used retrospective counterfactual surveys to investigate mode substitution (Wang et al., 2023). Most of these survey studies showed around 10% of shared e-scooter trips would have been made by bicycles, including private bicycles and bikeshare (Table 4-1). How often e-scooters substitute for private versus shared bicycles, however, is not yet clear, as many studies do not distinguish between these two transportation modes. Table 4-1 shows the mode substitution of e-scooters for bikeshare and private bicycles in surveys differentiating these two modes, and the ratio between these two percentage numbers varied across cities. More bikeshare trips than private bike trips were replaced by e-scooters in high-density cities. Therefore, according to the review of surveys, less than 10% and 5% of e-scooter trips replaced bikeshare trips in high-density cities and low-density cities, respectively.

Table 4-1. Share of trips replaced by shared e-scooters by transportation modes.

City	Bikeshare	Private bike	Bike (bikeshare+ private)	Walk	Driving alone	Taxi or TNC	Public transit	Population density (person per km)
Calgary, Canada (2020)	1%	4%	5%	56%	21%	12%	6%	4,436.5
Chicago, IL (2020)	5%	3%	8%	11%	32%	14%	14%	4,518
Denver, CO (2019)	6%	8%	14%	43%	10%	22%	7%	1,799
French cities (6t-bureau, 2019)	9%	3%	12%	44%	3%	6%	30%	52,584
Hoboken, NJ (2019)	6%	5%	11%	51%	11%	37%	13%	17,810
Milwaukee, WI (2019)	2%	5%	7%	40%	23%	22%	7%	2,261
Oakland, CA (2019)	5%	3%	8%	42%	13%	25%	9%	2,971
Portland, OR (2019)	4%	5%	9%	39%	19%	23%	11%	1,837
San Francisco, CA (Lime, 2018)	12%	7%	19%	61%	9%	51%	34%	6,679
The following surveys did not differentiate between bikeshare and private bikes, and the results were directly acquired from Wang et al. (2023).								
Tucson, AZ			8%	36%	24%	14%	3%	873
Los Angeles, CA			5%	48%	11%	22%	9%	3,137
San Francisco, CA			9%	31%	5%	36%	11%	6,679
Santa Monica, CA			7%	39%		49%	4%	4,130
Tampa, Florida			6%	38%	21%	27%	1%	1,353
Atlanta, Georgia			4%	48%	42%	2%		1,425
Bloomington, IN				54%	25%	16%	7%	1,314
St. Louis Park, MN			8%	5%	34%	37%		1,774
Raleigh, NC			49%			34%	11%	1,239
Alexandria, VA			13%	50%	46%	41%	18%	4,021
Arlington County, VA			4%	37%	13%	19%	5%	3,544
Rosslyn area, VA			12%	33%	7%	39%	7%	315
Blacksburg, VA				77%		6%	7%	892
Toronto, Canada			36%	57%		44%	53%	4,801
Munich, Germany			59%	80%		24%	59%	4,788
Thessaloniki, Greece			7%	44%		17%	33%	1,286
Oslo, Norway			6%	60%	3%	5%	23%	3,919
Zurich, Switzerland			14%	52%		10%	24%	4,862
Auckland, New Zealand			6%	53%		21%	7%	2,372
Christchurch, New Zealand			6%	52%	14%	9%	5%	1,282

Mode substitution effects for public transit and for-hire mobility services (i.e., taxi and ride-hail services) varied significantly across cities (Wang et al., 2023). In general, 5% to 20% of shared e-scooter rides substituted for public transit trips, while the mode substitution rate was sizeable (30% - 50%) in many cities with well-developed public transit systems, such as San Francisco (34%) (Lime, 2018), Paris (30%) (6t-bureau de recherche, 2019), and Toronto (53%) (Mitra & Hess, 2021). By contrast, the mode substation rates of e-scooters for taxi and ride-hail services were higher in US cities (25% - 40%) than in European cities (less than 20%) (Table 4-1).

These surveys did not elucidate the varied rates at which e-scooters replaced other forms of transportation across different cities and modes. However, a global study of urban accessibility by various transportation modes offered potential insights into these disparities (H. Wu et al., 2021). By employing public transit as a comparative baseline, the study uncovered a notably wider gap in accessibility between cycling and transit in the United States as compared to other regions. This disparity suggested a lower likelihood of e-scooters serving as a substitute for transit services in the U.S., attributed to the more limited range of destinations reachable via public transit. Additionally, the study highlighted the significantly higher car accessibility in North American cities relative to other global cities. This finding provided a plausible explanation for the observed greater substitution effect of e-scooters on taxi and ride-hail services in North America compared to other regions.

A few survey-based studies went further to investigate what other factors influenced modal substitution at the city level. A stated preference survey study shows dockless bikeshare substituted for public transit for most respondents, and young people living in cycling-friendly communities were more likely to replace transit trips with bikeshare rides than others (Chen et

al., 2022). Also, respondents living in neighborhoods with high bus stop density tended to substitute bikeshare rides for walking than public transit, suggesting the competitive and complementary relationship between dockless bikeshare and transit under different circumstances. A recent study utilized stated choice experiments to investigate whether e-scooters and scooter-N-ride (i.e., shared e-scooter + public transit) replaced the transportation mode for a respondent's most regular trip (Yan et al., 2021). Results revealed that males, non-whites, and people with lower educational attainment were more likely to use shared e-scooters. Also, the "e-scooter + transit" bundled pricing could contribute to the use of scooter-N-Ride.

While informative about travel behaviors and user demographics, survey results cannot reveal the net effect of shared micromobility on other travel modes, due to the limitation of counterfactual survey questions, reverse causality, and various survey biases. For instance, many surveys do not include questions about the potential complementary effects of e-scooters on other modes. Also, even though most questionnaires were well-developed, respondents may not be a representative sample of micromobility users and recall trip details due to non-response (Berg, 2005) and recall bias (Coughlin, 1990). Additionally, the majority of surveys did not ask respondents about the situations in which the riders would shift from other transportation modes to shared e-scooters (i.e., when and where the substitutions happened). To understand the details of these interactions, many scholars have conducted GIS-based studies by using system and trip data, discussed in the next section.

4.2.2. Cross-sectional GIS-based Studies

Cross-sectional GIS-based studies focus on analyzing the service area, vehicle availability, and distribution of trips, and infer interactions between shared e-scooters and other transportation modes using spatial-temporal and regression analyses. The examination of service

area and vehicle availability can provide a general picture of the associations between various transportation modes. A multi-city study has shown the service area of dockless micromobility was much more extensive than that of docked bikeshare, even though the actual service geography of micromobility (i.e., area where users can find a vehicle) was more limited than the designated service area (Meng & Brown, 2021). Many single-city studies found that the use of dockless e-scooters was not related to race/ethnicity and income level (Mooney et al., 2019; Caspi et al., 2020), so shared micromobility could expand service areas to transportation disadvantaged communities with a small number of bikeshare stations (Qian et al., 2020).

Studies comparing trip characteristics between dockless and docked micromobility often inferred how dockless micromobility may compete with or complement bikeshare. A study in San Francisco, CA revealed that docked bikeshare trips were shorter, less related to public bicycle rack density, and gained less elevation than dockless bicycle trips (Lazarus et al., 2020). Findings also suggested that dockless bicycle riders may prefer destinations with sufficient public racks or public racks located around riders' preferred destinations. In Washington, D.C., shared e-scooter trips were more widely distributed than docked bikeshare trips, with a higher travel volume outside the city center compared to docked bikeshare (McKenzie, 2019). Regarding the temporal distribution, casual bikeshare trips (i.e., trips made by users without a membership predominantly for leisure, recreation, or tourism activities) were similar to e-scooter trips. By comparison, member bikeshare trips (i.e., trips made by users with membership) were mostly served for commuting purposes (McKenzie, 2019; Younes et al., 2020). E-scooter users and bikeshare members were less sensitive to weather variables (e.g., temperature, wind speed, and precipitation) than bikeshare casual users (Younes et al., 2020). A Chinese study indicated that dockless bicycle trips were positively related to docked bikeshare trips, while the

relationship was relatively weak in the afternoon peak hours compared to other hours of the day, especially morning peak hours (Ma et al., 2020). Since individuals tend to be less patient or have strict time constraints in the morning peaks, dockless shared bicycles can address the difficulties in getting and returning bicycles when designated docks are located far from destinations or have no bicycles or available racks. The variation in trip characteristics among different modes of shared micromobility suggests that dockless micromobility may complement bikeshare, while competition can exist around bikeshare stations.

Researchers have utilized the high-resolution shared micromobility vehicle and trip data to explore its relationship with public transit. For instance, Kong et al. (2020) defined modal substitution (i.e., bikeshare trips can be replaced by public transit), modal integration (i.e., bikeshare trips connect to public transit), and modal complementation (i.e., bikeshare trips cannot be made by public transit) based on the location of origin and destination (OD) of bikeshare trips and transit stops. This study illustrated that the timing and characteristics of trips, rather than the geographical location where bikeshare trips occurred, significantly impacted the interaction between the bikeshare and public transit. Integration between bikeshare and public transit was more likely when trips were short in duration and took place on weekdays, public transit service frequency was high, and a substantial portion of users were members. Ziedan et al. (2021) adopted a similar approach to examine how shared e-scooters impact bus ridership in Nashville, Tennessee. Findings suggested that utilitarian e-scooter trips were related to a decrease (0.94%) in bus ridership, while recreational e-scooter trips were associated with an increase (0.86%) in bus ridership, leading to zero net impact.

Recent studies examined how shared e-scooters interacted with two or more transportation modes. Nawaro (2021) analyzed the travel patterns of shared e-scooters and

bicycles and found that the trip characteristics of these two transportation modes were similar to each other. However, e-scooter trips were more closely connected to public transport than shared bicycle trips. Yan et al. (2021) applied the method developed by Kong et al. (2020) to investigate how shared e-scooters competed with and complemented public transit and docked bikeshare in Washington, D.C. Shared e-scooters largely competed with docked bikeshare and public transit, according to the analyses on both supply (i.e., service area) and demand (i.e., trip origin and destination) sides. Notably, almost 10% of shared e-scooter trips were made as connecting with public transit stations. Additionally, a recent Norwegian study combining survey and trip data suggested that e-scooters both competed with and complemented public transit (Aarhaug et al., 2023). While the competition was stronger than that in the US, almost 20% of e-scooter trips were connected with public transportation.

Even though cross-sectional GIS-based studies can depict the travel patterns of examined transportation modes over time more clearly than surveys, these studies failed to make causal inferences on the net effects of shared micromobility on trips by other transportation modes. These trip data were largely not linked to users' characteristics due to privacy protection or the absence of collecting demographic data, so it was hard to discern who traveled by these transportation modes. These cross-sectional studies were also subject to endogeneity issues, such as omitted variables, sample and self-selection biases, and reversed causality. For instance, the use of public transportation declined significantly during the COVID-19 pandemic, so the complementary effects of shared micromobility may largely reflect the COVID-19 context. To address these endogenous issues, other researchers have utilized longitudinal data to conduct quasi-experimental studies.

4.2.3. Experimental Studies

Experimental studies aim to reveal the causal relationship and net effects of shared e-scooters on ridership of other transportation modes. However, a limited number of studies have been conducted due to the complexity of the study design. Li et al. (2019) found that launching a dockless bikeshare program caused a significant decrease (5.93%) in the use rate of London Cycle Hire (i.e., London's docked bikeshare system). The dockless bikeshare trips significantly replaced short docked bikeshare trips in peak hours on weekdays and in non-peak hours on weekends. Yang et al. (2021) utilized propensity score matching to examine the impact of e-scooter sharing on Divvy bikeshare ridership in Chicago. The results showed that the implementation of e-scooter sharing reduced bikeshare trips by nearly 10% per week per station, and the proportion of non-member and long-duration trips (30-60 min) decreased by 34.1% and 20.5%, respectively. Similarly, bikeshare trips during peak hours were unaffected by the e-scooter sharing program, while bikeshare trips in non-peak hours fell.

Additional studies have examined the relationship between shared micromobility and public transit. Campbell & Brakewood (2017) first examined how bikeshare impacted bus ridership at the route level in New York City. They found the presence of bikeshare stations within the buffer areas of bus routes led to a 2.4% decrease in bus ridership for every thousand bikeshare stations, with bus stations lacking nearby bikeshare infrastructure serving as a control group. Fan & Zheng (2020) and Martin & Xu (2022) employed a similar approach to split transit routes into treatment and control groups; their studies confirmed the complementary effects of dockless bikeshare systems on public transit ridership. Zhu (2022) adopted the spatial scan statistics for origins and destinations of dockless bikeshare trips to determine the treatment and control groups of subway stations in Shanghai. Results revealed that introducing dockless

bikeshare had no impact on subway ridership. A recent national-level study utilized the entry of the first two dockless bikeshare systems into major Chinese cities as a quasi-experiment (Huang et al., 2023). Findings suggested that introducing dockless bikeshare reduced bus ridership by 5.1% and had no impact on rail ridership, but bikeshare may increase rail ridership in areas with low population and transit network density.

Overall, most previous studies explored how shared micromobility affected other transportation modes by conducting surveys and/or cross-sectional GIS-based studies. Few studies utilized quasi-experiments to infer the causal relationship and estimate the net effect size, and the examination of heterogeneity and discussion on equity implications were absent in these studies. Additionally, as transportation is an interconnected dynamic system, it is necessary to examine all possible interactions between the new and existing transportation modes, which can alleviate or aggravate trip inequalities among communities. For example, dockless e-scooters may compete with docked bikeshare but integrate with or complement public transit, so the coordination between dockless shared e-scooters and public transit may close more gaps in trips than other interactions. Therefore, including all potential interactions within the transportation system is worth pursuing, especially considering the dockless feature of shared e-scooters.

4.2. Theoretical Framework

Figure 4-1 shows the possible interactions between shared micromobility and existing transportation modes, which can be theorized as three relations: complementation, substitution, and integration (Kong et al., 2020). The integration typically leads to an enhancement of existing transportation methods. A relevant example is the use of shared micromobility vehicles for accessing public transit. Introducing shared micromobility can extend the service radius of

transit, enabling residents in transit deserts to ride shared e-scooters to access transit stations. This integration can increase both shared micromobility and public transit trips by leveraging the advantages of each mode.

In contrast, substitution is observed when the adoption of a new transportation mode results in a decline in the usage of existing ones. This phenomenon is exemplified by the decrease in taxi usage concurrent with the rise of ride-hail services, as reported in multiple studies (Rayle et al., 2016; SFMTA, 2014), with similarities in travel distance, time, and speed (Schneider, 2022). Despite both providing for-hire services, ride-hail options have eclipsed taxis, attributed to factors like service coverage, availability, dynamic pricing, and overall quality (Brown, 2019; Brown & LaValle, 2021; Conway et al., 2018).

