TRB Annual Meeting

MICROMOBILITY EQUITY: A COMPARISON OF SHARED E-SCOOTERS AND STATION-BASED BIKESHARE IN WASHINGTON DC

--Manuscript Draft--

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ABSTRACT

Many cities around the world have introduced micromobility service and witnessed their rapid growth in recent years. Shared dockless e-scooters show potential to benefit neighborhoods that lack access to station-based micromobility service but they may also exacerbate the existing spatial disparities. While some studies have examined the equity of station-based bikeshare systems, limited knowledge is available regarding dockless e-scooter services. This study uses Washington DC as a case study, a city with both dockless e-scooter and station-based bikesharing systems, to analyze and compare equity in the two types of micromobility options. We propose an analytical framework to examine how dockless e-scooter and station-based bikesharing differ regarding a set of equity-related outcomes (i.e., availability, accessibility, usage, and idle time) across neighborhoods in different socioeconomic categories. Results reveal that dockless e-scooter services increase accessibility to shared micromobility options for disadvantaged neighborhoods but also widen the access gap across neighborhoods. Compared to bikesharing, shared e-scooters have a higher level of spatial accessibility overall due to greater supply; however, the greater supply largely leads to longer idle time of shared e-scooters rather than greater number of trips. Finally, it appears that the bikeshare system's equity program effectively promotes low-income use but e-scooters' equity program does not. Increasing vehicle supply alone would probably not lead to higher micromobility use in Black-majority neighborhoods. Instead, policymakers should combine a variety of strategies such as promoting the enrollment of equity programs and reducing access barriers (e.g., smartphone and banking requirements) to micromobility services.

Keywords: Micromobility, dockless e-scooter, transportation equity

INTRODUCTION

In recent years, shared micromobility services have experienced rapid growth in cities across the globe, expanding transportation options for many travelers. However, low-income populations can often be excluded from the broad benefits of these services due to a variety of barriers such as lack of spatial access (physical barrier), lack of access to banking (financial barrier), and lack of access to a smartphone or data plan (technological barrier) *(1, 2)*. Accordingly, understanding the equity of micromobility services is of major importance to transportation planners and policymakers.

So far, researchers have mostly focused on the equity of station-based micromobility systems *(3, 4, 5)*. Previous studies have shown that bikesharing users are disproportionately white, male and wealthier, people of color are obviously underserved *(6, 7)*. For instance, a recent survey conducted by the Washington Area Bicycle Association found that bikesharing use by low-income travelers was lower compared with the general population *(1)*. A plausible reason is that low-income individuals lack convenient spatial access to bikesharing due to insufficient station density. Hence, some researchers have analyzed the inequalities in spatial distribution of mobility across neighborhoods of different socio-economic characteristics. These studies have consistently found that residents of low-income neighborhoods are disproportionately underserved. Chen et al. *(8)* developed a modeling approach to measure individuals accessibility in southern Tampa and found that accessibility to bikesharing was not evenly distributed across neighborhoods of different socio-demographic status. The authors observed lower accessibility in the black subgroup and middle-income group. Similarly, one study that focuses on the City of Seattle showed greater bike availability in socioeconomically advantaged neighborhoods with higher median incomes and more college-educated residents *(9)*.

Due to their more recent emergence, shared e-scooter services have not been thoroughly studied. Free-standing with fewer spatial restrictions, shared dockless e-scooters show a potential to enhance spatial accessibility to destinations and to close the network gap of station-based systems. On the other hand, since shared e-scooters services are usually operated by for-profit private entities, the operators tend to put less emphasis on the equity implications. E-scooter trips tend to be more expensive than bikeshare trips, and so some travelers can