Last, the complementation shows that the new mode generates trips independent of existing ones, resulting in a net increase in trips. Shared mobility, such as dockless micromobility and ride-hail, can significantly complement the urban transportation system by providing services in historically underserved areas (Dill & McNeil, 2020). Thus, the newly introduced mobility service may enable residents to visit new destinations that were not accessible by existing transportation modes, which has no direct impact on current trips.

Additionally, trips by introduced modes may have multiplier and spillover effects on other transportation modes. For multiplier effects, if a person rides an e-scooter from points A to B (a complementary trip), they may use other transportation modes to go back to point A or from points B to C (the induced trips). Therefore, the integration and complementation may indirectly increase the trips by exiting modes. Regarding the spillover effects, these new shared micromobility trips by e-scooters may promote bicycling in general, which may also increase the use of bikeshare and private bicycles (Teixeira et al., 2021).

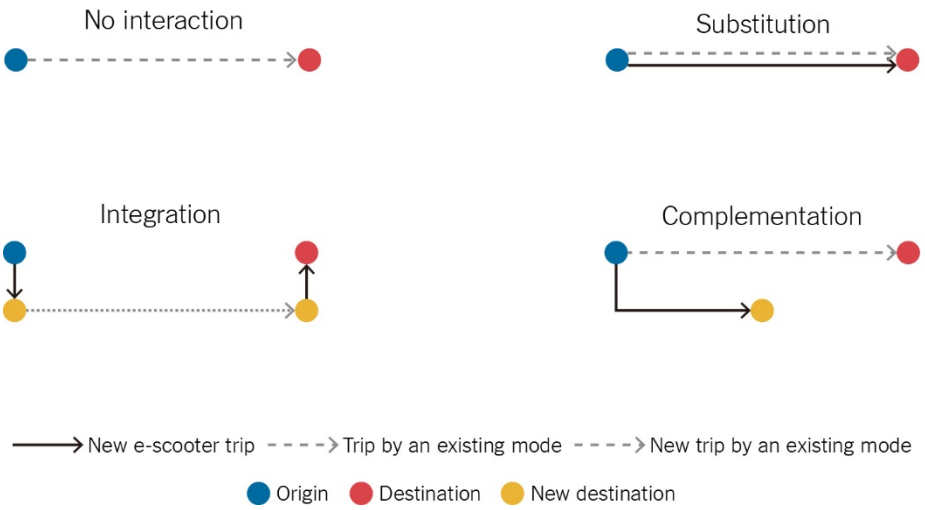


Figure 4-1. Potential interactions between shared e-scooters and existing travel modes.

The nature of these relationships is context-dependent, influenced by various factors including the availability and characteristics of existing transportation services, infrastructure development, built environment attributes, and demographic characteristics of users and neighborhoods. Consequently, a transportation mode may simultaneously compete with and complement existing modes in different areas or traveler contexts, indicating diverse treatment effects across populations and geographies. For instance, Hall et al. (2018) found that the interaction between ride-hail and public transit varies depending on the urban context: Ride-hail replacing public transit in areas with high transit stop density while facilitating transit access in less-served neighborhoods. Therefore, the impacts of shared e-scooters on trips in the EPA may be different from those in the non-EPA.

4.3. Methods

4.3.1. Study Area and the 2019 E-scooter Pilot Program

Chicago has been facing challenges in ensuring equal accessibility. For instance, most Divvy bikeshare locations are located outside the communities of concern in Chicago (Qian &

Jaller, 2020); uneven public development aims to serve high-income residents and tourists but around the downtown area, while working people face declining service levels and unreliable transit infrastructure (Farmer, 2011). Additionally, taxi services in Chicago have been found to underserve Black and low-income communities; taxi drivers in Chicago attribute limited service in low-income communities of color primarily to such economic concerns but acknowledge that racism and fear also come into play (Cohen, 2015). Although the introduction of ride-hail services has mitigated some inequalities in for-hire vehicle mobility, disparities remain in the distribution of ride-hail and taxi trips (Meng, Brown, & Barajas, 2024). This indicates ongoing challenges in achieving transportation equity, even with advancements in shared micromobility options. Given these challenges, Chicago's commitment to equitable transportation is reflected in its comprehensive bikeshare and pedestrian infrastructure. A national study focusing on shared micromobility equity reveals a more equitable distribution of e-scooter services in Chicago compared to other cities (Meng & Brown, 2021). This aligns with Chicago's longstanding efforts to address transportation inequities, particularly for marginalized communities, as outlined in Appendix D.

Specifically, Chicago was chosen as a case study for three major reasons. First, its 2019 e-scooter pilot program—implemented from June 15 to October 15, 2019—operated in a designated area, enabling the quasi-experimental study design (i.e., the assignment to experimental and control groups). During the pilot, operators were allowed to deploy scooters within communities in the northwest and west parts of the city (red-outlined polygon in Figure 4-2), which is diverse in terms of demographics, land uses, and access to other transportation options. Second, the e-scooter pilot program identified a transportation equity priority area (EPA) (blue-outlined polygon in Figure 4-2) by using the Chicago Department of Public Health

(CDPH) Healthy Chicago 2.0 Economic Hardship Index and additional mobility and demographic factors (City of Chicago, 2021a). Residents in these areas faced elevated economic, health, and mobility barriers. The operators were required to distribute 50% of shared e-scooters to the EPA at the beginning of operation each day, so the shared micromobility vehicles were *equally distributed* between the EPA and non-EPA. This identification of the EPA facilitated examining the heterogeneous effects and equity implications by comparing the changes in trips between the EPA and non-EPA. Third, Chicago has publicized the trip or ridership data of various transportation services, which enables exploring how shared e-scooters affect the trips of these transportation modes. Lastly, the communities outside the e-scooter operational area in Chicago are also very diverse in terms of built environment and demographics, so the formation of a comparable control group is feasible.

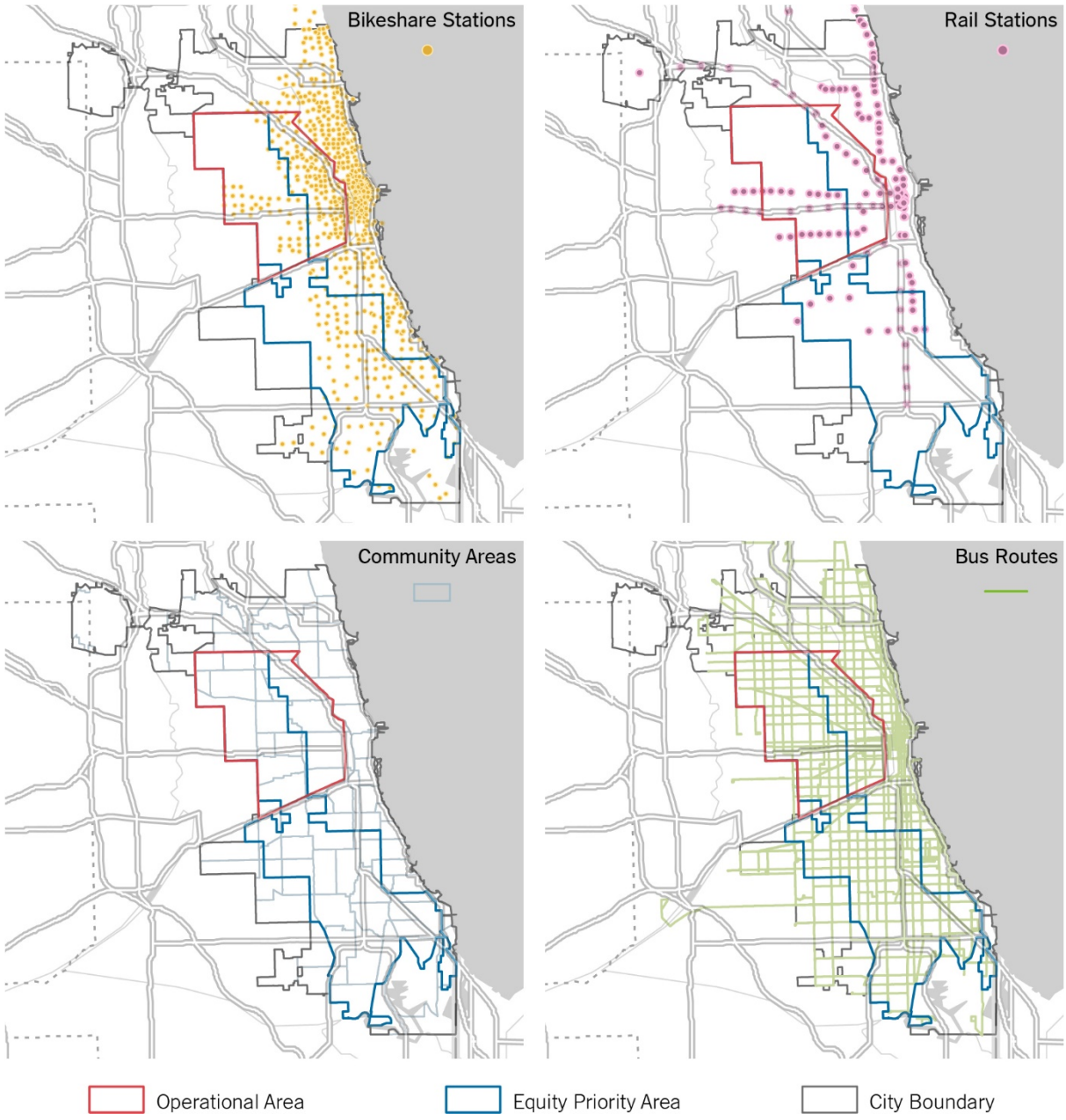


Figure 4-2. Study area and analysis units.

Note: The geographic data were acquired from the data portal of Chicago.

4.3.2. Data, Analysis Units, and Variables

Table 4-2 presents the data utilized in this study, encompassing trip-level data for e-scooters, bikeshare, ride-hail, and taxi services, ridership data for rail and bus, and socio-

demographic and built environment variables for community areas[11] in Chicago. I collected the trip and ridership data of all transportation modes 15 weeks before and after the implementation of the 2019 shared e-scooter pilot. The time frame of data used for answering different questions is shown in Figure 4-3. The whole 30 weeks' data were used to understand how the implementation of shared e-scooters affects the number and distribution of trips made by existing transportation services, and the first 15 weeks' data combined with the effects of shared e-scooters reveal the change in trip inequality. Even though the data is not the latest, travel in 2019 was not influenced by the COVID-19 pandemic, which had heterogeneous impacts on different groups of people (Hunter et al., 2021). However, this pilot program lasted for a short period, so the external validity of this study was limited by the study period.

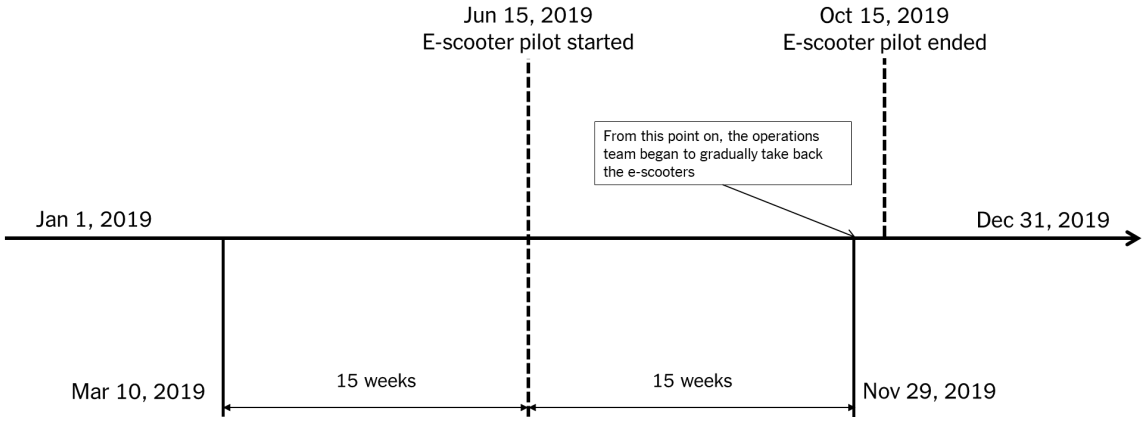


Figure 4-3. Timeline of e-scooter pilot program and data collection.

Table 4-2. Descriptions of data applied in this study.

Data	Details	Source
Transportation		
E-scooter trips in 2019	Start/end time Start/end community area	Chicago Data Portal

[11] Chicago community areas originated in 1920 to reflect consistent socio-economic characteristics and health metrics across stable "natural areas" within the city created by physical barriers such as rivers, parks, and railroads (Grossman et al., 2005).

Divvy bikeshare trips in 2019	Start/end time Start/end latitude and longitude Trip distance (miles)	Divvy.com
Ride-hail trips in 2019	Start/end time Start/end community area	Chicago Data Portal
Taxi trips in 2019	Start/end time Start/end community area	Chicago Data Portal
Bus route-level ridership in 2019	Daily counts of bus passenger boardings at a bus route	Chicago Transit Authority
Railway station-level ridership in 2019	Daily counts of passenger boardings at an L station	Chicago Transit Authority
Socio-demographics		
Race/ethnicity	The proportion of people from different racial/ ethnical backgrounds (%)	2019 Community Data Snapshot and 2019 5-year ACS data
Female	The proportion of females (%)	2019 Community Data Snapshot and 2019 5-year ACS data
Youth	The proportion of people aged 18 (%)	2019 Community Data Snapshot and 2019 5-year ACS data
Elderly	The proportion of people aged 65 and above (%))	2019 Community Data Snapshot and 2019 5-year ACS data
Income	Median household income (US dollar)	2019 Community Data Snapshot and 2019 5-year ACS data
Zero-car households	The proportion of households without a car (%)	2019 Community Data Snapshot and 2019 5-year ACS data
Built environment		
Population density	The number of people per sq mile (persons/mi^2)	2019 Community Data Snapshot and Smart Location Database
Employment density	Jobs per square mile (jobs/mi^2)	2019 Community Data Snapshot and Smart Location Database
Residential density	Housing units per acre on unprotected land (units/mi^2)	2019 Community Data Snapshot and Smart Location Database
Transit density	Transit stops per square mile (stops/mi^2)	2019 General Transit Feed Specification
Land-use mix	Shannon entropy of 6 land use types: residential, commercial, industrial, open space, mixed-use, and others	Land Use Inventory in 2018, Chicago Metropolitan Agency for Planning

Intersection density	Street intersections per square mile (intersections/mi^2)	2019 Community Data Snapshot and Smart Location Database
Distance to transit	The Euclidean distance between the station and the nearest transit stop (mi)	2019 General Transit Feed Specification
Distance to city center	The Euclidean distance between the station and the centroid of the downtown district (mi)	Chicago data portal

The analysis unit, data aggregation, and variables for the statistical analysis are shown in Table 4-3. The information on trip origin and destination was available for the bikeshare system, the trips of a bikeshare station were calculated as the sum of trips starting and ending at this station. For taxi and ride-hail services, to protect user privacy, the city removed the census tract information for any trip that was the sole trip in a census block group within a 15-minute period (City of Chicago, 2023a). By comparison, taxi and ride-hail data aggregated at the community area level were more accurate by including the more complete location information of community areas. Therefore, I opted to utilize the community area as the analysis unit for analyzing how shared e-scooters affected taxi and ride-hail trips. Bus and railway ridership[12] were calculated by summing up boardings at the bus route and railway station, respectively.

Table 4-3. The specification of dependent variables.

Variables	**Analysis unit**	**Descriptions**
Bikeshare trips	Bikeshare station	The counts of trips started and ended
Railway ridership	L station	Station-level ridership
Bus ridership	Community area	Route-level ridership
Taxi trips	Community area	The number of trips started and ended
Ride-hail trips	Community area	The number of trips started and ended

[12] To avoid word redundancy, I used "trips" to refer to the dependent variables for all these transportation modes in the following text.

4.3.3. Geographic Analysis: Spatial Patterns of Trips by Transportation Modes

I first geo-visualized trips by pre-existing transportation modes within 15 weeks before the implementation of shared e-scooters. I aggregated trips by all these modes at the community area level to facilitate spatial correlation analysis. Since trips by bikeshare, railway, and bus were originally aggregated at the station or route level, I transformed the aggregation with the following approaches. For bikeshare and railway, I created 0.25-mile buffers for bikeshare stations and 0.5-mile buffers for railway stations, according to previous studies on acceptable walking distance to access these two transportation modes (El-Geneidy et al., 2014; Ursaki & Aultman-Hall, 2015). Trips at a specific station were allocated to community areas by the area weight (i.e., the service area in a community area divided by the total area). For the bus system, trips of a specific bus route were allocated to community areas by the length-weight (i.e., the length of a route in a community area divided by the total length). For instance, if a bus route is 10 miles long, crossing two communities. 6 miles of this bus route are in community A, and 4 miles of the route are in community B. Then, 60% of the ridership of this route will be allocated to community A, and 40% of the ridership will be allocated to community B.

Second, I standardized the spatial distributions of ridership by the sum of residents and jobs, which denotes the real number of people who can access a specific transportation mode. Last, I conducted the bivariate Moran's I analysis to examine the significance of the spatial correlation between trips of paired modes for all examined transportation modes, which can be defined as:

$$I_B = \frac{\sum_i (\sum_j w_{ij} y_j \times x_i)}{\sum_i x_i^2} \quad (4.1)$$

Where x_i is the ridership of transportation x in community area i; y_j is the ridership of transportation y in community area j; w_{ij} is the spatial weight between community areas i and j.

Moran's I measure how the degree to which the value x at a given community i is correlated to values y in adjacent neighborhoods. Notably, the positive Moran's I denotes the concentration of high-high values or low-low values x and y, while the negative Moran's I denotes the concentration of high-low or low-high values x and y. The spatial correlation analysis and the geographic distributions of trips can intuitively reveal the spatial concentration of trips by existing transportation in Chicago.

4.3.4. PSM-DID Analysis: Examining the Effects of E-scooters on other Transportation Modes

The primary data analysis method is the difference-in-difference (DID) model based on propensity score matching (PSM). PSM aims to address selection bias by selecting units in the control group with similar characteristics to those in the treatment group. The propensity score represents the likelihood of assigning an analysis unit with specific factors to either the treatment or control group. To conduct the PSM analysis, I first assigned bikeshare stations, L train stations, and community areas into treatment and control groups in terms of their proximity to the shared e-scooter operational area. The treatment group includes bikeshare stations, L train stations, and community areas located within a quarter-mile buffer of the e-scooter operational area, while the control group consists of stations and community areas outside the buffer. This buffer distance is reasonable for accessing shared micromobility vehicles (Ursaki & Aultman-Hall, 2015). For the bus routes, I calculated another length weight, the length of a route in the operational area divided by the total length, and the top fifty percent of the routes were divided into the treatment group. I utilized the Psestimate module to identify relevant covariates for PSM models, which proved effective in determining the necessary factors for our study. The PSM model was defined as follows:

$$P(T = 1|X) = \frac{EXP(\alpha + \beta X)}{1 + EXP(\alpha + \beta X)} \quad (4.2)$$

Where T is an indicator of the treated group (T=1 if an analysis unit is in the treatment group and otherwise T=0); X is the covariates; β is a vector of coefficients. For bikeshare stations, L train stations, and bus routes, the block-group level neighborhood characteristics were aggregated at each analysis unit, and the aggregation method is the opposite of the aggregation of trips at the community level stated above.

DID is a statistical method to infer a causal relationship based on the quasi-natural experiment, which compares changes in the average treatment group to the average control group changes over time. DID aims to minimize the effects of extraneous factors, and PSM can help remove the selection bias of the designating treatment group. The greatest threat to this causal inference design was that the designation of the operational area was driven by other factors that may impact the trips by other transportation modes. The 2019 pilot report states the rationale for designating the operational area: "[t]he service area was designed to test e-scooters in a diverse set of neighborhoods, with diverse populations, different community types, business districts, and residential densities." Transportation policies apart from shared e-scooters are unlikely to target solely the area within the operational boundary as they cut across community boundaries and do not constitute a single population or demographic group. For instance, policies for improving service levels are implemented at the route level; equity policies tend to focus on communities with distinct, rather than divergent, characteristics. Additionally, no evidence shows that other policies, programs, or events that would meaningfully shift ridership during the study period specifically occurred in either the operational or the non-operational area.

The matched bikeshare stations, L train stations, bus routes, and community areas were categorized into four groups: 1) the treatment group before the pilot, 2) the treatment group after

the pilot, 3) the control group before the pilot, and 4) the control group after the pilot. The general DID model can be defined as:

$$\log\left(\overline{Trip}_{it}^{PSM}\right) = \beta_0 + \beta_1 treat_{it} \times post_{it} + place_i + week_t + \varepsilon_{it} \quad (4.3)$$

Where i represents individual bikeshare station, L train station, bus route, or community area; t week number in a year; $treat_{it}$ denotes whether i is in the treatment group in week t; $post_{it}$ denotes whether t is after implementing the shared e-scooter for i; $place_i$ designates the fixed effect of the station, bus route, or community area i; $week_t$ signifies the fixed effect of week t; $\overline{Trip}_{it}^{PSM}$ indicates the weekly trip or ridership at i in week t after matching.

I developed negative binomial regression models with fixed effects for the DID analysis due to the overdispersion of the counted dependent variables. I reported the incidence rate ratio (IRR) rather than coefficients to make the results more interpretable. If the IRR is greater than 1, it indicates an increase in the incidence rate, and if it is less than 1, it indicates a decrease. For instance, if the IRR for a variable is 1.2, it means that implementing shared e-scooters leads to a 20% increase in trips by another transportation mode, assuming all other variables are held constant. I repeated the DID models to evaluate all transportation modes in the EPA versus non-EPA.

4.3.5. Statistical Tests: Evaluating the Quality of PSM-DID Analysis

Lastly, I conducted several statistical tests to ensure the validity of the PSM-DID models. I ran the balancing and common support tests to ensure the control and treatment groups were similar in terms of their characteristics. I also ran the common trend test to ascertain the presence of a consistent pattern of change in both the treated and control groups leading up to the initiation of the shared e-scooter pilot program. I employed a standard event study methodology, wherein the interaction between the dummy week variable and shared e-scooter adoption

replaced the interaction term used in the DID model. The model employed for investigating the common trend is defined as follows:

$$\overline{Trip}_{it}^{PSM} = \delta_0 + \sum_{t=-15}^{15} \delta_i tp_{it} + place_i + week_t + \varepsilon_{it} \quad (4.4)$$

Where tp_{it} is the dummy variable before or after introducing shared e-scooters. tp_{it} equals 1 for individual i in the treated group and equals 0 for individual i in the control group in the week to which t corresponds. Appendices G to I show the results of these statistical tests, which ensure the validity of the following regression analysis.

4.4 Results

4.4.1 Where Were Trips Before Scooters Came to Chicago?

The spatial analysis aimed to provide a baseline estimate of spatial distributions of trips by transportation modes within three months prior to the introduction of shared e-scooters in Chicago. Figure 4-4 shows the spatial pattern of per capita trips by transportation modes before implementing the shared e-scooter pilot, with the natural break as the classification method. The darker color represents the higher value of per capita trips for a specific transportation mode in a community area. Communities with greater per capita bikeshare, railway, ride-hail, and taxi trips were concentrated in the downtown and northern side of Chicago (non-EPAs), inhabited predominantly by white and affluent residents (Appendix E). By comparison, bus trips are distributed more evenly according to the population throughout Chicago, so many communities with higher per capita trips were in the EPA.

Table 4-4 shows the results of bivariate spatial correlation, which demonstrates the relationship between variable *x* and the spatial lag of variable *y*. Bikeshare trips per capita display a significant spatial correlation with railway, taxis, and ride-hail trips, exhibiting the

absence of high-frequency trip clusters within the EPA. In contrast, bus ridership exhibits a more uniform distribution across the city, and the spatial correlation table shows bus trips per capita are not related to—or at most, weakly related to—the spatial distribution of other transportation modes. For instance, the western and southern parts of Chicago include many community areas characterized by high per capita bus trips, while the per capita trips

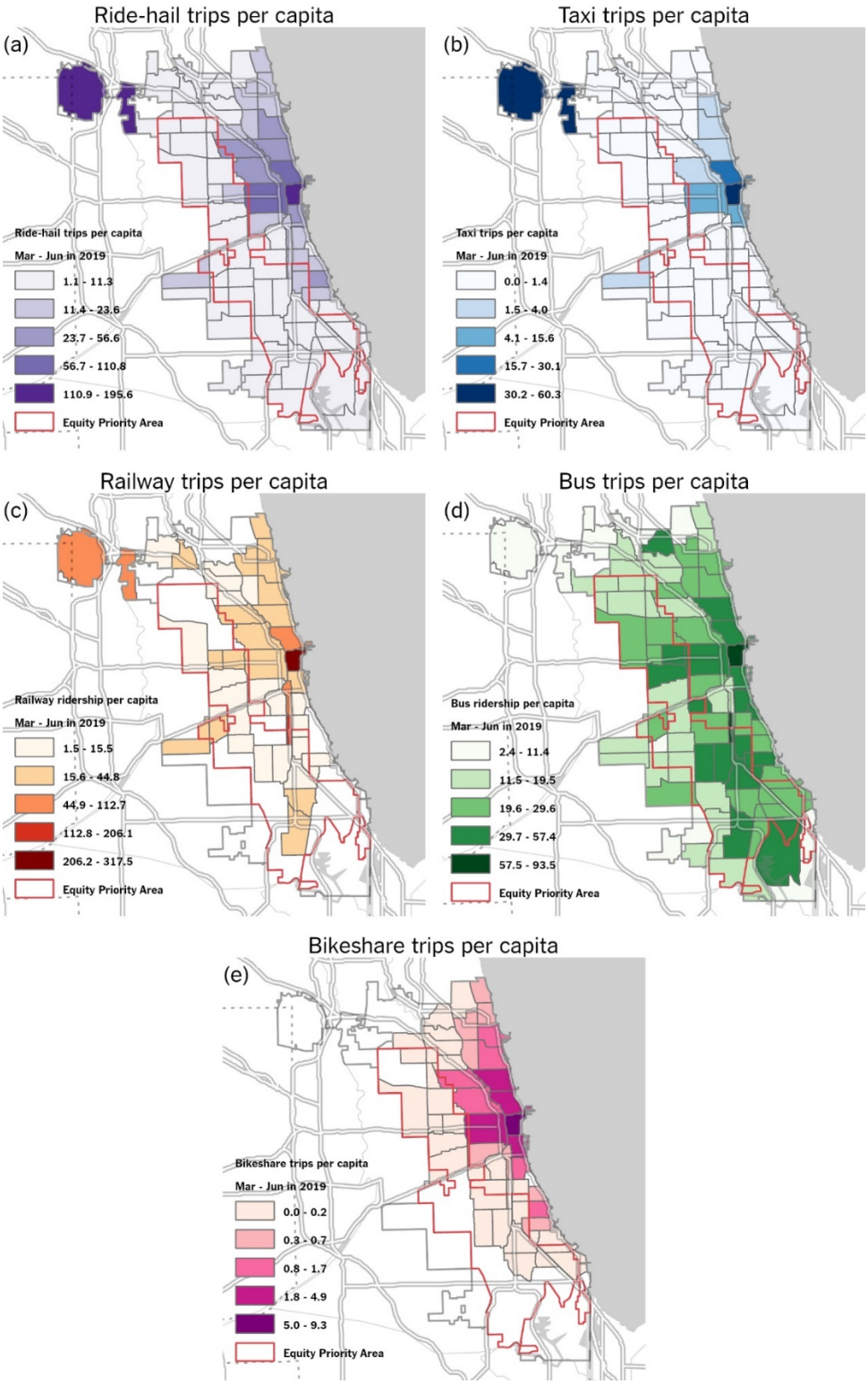


Figure 4-4. The spatial distribution of ridership of transportation modes before the launch of shared e-scooters in Chicago.

Table 4-4. Bivariate Moran's I analysis of trips by transportation modes in Chicago.[13]

	Bikeshare	Bus	Railway	Ride-hail	Taxi
Bikeshare		0.040	0.206***	0.549***	0.385***
Bus	0.042		0.07*	0.114**	-0.048
Railway	0.217***	0.045		0.212***	0.125**
Ride-hail	0.536***	0.073*	0.195***		0.286***
Taxi	0.425***	-0.071*	0.106**	0.316***	

**** p<.01, ** p<.05, * p<.1*

4.4.2. The Effects of Scooters on Trips by Existing Modes

The launch of the e-scooter program significantly reduced the average weekly bikeshare ridership by 4.3% at bikeshare stations within the e-scooter operational area relative to bikeshare stations outside of the scooter operational areas (Table 4-5). The outcomes observed within the EPA, however, starkly contrasted with those in the non-EPA. The introduction of e-scooters led to a 9.2% increase in bikeshare trips in the EPA but a 5.4% decrease in the non-EPA (Table 4-5)

The shared e-scooters negatively impacted rail trips (-2.1%) but had no impact on bus ridership. The non-EPA experienced a greater percentage decrease in rail trips (-3.4%) than the EPA (-1.3%). Additionally, shared e-scooter implementation had no associations with bus trips in either the EPA or non-EPA.

The introduction of shared e-scooters led to an overall 1.9% increase in ride-hail trips. While scooters led to a 6.8% increase in the non-EPA, shared e-scooters were not significantly related to changes in ride-hail trips in the EPA. Lastly, shared e-scooter implementation resulted in decreases in taxi trips in the whole operational area (-3.9%), the EPA (-8.3%), and the non-EPA (-4.9%).

[13] Formula 4.1 shows the designation of x and y impacts the results of spatial correlation analysis, which is different from the aspatial correlation analysis, such as Pearson correlation analysis.

Table 4-5. Impacts of shared e-scooters pilot on weekly trips by transportation modes in the operational area in Chicago.

	Bikeshare	Rail	Bus	Ride-hail	Taxi
(a) Overall					
E-scooter	0.957***	0.979***	1.01	1.019**	0.961***
	(0.007)	(0.007)	(0.015)	(0.007)	(0.014)
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Week Fixed Effect	Yes	Yes	Yes	Yes	Yes
Number of observations	14184	1980	2442	1380	1380
Log L	-63309.5	-16209.8	-22703.9	-11544.1	-7728.3
Wald chi2	39945	835.68	368.11	1354.84	1383.86
Prob > chi2	0.000	0.000	0.000	0.000	0.000
(b) EPA					
E-scooter	1.092**	0.987*	0.987*	1.036	0.917***
	(0.045)	(0.008)	(0.007)	(0.04)	(0.018)
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Week Fixed Effect	Yes	Yes	Yes	Yes	Yes
Number of observations	2741	870	1380	630	630
Log L	-7817.3	-6449.6	-12290.7	-4916.7	-2821.23
Wald chi2	1232.92	668.18	1532.32	1112.64	809.16
Prob > chi2	0.000	0.000	0.000	0.000	0.000
(c) Non-EPA					
E-scooter	0.946***	0.966***	0.967	1.03**	0.951**
	(0.007)	(0.012)	(0.039)	(0.01)	(0.019)
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Week Fixed Effect	Yes	Yes	Yes	Yes	Yes
Number of observations	11443	1110	1062	750	750
Log L	-55091.76	-9624.7	-9428.9	-6558.0	-4483.0
Wald chi2	40847.52	414.4	124.53	550.89	855.05
Prob > chi2	0.000	0.000	0.000	0.000	0.000

*p ≤ 0.1, **p ≤ 0.05, ***p ≤ 0.01.

4.5. Discussion

Previous studies have examined how shared micromobility systems interacted with the existing transportation modes, but these studies could not infer the net effects of the shared micromobility on trips by other transportation modes due to the non-experimental nature of the study design. Also, few quasi-experimental studies examined a single transportation mode, which could not reveal the overall impacts of shared micromobility on transportation. In this study, I examined the effects of the shared e-scooter pilot on trips by bikeshare, railway, bus, taxi, and ride-hail and investigated how these effects impacted trip inequalities between the EPA and non-EPA in Chicago. Based on the theoretical framework and literature, I discussed what led to the impacts of shared e-scooters on existing transportation modes in the following subsections, which divided modes with similar characteristics into the same group.

4.5.1. Shared Micromobility

The negative impact of dockless micromobility on docked micromobility ridership was consistent with previous surveys examining the modal substitution (City of Chicago, 2020; Li et al., 2019; Wang et al., 2023; Yang et al., 2021). Dockless micromobility is characterized as a flexible, electric, and pleasant/fun transportation mode (Chen et al., 2020), and shared e-scooter trips are, on average, shorter in both travel time and distance compared to bikeshare trips (NACTO, 2019), so it is reasonable that e-scooter trips may replace short and medium-duration bikeshare trips.

However, the shared e-scooter pilot has heterogeneous impacts on bikeshare trips—positive in the EPA and negative in the non-EPA. This heterogeneity in treatment effects could be attributed to several factors. Firstly, the demand for active transportation in the EPA might surpass that in other areas, given that residents of marginalized neighborhoods tend to walk and

cycle more than the general population (Brain, 2014). Secondly, the cost dynamics played a pivotal role. In 2018, Divvy introduced the $3 single-ride option and raised the price of a day pass from $9.95 to $15. By comparison, e-scooter operators charged 1$ to unlock an e-scooter and 15 to 35 cents per minute. Therefore, shared e-scooter was generally cheaper for causal use under 10 minutes than bikeshare. However, the average price per trip for e-scooter sharing exceeded that of docked bikeshare, especially for subscribers, making scooters a more economical option for very short trips, as per the prevailing pricing structure (City of Chicago, 2021; NACTO, 2018; PBOT, 2019). Given the share of subscribers was higher in the EPA than that in the non-EPA, introducing shared e-scooters could have more negative impacts on bikeshare trips in the non-EPA. Thirdly, Chicago's pilot program evaluation report underscored that nearly half of the users engaged with e-scooters on an occasional basis (less than once a week) and more than half of the users never used bikeshare before (City of Chicago, 2020). E-scooters might serve as an entry point for individuals to explore micromobility. New e-scooter users in the EPA could potentially transition to bikeshare subsequently due to its lower costs; people may use the micromobility with friends or family, which could facilitate the combo of shared bikes and scooters to satisfy groups' needs.

Additionally, shared e-scooters and required community outreach and education programs could potentially diminish the social barriers linked to micromobility experienced by marginalized communities. Many individuals from marginalized backgrounds might be hesitant to use bikeshare due to societal stigma and the perception that it is not intended for them (Shaheen et al., 2017). E-scooter programs, especially those incorporating equity-focused policies (City of Chicago, 2021a), have the potential to alter these perceptions within certain communities. Recent research also suggests that socio-psychological factors primarily influence

the initial adoption of shared e-scooters, while subsequent usage frequency is determined by demographics (Blazanin et al., 2022). Integrating these findings with existing literature, my results imply that initiatives supporting the initial use of shared e-scooters may have ancillary benefits, promoting bikeshare adoption due to their comparable modal experiences but lower costs, in low-income and minority communities underserved by bikeshare services.

4.5.2. Public Transit

In Chicago, shared e-scooters uniformly had negative impacts on railway trips and no impacts on bus ridership across various communities, indicating that the adverse effects generally outweighed any positive contributions to transit ridership. This trend implied the integrating relationship between shared e-scooters and public transit was marginal. Notably, the decline in public transit trips was more pronounced in non-EPA than in EPA. This observation aligns with findings from Wang et al. (2023), which found a higher substitution rate of shared e-scooters for public transit trips in larger, denser cities as opposed to smaller, less dense ones. Therefore, it was expected that shared e-scooters would have greater negative impacts on public transit in the denser, non-EPA areas with a well-connected transit network compared to EPAs with comparatively fewer transit services.

As previously discussed in the literature review, roughly overlapping accessibility between two modes of transportation is a prerequisite for potential competition—a condition clearly met for short-distance travel in Chicago. Shared e-scooters have the advantage over railways in three aspects. Firstly, the direct point-to-point service offered by shared e-scooters presents a more convenient option compared to public transit. This preference is supported by a stated preference study in Singapore (Cao et al., 2021), which found that increased transfer and walking distances for accessing and egressing transit stations diminish the likelihood of choosing

transit over shared e-scooters. Secondly, the flexibility and reliability of shared e-scooters are advantageous over public transit. Numerous studies highlight that factors such as unreliability, infrequency, and inaccessible transit environments significantly deter public transit usage and affect customer loyalty (de Oña et al., 2016; van Lierop & El-Geneidy, 2016). Even though this advantage of shared e-scooters suggests a spatial substitution for public transit, e-scooters can complement public transit temporally in another way. Furthermore, transitioning to shared e-scooters may circumvent potential harassment issues on public transit, a concern disproportionately affecting women, transgender, and gender-nonconforming individuals (Ding et al., 2020; Lubitow et al., 2020).

On the other hand, the net negative and non-significant impacts may also result from the weak integration of shared e-scooter and transit. Chicago did not launch any mobility on demand or mobility as a service program to integrate multiple types of mobility services. Therefore, it was not convenient for users to transfer from one transportation mode to another seamlessly. Another aspect deterring the integration pertains to the fare structures of shared micromobility and public transit. The fare for shared e-scooter connecting trips was much higher than transit fares in Chicago. For instance, considering a 1-mile connecting trip by e-scooter at a speed of 10 mph, the total fare for two connecting trips (to/from) amounted to approximately 3.8 dollars (calculated as 2 * (1 [unlock fee] + 6 [minutes] * 0.15 [per-minute cost])) (Ackerman, 2019), surpassing the bus fare (2.25 dollars) and train fare (2.5 dollars) (Chicago Transit Authority, 2023).

The significant disparity in substitution effects between the EPA and the non-EPA can be ascribed to distinct built environment features. Notably, areas such as the Loop (Chicago's downtown), the near-north region, and university districts are characterized by high population

density, mixed land use, well-connected infrastructure, and abundant active transportation facilities. Extensive empirical research supports the correlation between these attributes and increased engagement in active travel, particularly for short-distance point-to-point journeys (Frank et al., 2006; Owen et al., 2007; Planetizen, 2023). In stark contrast, the EPA is situated at a considerable distance from the city center, marked by lower population density and a lack of cohesive and accessible cycling infrastructure, as evidenced by the data provided by CDOT (2023).

4.5.3. For-hire Motorized Mobility

The increase in ride-hailing trips due to shared e-scooters contrasted with existing reports from Chicago and several other cities, where the alternative travel mode for a significant portion of e-scooter trips was ride-hail service (City of Chicago, 2020; Wang et al., 2023). One plausible explanation could be triple triple-down effects of new e-scooter trips, a factor not typically accounted for in city surveys. The 2019 e-scooter pilot program report revealed that infrequent riders tend to use e-scooters primarily for discretionary recreational purposes (City of Chicago, 2020). Since the survey asked a counterfactual question regarding the alternative mode for e-scooter trips without asking whether the e-scooter trip was new, many of these e-scooter trips might have been new trips complementing the existing transportation system. If one uses an e-scooter from points A to B, one may use other transportation modes to access point C or return to point A. Given that most respondents chose the ride-hailing service as the alternative mode, trips related to the e-scooters trips might have been made by ride-hailing.

Furthermore, the integration of shared e-scooter services into ride-hail applications may contribute to increases in ride-hail trips following e-scooters' introduction. Ride-hailing

platforms, like Uber and Lyft[14], incorporated e-scooter services into their apps' interfaces, providing users with a unified experience. This integration allows individuals to plan their entire journey, encompassing both e-scooter rides and Lyft tips using a single app. Such enhanced convenience may influence users to opt for ride-hailing services for segments of their daily travel less conducive to e-scooter use, particularly for longer distances or during adverse weather conditions.

The negative effects of shared e-scooters on taxi trips should result from the direct substitution (Figure 4-1), as both modes offered point-to-point travel services. However, the number of taxis has declined since the ride-hail entered Chicago (Schneider, 2023), so shared e-scooters may be a more reliable and cost-effective travel option than taxis. Additionally, the taxi platform did not incorporate shared e-scooter service, so shared e-scooter trips can hardly have triple-down effects on taxi trips.

4.5.4. Limitations

This study utilizes a quasi-natural experiment approach to examine the causal effects of implementing a shared e-scooter program on the inequalities in trips by existing transportation modes in Chicago. However, the generalizability of results is subject to the specificity of the 2019 e-scooter pilot in Chicago. First, the 2019 shared e-scooter program in Chicago was a pilot time with a relatively short time span, so it is unclear whether analysis results may vary according to the time span. Second, the Chicago Transit Agency implemented equity requirements for shared micromobility operators to ensure that vehicles were evenly distributed across communities in the operational area. Shared micromobility systems with different equity

[14] Lyft's e-scooter service was inserted in Lyft's app; Uber and Lime established a partnership to provide Lime's e-scooter service via Uber's app, though Lime had its own app.

policies and requirements may impact how the transportation disadvantaged utilize shared e-scooters, which can affect the effects on trip inequalities. Third, the findings of this study are also hard to generalize to other municipalities with different social, economic, and political contexts, especially for low-density cities with limited transportation alternatives. Last, the data used in this study were collected from June to October in the year prior to the COVID-19 pandemic, so it is uncertain whether COVID and seasonality would alter the interactions between shared e-scooters and other transportation modes. Additionally, there are two threats to the internal validity of this study. First, the assignment of route-level bus trips to community areas cannot show the accurate trips generated in these communities. For a bust route, it is highly unlikely trips are evenly distributed across communities along this route. On the other hand, since Chicago has developed various transportation equity programs and the operational area of the pilot is limited, concurrent programs may target certain communities outside the operational area. Thus, these unobserved variables could affect the results.

4.6. Policy Recommendations

4.6.1. Shared Micromobility

The findings of this study carry significant policy implications. Firstly, the introduction of shared dockless e-scooters, despite potentially reducing bikeshare ridership (-4.2%), leads to a substantial overall increase in micromobility trip-making. In Chicago, micromobility ridership surged by 50% from 2018 to 2019, reaching 2.6 million trips during the pilot program months. This suggests that the addition of a new modal option could encourage people to shift modes to better meet their travel preferences or could serve previously unmet demands.

Second, policymakers need to be attentive to the varied impact e-scooters can have on

bikeshare ridership across different geographical areas, particularly within the EPA where the demand for active transportation is evidently high. Expanding the reach of shared e-scooters to areas underserved by docked bikeshare or within the EPA might not diminish bikeshare ridership but could serve as a supplementary service. Cities should work with the operators and research institutes to conduct detailed community need assessments for understanding the needs of residents in different areas, and then deploy sufficient micromobility vehicles across the city.

Last, cities must formulate comprehensive policy packages to encourage active travel within the EPA. While shared dockless e-scooters can alleviate some social barriers, various intersectional obstacles might deter potential micromobility users, as indicated in previous studies (McNeil, Dill, MacArthur, & Broach, 2017). For instance, the growing concerns about active travel safety and cost have been excluding potential shared micromobility users. Future qualitative studies should delve deeper into these barriers to understand the individual choices between shared e-scooters and bikeshare systems.

4.6.2. Public Transit

The heterogenous examination suggests the integration of shared micromobility service into the public transit system is a crucial step toward creating a more equal urban transportation network. Even though the introduction of shared e-scooters alleviated the inequalities in railway ridership, the realization built upon greater negative impacts in the non-EPA than EPA. Therefore, integration (i.e., addressing the first/last mile problem) may be less frequent than substitution. To strengthen this integration, several key strategies and initiatives can be implemented. Integrating micromobility services into existing public transit fare structures and payment systems allows passengers to use a single ticket, transit pass, or app for both transit and micromobility rides. Integrating them across various modes of transportation (i.e., mobility on

demand or mobility as a service) simplifies the user experience and encourages greater adoption of shared micromobility plus transit. A recent study summarizes the bundled mobility programs in cities worldwide and related studies, and evidence has shown that integrating shared micromobility with transit can increase transit ridership (Beale et al., 2023). Nevertheless, to address the equity concerns, the authors point out that policymakers should combine the bundled program with the income-based program that includes accessible payment options and alleviates financial barriers.

In the EPA, planners should remove barriers in the built environment to create a seamless and efficient experience for commuters utilizing both modes of transportation. Establishing dedicated lanes or shared paths for e-scooters leading to transit stops is a practical and effective solution that can significantly enhance urban mobility and encourage the adoption of e-scooters as a convenient mode of transport. Planners should identify high-traffic routes connecting residential areas, commercial districts, and transit stops. These routes should be strategically chosen based on commuter demand, minimizing travel time and providing direct access to popular transit hubs. In the non-EPA, designing transit stations to accommodate shared micromobility vehicles, such as dedicated parking areas or charging docks. Well-marked, secure, and easily accessible spaces for parking e-scooters and bikes at transit hubs enhance the overall convenience and encourage commuters to use these services as part of their daily routines, and the availability of charging facilities can reduce the time of charging and re-deploying e-scooters across the city.

4.6.3. For-hire Motorized Mobility

A crucial consideration for policymakers is reconsidering the existing cap on the number of e-scooters permitted within the city. The 2019 e-scooter pilot in Chicago sets the fleet size

limit at 2500 e-scooters, and the scarcity of shared e-scooters adversely affects their perceived reliability (Javadinasr et al., 2022). A shortage of e-scooters may lead riders to view them primarily as recreational options rather than reliable modes of utilitarian transportation. This perception hampers the e-scooter's potential to serve as dependable alternatives for daily commuting, impacting their overall viability as a transportation solution. Furthermore, the shortage of e-scooters results in increased prices for using these services, diminishing their cost-effectiveness when compared to ride-hailing options. In contrast, when ride-hailing services were introduced in Chicago, the city opted not to impose any restrictions on the number of ride-hailing vehicles. This strategic decision facilitated a rapid increase in ride-hailing trips, significantly reducing taxi usage and fostering a more equitable landscape within the for-hire motorized mobility system (Meng, Brown, & Barajas, 2024). Similarly, if cities do not limit the fleet sizes of shared micromobility systems, the greater substitution effects can urge taxi and ride-hailing drivers to serve previously underserved areas. Therefore, it is essential to adopt a consistent and equitable approach, eliminating arbitrary limitations on shared e-scooters.

4.7. Conclusions

The introduction of shared dockless e-scooter programs in Chicago presents a valuable opportunity to investigate the intricate dynamics between emerging micromobility options and existing transportation modes, especially in the transportation equity priority area. This study delves into the effects of these interactions on trips made by existing transportation modes, including bikeshare. The findings indicate that the implementation of shared e-scooter programs led to a decrease in trips by bikeshare, railway, and taxis in the whole city. By comparison, a positive impact was observed on ride-hail trips, while no significant effect was noted on bus

trips. Within the EPA, shared e-scooters had positive impacts on bikeshare trips. Furthermore, the introduction of shared e-scooters resulted in a more substantial percentage decline in railway trips in the non-EPA than in EPA. In contrast, taxi trips decreased more in the EPA than in non-EPA. Additionally, shared e-scooters did not impact ride-hail trips within the EPA and bus trips, underscoring the intricate and location-specific nature of these interactions between micromobility services and existing transportation modes.

CHAPTER V

CONCLUSIONS

This dissertation focuses on the inequalities in shared micromobility by conducting three studies at the global, national, and local scales. The inequality studies in shared micromobility include a wide range of issues: the descriptions, determinants, and consequences of inequalities in shared micromobility. Previous studies predominantly examined the determinants of unequal distribution of shared micromobility services and trips at the community level. The studies on the impacts of shared micromobility relied on inference based on geographic data or surveys, which did not examine the causal relationship and who and where are impacted by a certain distribution of shared micromobility services and trips. Additionally, most shared micromobility equity studies tend to be positive rather than normative, without incorporating genuine discussion on equity principles. The three individual studies in this dissertation aim to address these research gaps.

The global-level study leverages world city theory to investigate how shared micromobility companies were established and expanded. Based on the analysis of the world city network, this study employs mixed methods to identify factors leading to the inequalities in system distribution across cities. World city analysis indicates that the rapid expansion of shared micromobility is closely associated with world cities of ride-hailing, advanced producer services, and startups and venture capital investments. The regression analysis shows that the number of regional offices within a country is the most significant predictor for the number of shared micromobility systems in a city, primarily accounting for variations across countries. After controlling for country-level variables, the analysis shows that population size, economic activity intensity, built-up area, and precipitation are positively associated with the number of shared

micromobility systems. In contrast, built-up area per capita, the proportion of non-built-up areas, and temperature are negatively associated with system count. These findings suggest that densely populated, economically advanced, high-density, compact, and climate-friendly cities are more likely to host a greater number of shared micromobility systems. In addition to concerns raised in prior research, the qualitative analysis identifies four new significant barriers to implementing shared micromobility: the restrictive or lax regulatory framework, the perceived low demand for shared micromobility, opposition from two distinct groups, and the exclusion of active transportation from long-term transportation planning. This study extends the scope of inequality study in shared micromobility by examining the adoption of shared micromobility systems at the city level.

The national study utilizes the theoretical framework of the opportunity-equalizing principle to evaluate the efficacy of shared micromobility equity policies and requirements in the US. Structural equation modeling was developed to examine how policies for equalizing resources and opportunities affect vehicle and trip inequalities in shared micromobility systems. The inequalities in shared micromobility vehicles and trips are intrinsically connected. Policies rooted in strict egalitarianism for equalizing vehicle distribution, are associated with decreased vehicle distribution inequalities directly and reduced trip distribution inequalities indirectly. In contrast, policies based on luck egalitarianism, which aim to ensure equal opportunities, have proven ineffective in producing equitable outcomes. Furthermore, the dockless nature of shared micromobility systems does not inherently relate to these inequality indicators. Reduced per-capita fleet size is closely correlated with heightened trip inequalities. Drawing on the theoretical frameworks established by Roemer (1993, 1996, 2002), the present work first applies this model to evaluate the performance of shared micromobility equity policies with explicit equity

principles.

The local study treats 2019 shared e-scooter pilot in Chicago as a quasi-experiment, aiming to examine how shared e-scooters interact with the existing transportation modes—bikeshare, railway, bus, taxi, and ride-hailing—especially within the transportation equity priority area. In Chicago, bikeshare, railway, taxi, and ride-hailing trips were disproportionately concentrated in the non-equity priority area, except for bus trips that are more evenly distributed among communities. The introduction of shared e-scooters produced varied impacts on different transportation modes between equity priority and non-equity priority areas. In the equity priority area, shared e-scooters significantly increased bikeshare usage and reduced taxi usage while only slightly diminishing public transit trips. Conversely, in the non-equity priority area, shared e-scooters notably decreased bikeshare, railway, and taxi trips but led to an increase in ride-hailing trips. Building on previous research involving surveys and GIS-based analyses, this study uses a quasi-experimental design to identify the causal effects of introducing shared e-scooters on trips by existing transportation modes. Additionally, the findings offer insights into how introducing shared e-scooters might help reduce trip inequalities between advantaged and disadvantaged communities.

APPENDICES

Appendix A. Interview Guide for City Staff and Scholars in Cities without a Shared Micromobility System

Introduction to Background

1. Could you describe your role in urban and transportation planning in the city?

2. How would you describe the general perception of shared micromobility in your city? Is there a noticeable demand or interest among residents for such systems?

Initial Considerations and Community Input

3. Were you aware of any discussions or plans by the city to implement a shared micromobility system? What was the nature of these discussions?

4. How were residents involved in the planning process? Were there any public forums, surveys, or other methods of gathering community input?

Challenges and Barriers

5. From your perspective, what were the main challenges or obstacles that prevented the implementation of a shared micromobility system in your city?

6. Were there specific concerns or objections raised by the community or local businesses regarding shared micromobility?

Stakeholder and Decision-maker Dynamics

7. How do you perceive the roles and reactions of various stakeholders (e.g., city officials, transportation planners, private companies) in the discussion around shared micromobility?

Factors Influencing Non-Implementation (if applicable)

8. In your opinion, what were the primary reasons the city decided not to proceed with a shared micromobility system?

9. How did regulatory, policy, or political considerations shape the decision-making process regarding the shared micromobility?

Alternative Transportation Solutions and Future Prospects

10. What alternative transportation solutions has the city pursued or considered in the absence of a shared micromobility system?

11. Under what circumstances do you think the city, or the community might revisit the idea of implementing a shared micromobility system?

Appendix B. Interview Guide for Employees in Shared Micromobility Companies

Introduction to Background

1. Can you briefly describe your role in market development in [company's name]? How have you been involved in the market development process?

2. Can you describe your company's strategy for expanding shared micromobility into new regions at the global level? Has there been any changes in the past few years?

Global Business Expansion

3. What is the thinking process of global business expansion? What were the key factors determining whether to enter a county/region for [company's name]?

4. Do [company's name] consider expanding the service to developing countries now? What are the major challenges for developing shared micromobility systems and creating partnerships in developing countries?

Local Business Expansion

5. How does your company assess the market potential of a city before deciding to launch your services there?

6. What are the key factors that influence the decision to introduce the shared micromobility system to a particular city within a country/region?

7. Could you explain how the local regulatory framework impacts your decision to operate in a city?

8. In what ways do community needs and stakeholder interests shape your expansion into new locations?

9. What other significant challenges does your company face when entering a new market, and how does it adapt to overcome them?

Appendix C. The Relations Between Variables in the Structural Equation Model

Table C-1. Latent variables in the structural equation model.

Variables	Estimate	Std. Err	z-value	p-value	Std.lv	Std.all
Latent variable: Resource-equalizing policy						
Service area	1.000				0.372	0.744
Deployment	0.915	0.133	6.870	0.000	0.340	0.704
Rebalance						
Latent variable: Opportunity-equalizing policy						
Phone alternative	1.000				0.356	0.712
Cash option	1.201	0.134	8.954	0.000	0.427	0.862
Reduced rate	1.003	0.169	5.950	0.000	0.357	0.717
Adaptive vehicles	0.635	0.142	4.456	0.000	0.226	0.623
Multi language	0.623	0.174	4.283	0.000	0.265	0.574
Outreach program	0.684	0.157	4.363	0.000	0.244	0.498

Table C-2. Regressions in the structural equation model.

Variables	Estimate	Std. Err	z-value	p-value	Std.lv	Std.all
Exogenous variable: Inequality in vehicle distribution						
Equal resource	-0.077	0.020	-3.834	0.000	-0.029	-0.155
Inequality in trips	1.044	0.069	15.061	0.000	1.044	0.774
Income Gini	-0.092	0.200	-0.459	0.647	-0.092	-0.018
Segregation	0.155	0.065	2.373	0.018	0.155	0.089
Dockless	-0.020	0.014	-1.469	0.142	-0.020	-0.049
Exogenous variable: Inequality in trips						
Equal opportunity	0.005	0.024	0.231	0.817	0.002	0.014
Inequality in trips	0.452	0.183	2.463	0.014	0.452	0.610
Income Gini	-0.111	0.141	-0.791	0.429	-0.111	-0.030
Segregation	0.001	0.067	0.019	0.985	0.001	0.001
Dockless	0.011	0.009	1.139	0.255	0.011	0.03
Fleet size	-10.359	3.854	-2.688	0.007	-10.359	-0.366

Appendix D. Equitable Transportation Policies and Programs Implemented in Chicago

Table D-1 summarizes the transportation equity policies and programs implemented in Chicago, which shows the long-term goals of addressing transportation inequalities and inequitable issues.

Table D-1. Equitable transportation policies and programs implemented in Chicago.

Policies	Aims	Source
General		
Strategic Plan for Transportation	Four key pillars consist of this plan: access to opportunity, aligning our streets with our values, streets free from violence, and a CDOT that works. Each pillar highlights the equity challenges (i.e., specific problems faced by BIPOC communities).	(City of Chicago, 2021b)
On to 2050	Enhance regional planning projects to facilitate improved job accessibility for those in economically marginalized circumstances	(TransitCenter, 2021)
Vision Zero Chicago	Eliminate traffic fatalities and serious injuries by 2026, which underscores the importance of involving residents in decision-making processes	(City of Chicago, 2023b)
Active travel		
Chicago cycling strategy	Implement a cycling network for everyone by expanding the network and growing the visibility in all communities, particularly those that have historically had less bike infrastructure.	(CDOT, 2023)
Shared micromobility system	Include Divvy bikeshare and shared e-scooter programs operated by several companies. There are several equity requirements for shared e-scooter operators.	(City of Chicago, 2024)
Ride-hail and transit		
Ride-hail vouchers	Provide vouchers and subsidies for residents lacking direct access to public transit	(Lyft, 2023)
Public transit benefit program	Help low-income residents have access to affordable public transportation, empowering them to travel without financial constraints.	(CTA, 2023b)

Red line extension	Expand transit services into historically underserved neighborhoods, aiming to reduce people's reliance on cars but also foster a sense of community and belonging.	(CTA, 2023)
Equitable transit-oriented development	Encourage residents to live and work in transit-accessible locations.	(City of Chicago, 2023a

Appendix E. The Characteristics of Neighborhoods by Treatment Group and Equity Priority Area in Chicago

Table E-1 provides comprehensive summaries of block-group level neighborhood characteristics concerning their geographic relationship with the operational area and equity priority area (EPA). I acquired neighborhood-level socio-demographic variables from the 2019 five-year American Community Survey and neighborhood-level built environmental variables from the Smart Location database. Neighborhoods within the operational area of the e-scooter pilot exhibit similarities with those outside the service vicinity, with one notable exception: a higher proportion of Latinos and a lower representation of Black residents characterize neighborhoods within the operational zone.

By comparison, neighborhoods located within the EPA manifest disparities in socio-demographics and built environment features compared to those outside this area. Firstly, the EPA hosts a higher concentration of young and female residents, juxtaposed with fewer affluent and white individuals in comparison to non-EPA neighborhoods. Secondly, significant disparities in neighborhood density metrics are evident within the EPA. Both the average and standard deviation of neighborhood density in the EPA substantially exceed those in non-EPA regions. For instance, while non-EPA neighborhoods may exhibit extreme variations in housing unit density, ranging from remarkably low to exceptionally high densities (such as observed in the north suburbs versus downtown areas), EPA neighborhoods present a more balanced distribution of housing units.

Furthermore, an analysis of walkability and transit-friendliness reveals noteworthy distinctions. Generally, neighborhoods outside the EPA demonstrate superior walkability and transit-friendliness. Metrics such as high transit density, mixed land use, a dense network, and

shorter distances to both transit facilities and the city center, traditionally indicative of enhanced walkability (Adkins et al., 2017; Owen et al., 2007), are more prevalent in non-EPA areas. This comprehensive analysis offers a nuanced understanding of neighborhood dynamics, illuminating the diverse socio-demographic and environmental factors at play within the operational and equity priority areas.

Table E-1. Summary statistics of block-group level neighborhood characteristics by treatment and equity priority areas.

Variables	Treated: no		Treated: yes		EPA: no		EPA: yes	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
Population	1618	1220.8 (621.7)	588	1329 (674.1)	1235	1334.5 (656.5)	971	1141.7 (596.1)
Female (%)	1611	52.1 (7.4)	588	50.7 (7.2)	1229	50.9 (7)	970	52.8 (7.7)
Male (%)	1611	47.9 (7.4)	588	49.3 (7.2)	1229	49.1 (7)	970	47.2 (7.7)
Youth (%)	1611	20.2 (10)	588	21.8 (9.2)	1229	17.7 (9.5)	970	24.2 (9.1)
Elderly (%)	1611	14.6 (9.6)	588	10.8 (7.2)	1229	13 (10)	970	14.4 (7.9)
Median household income	1520	65405.3 (38021.6)	553	59641.6 (33113.9)	1183	79890.8 (38848.6)	890	42569.6 (19071.9)
Zero-car household (%)	1610	25.1 (17.9)	588	24.2 (15.9)	1228	24 (17.6)	970	26 (17)
Asian (%)	1611	6.3 (10.9)	588	3.6 (6.4)	1229	8.8 (11.8)	970	1.5 (4.3)
Black (%)	1611	37.1 (41.4)	588	29 (36.8)	1229	17 (27.8)	970	57.6 (42.4)
Latino (%)	1611	20.8 (26.7)	588	40.7 (31.8)	1229	20.9 (21.5)	970	32.7 (36.2)
White (%)	1611	46.6 (35)	588	48.5 (30.5)	1229	64.2 (27.2)	970	25.3 (28.6)
Population density (n/acre)	1618	35.2 (37.7)	588	32.5 (20.6)	1235	42.2 (42.2)	971	24.7 (13.8)
Residential density (n/acre)	1618	18.7 (27.2)	588	13.1 (11.5)	1235	23.1 (30.8)	971	9.7 (4.8)

Employment density (n/acre)	1618	12 (62.8)	588	8.6 (27.8)	1235	17.8 (73.7)	971	2.5 (4.5)
Transit density (n/sq mi)	1618	62.7 (57.1)	588	66.9 (42.7)	1235	68.8 (63.9)	971	57.6 (35.8)
Land use mix	1618	0.6 (0.3)	588	0.6 (0.3)	1235	0.7 (0.2)	971	0.6 (0.3)
Intersection density (n/acre)	1618	170.6 (110.2)	588	170.6 (102.9)	1235	191 (121.4)	971	144.8 (82)
Dis2transit (m)	1615	279.6 (139.8)	588	242.6 (98.4)	1232	269.3 (136.5)	971	270.4 (123.8)
Dis2Center (m)	1618	12493.5 (5159)	588	8737.2 (3340)	1235	10679 (5584.1)	971	12526.8 (3976.2)

Appendix F. Average Weekly Ridership of Different Transportation Modes during the Study Period

The figures below illustrate the shifts in ridership within both treated and control groups across various transportation modes before and after the introduction of shared e-scooters. The disparities in weekly ridership between these groups exhibit consistent patterns for all transportation modes throughout the city in the period preceding the initiation of the e-scooter pilot program (from week -15 to week 0). These differences remained stable, indicating common trends in ridership.

Following the implementation of shared e-scooters, the deviation, calculated as the ridership of the treated group subtracted from that of the control group, experienced a nuanced trajectory. For bikeshare, train, and bus, there was a decrease in this deviation, followed by a subsequent increase that persisted until the conclusion of the pilot program. With regard to taxis and ride-hailing, ridership of control groups decreased more than that of treated groups, so the difference increased after the implementation of shared e-scooters.

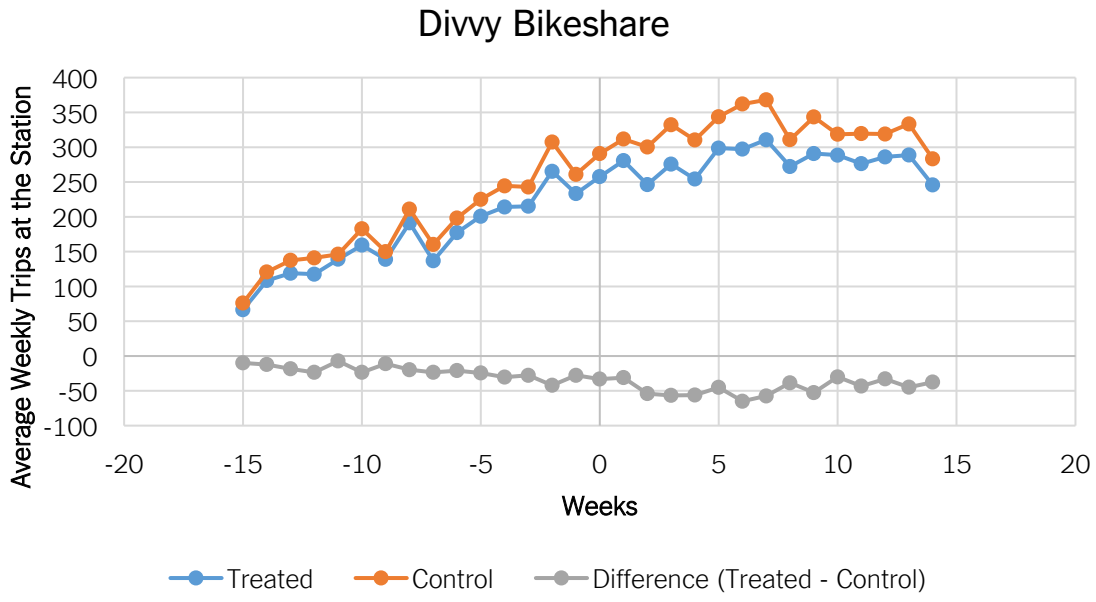


Figure F-4. Average weekly trips by railway before and after implementing the shared e-scooter pilot program.

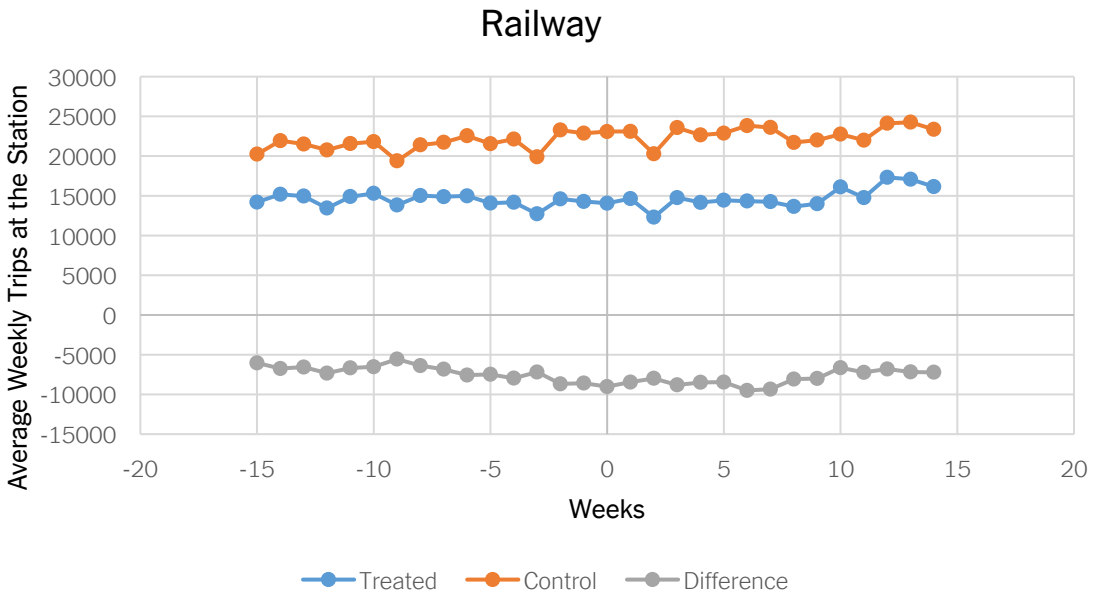


Figure F-4. Average weekly trips by railway before and after implementing the shared e-scooter pilot program.

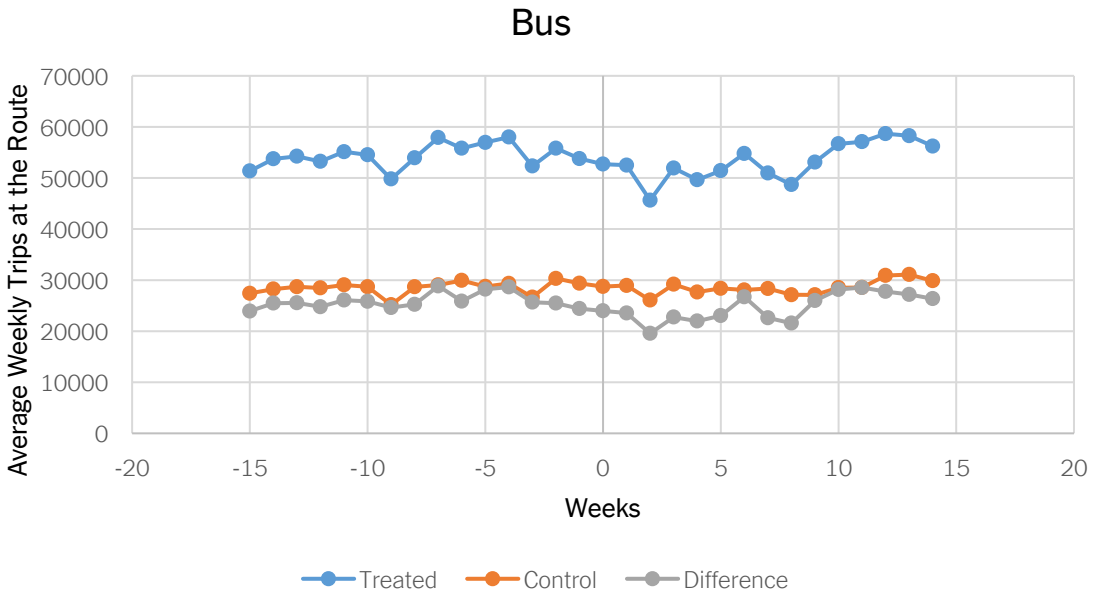


Figure F-4. Average weekly trips by bus before and after implementing the shared e-scooter pilot program.

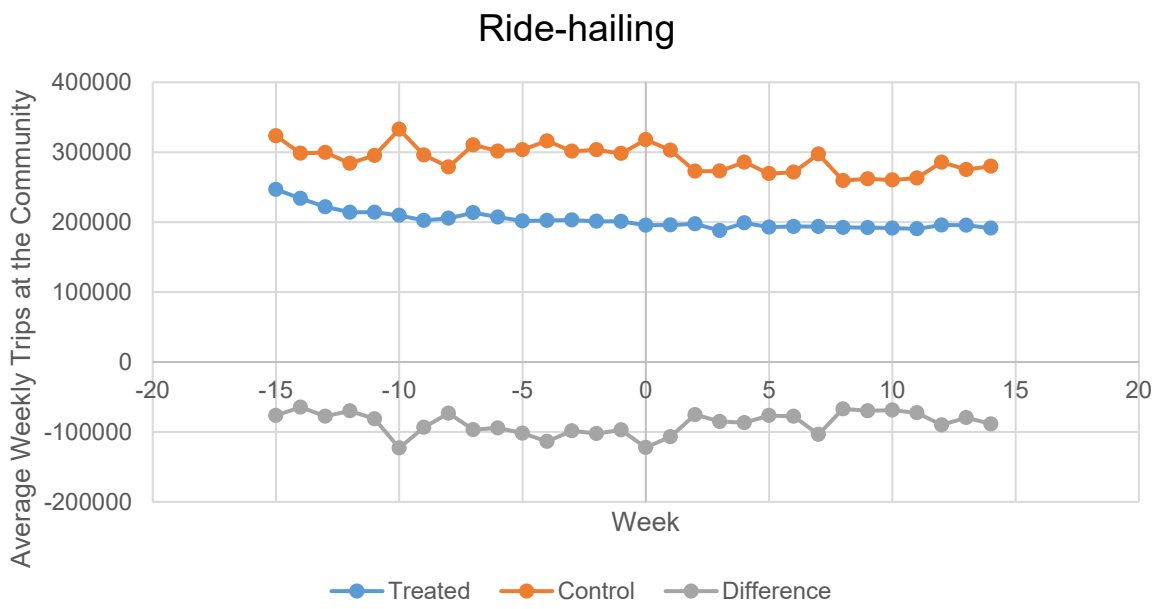


Figure F-4. Average weekly trips by ride-hail before and after implementing the shared e-scooter pilot program.

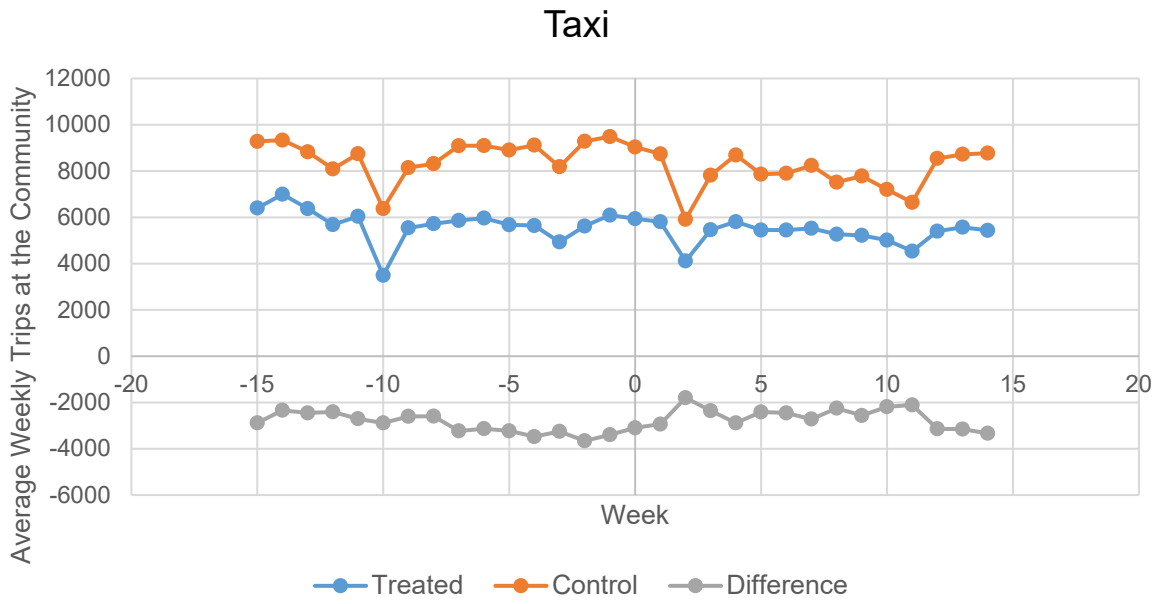


Figure F-5. Average weekly trips by taxi before and after implementing the shared e-scooter pilot program.

Appendix G. Balancing and Common Support Tests

Balance tests are pivotal to ensure the absence of significant differences in covariates between treated and control groups. As depicted in the diagrams on the left of the figures below, a noteworthy reduction in standardized percentage bias across covariates was observed post-matching, with most covariates demonstrating biases below the 10% threshold. This reduction underscores the efficacy of the matching process in mitigating biases among the study groups.

The common support tests in the diagrams on the right of the figures below, on the other hand, scrutinize the distribution of propensity scores and identify areas of overlap between the treated and control groups.

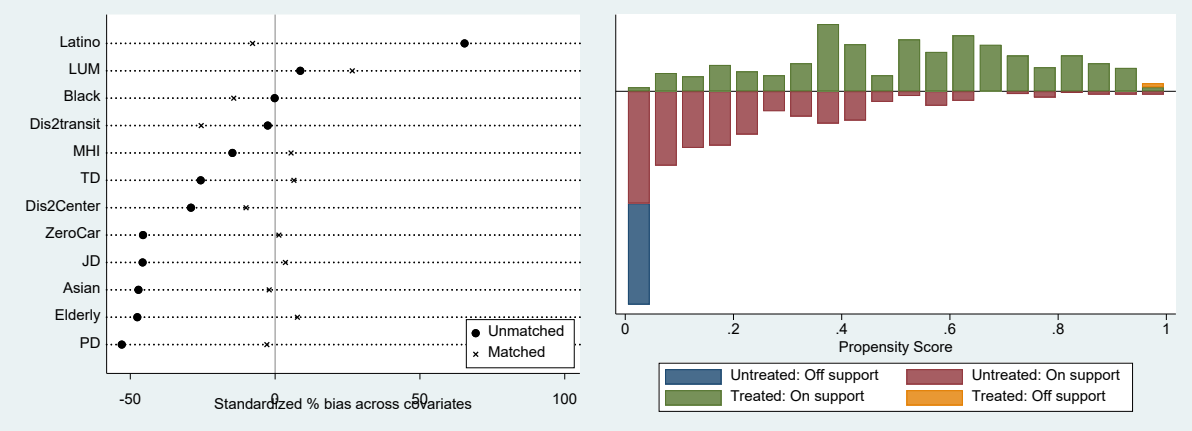


Figure G-1. The balancing (left) and common support (right) tests of the PSM for bikeshare.

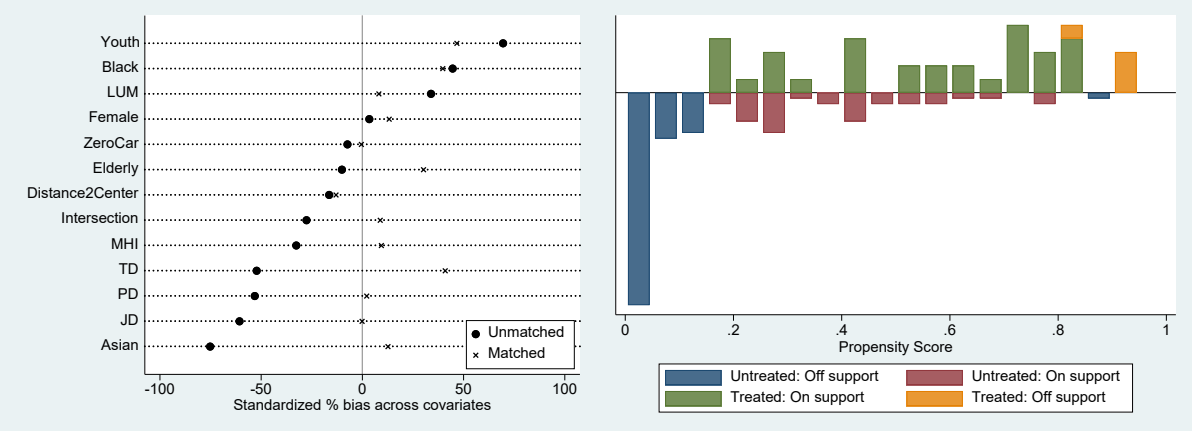


Figure G-2. The balancing (left) and common support (right) tests of the PSM for the train.

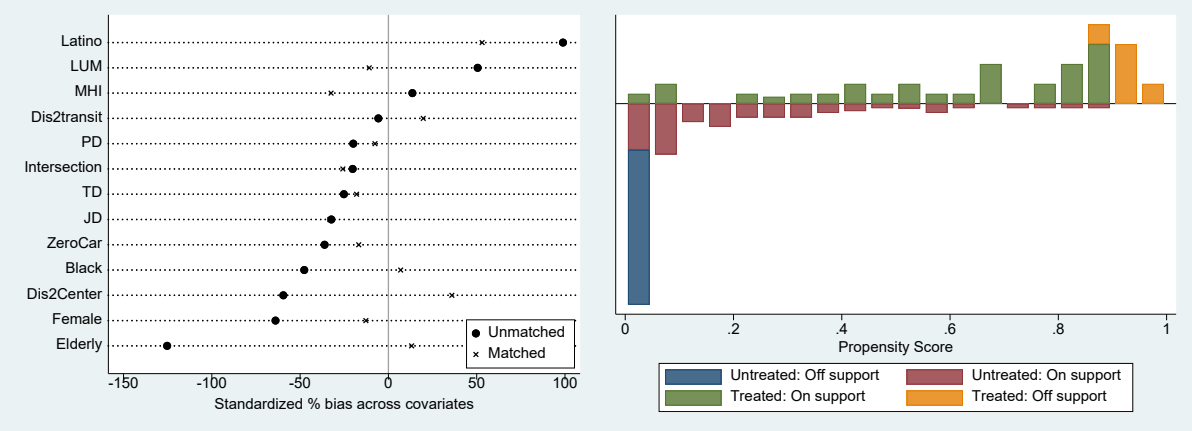


Figure G-3. The balancing (left) and common support (right) tests of the PSM for bus routes.

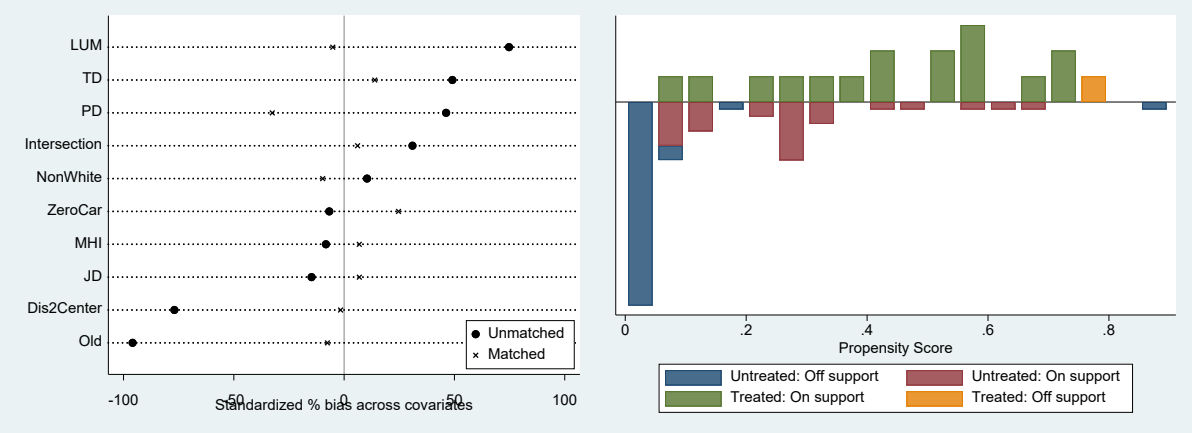


Figure G-4. The balancing (left) and common support (right) tests of the PSM for community areas (taxis and ride-hailing).

Appendix H. Kernel Density Analysis

Illustrated in the following figures, the distribution of propensity scores before the commencement of the shared e-scooter pilot program revealed a clustering of stations in the treatment group around zero. However, following the implementation of nearest neighborhood matching, these density distributions exhibited extensive overlap. This compelling evidence underscores the success of PSM in mitigating the selection bias stemming from the delineation of the operational area.

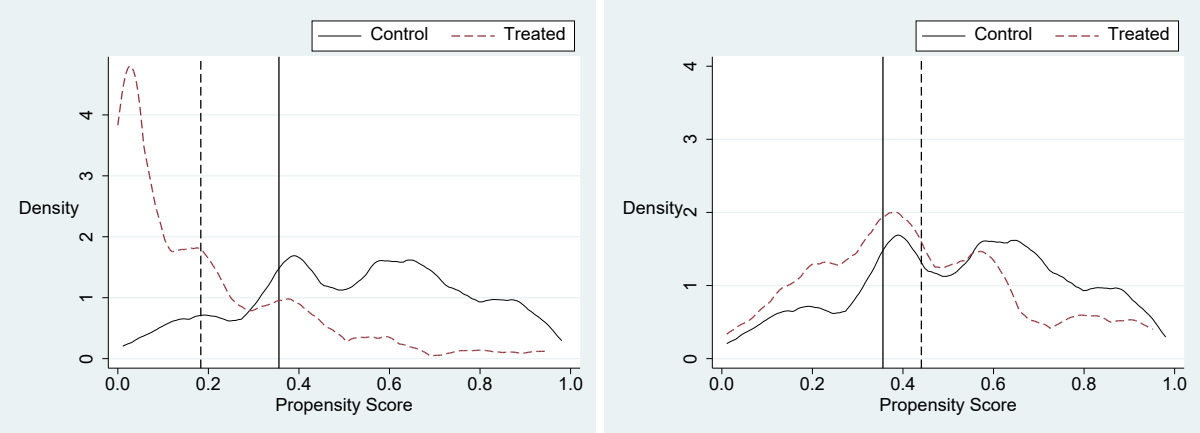


Figure H-1. Kernel density of propensity score in treated and control groups before matching (left) and after matching (right), bikeshare.

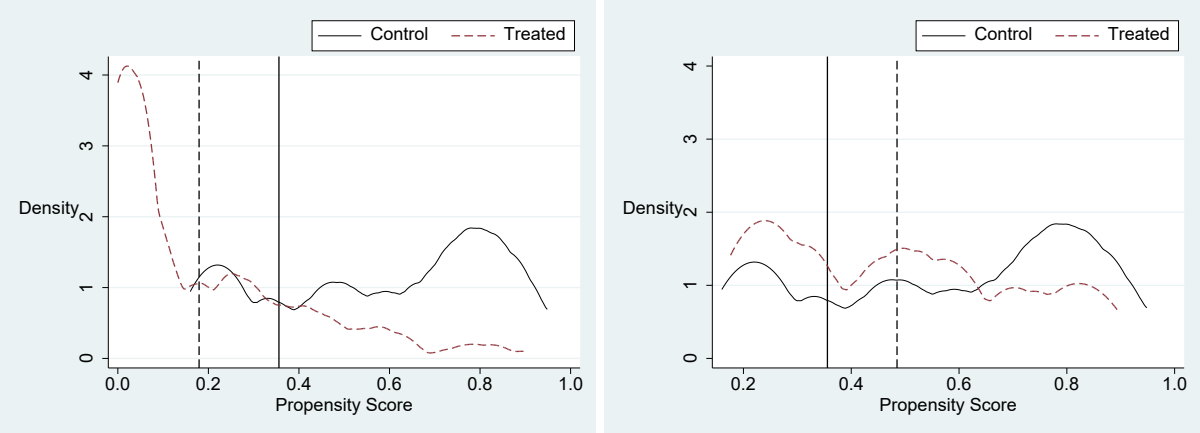


Figure H-2. Kernel density of propensity score in treated and control groups before matching

(left) and after matching (right), railway.

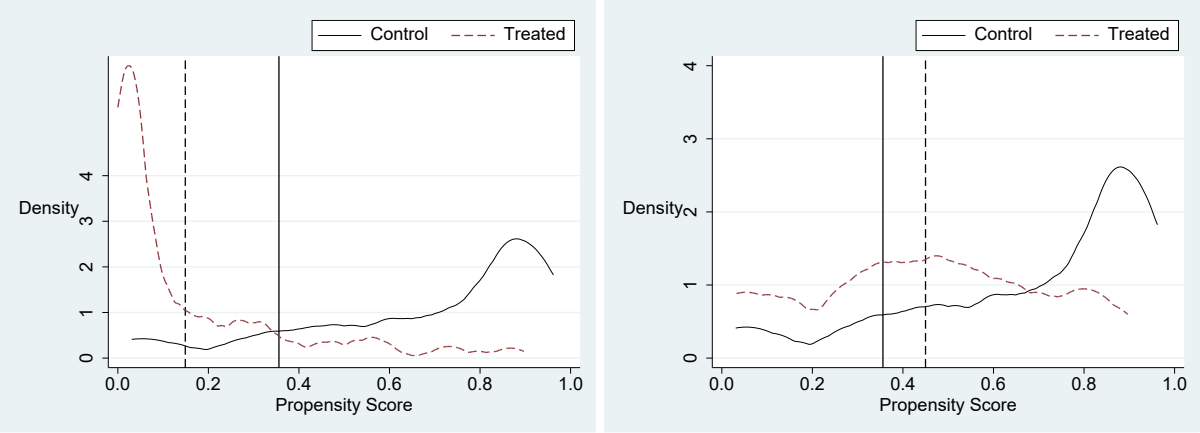


Figure H-3. Kernel density of propensity score in treated and control groups before matching (left) and after matching (right), bus.

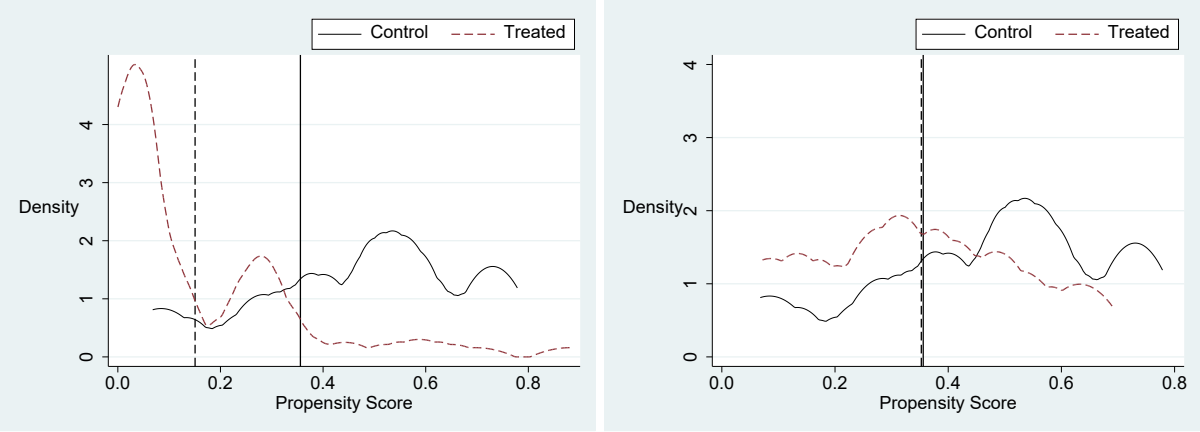


Figure H-4. kernel density of propensity score in treated and control groups before matching (left) and after matching (right), taxi and ride-hail.

Appendix I. Common Trend Tests

The coefficients preceding week -1 demonstrate no significant deviation from zero, affirming the presence of parallel trends in the period preceding the e-scooter launch.

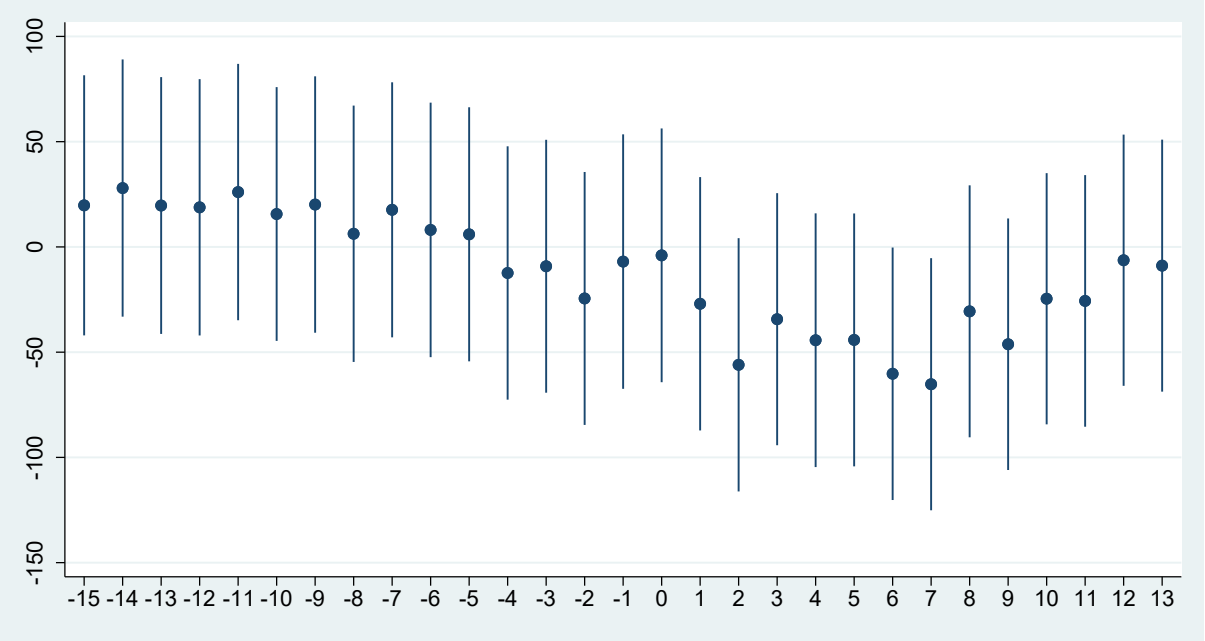


Figure I-1. Results of parallel trend test after propensity score matching, bikeshare.

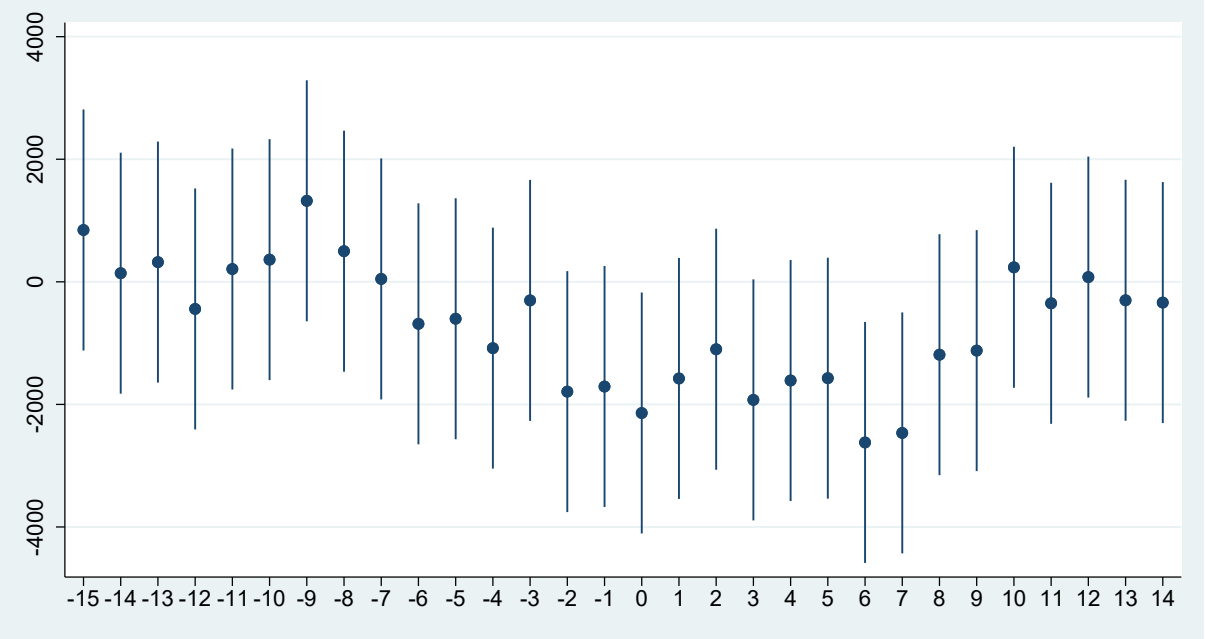


Figure I-2. Results of parallel trend test after propensity score matching, railway.

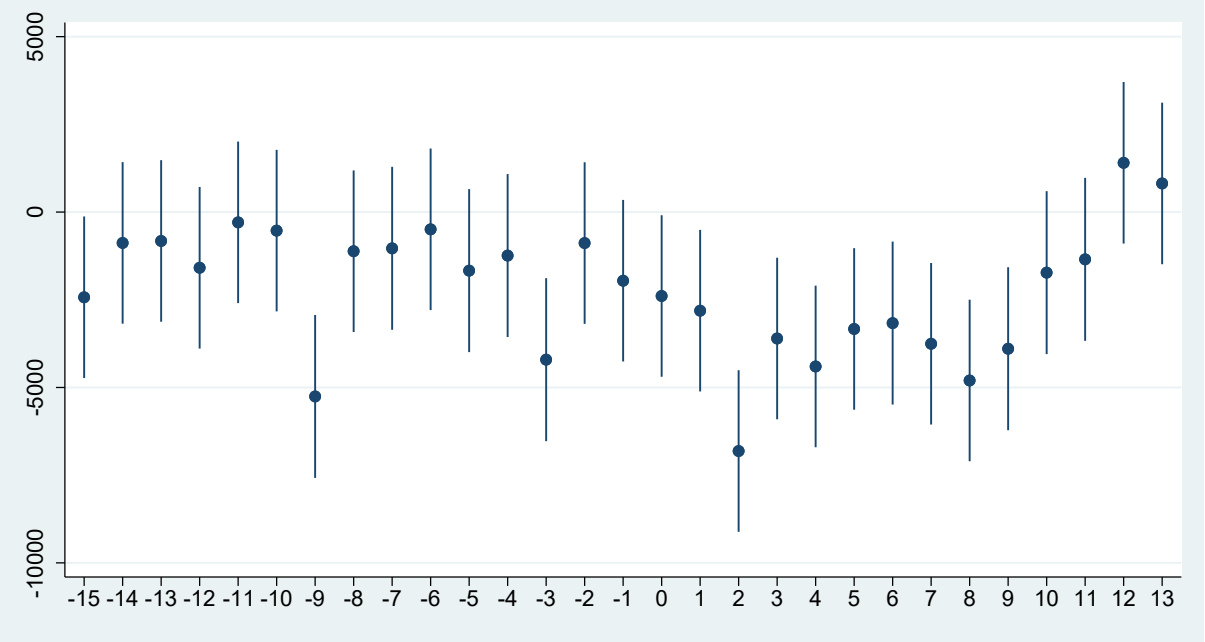


Figure I-3. Results of parallel trend test after propensity score matching, bus.

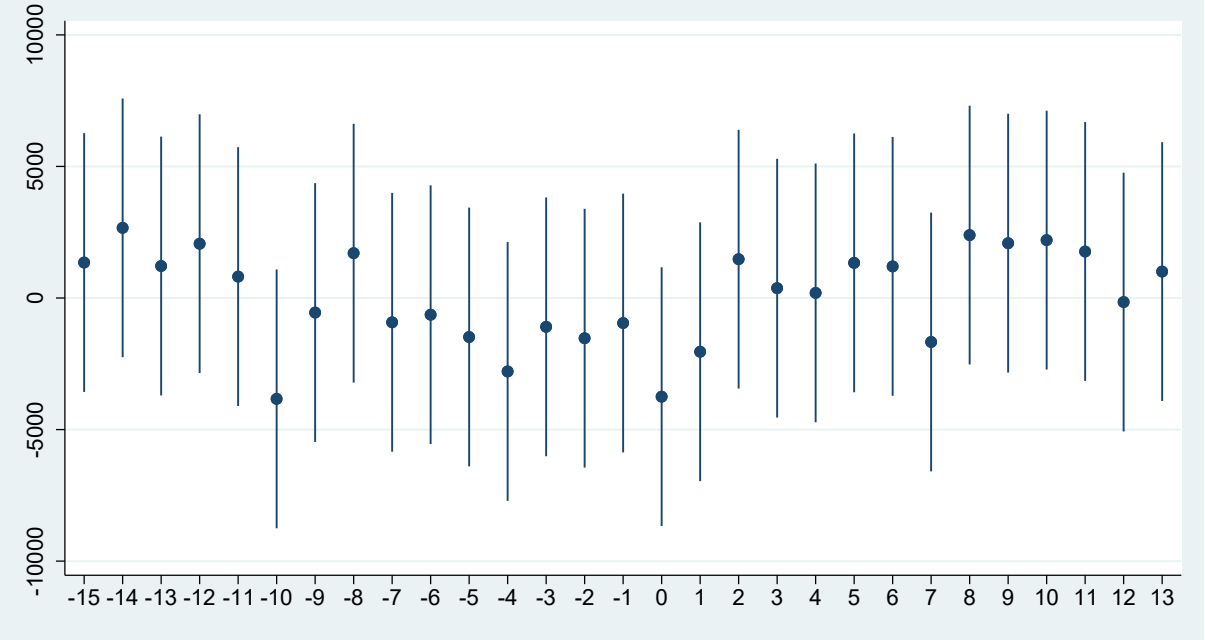


Figure I-4. Results of parallel trend test after propensity score matching, ride-hailing.

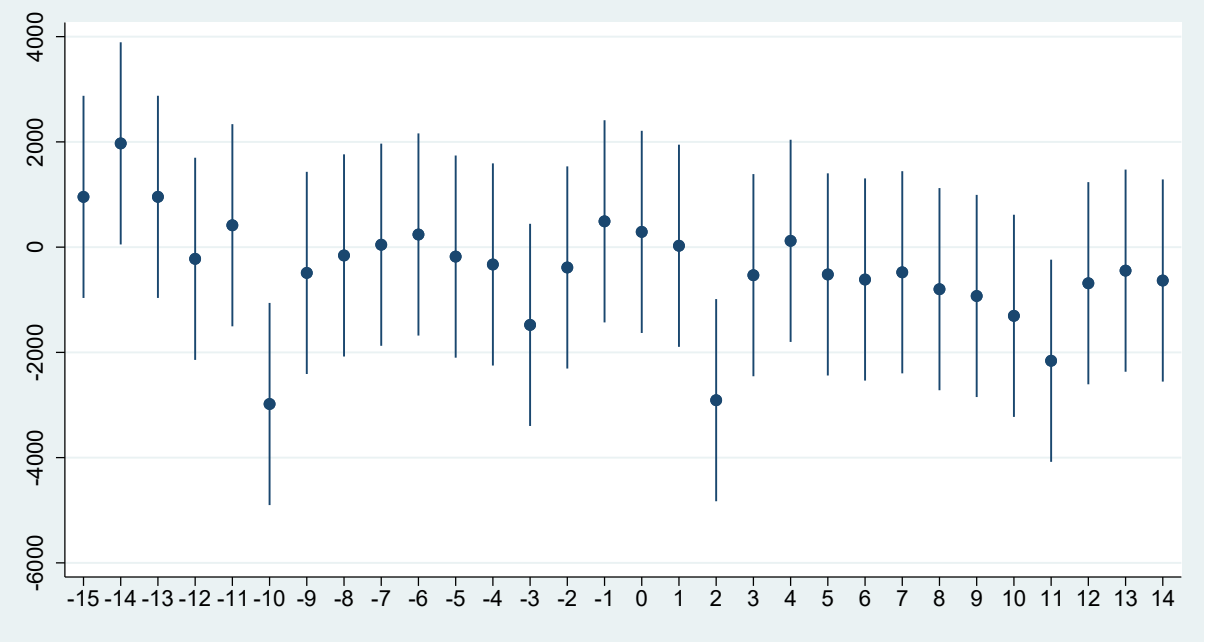


Figure I-5. Results of Parallel Trend Test After Propensity Score Matching, Taxi

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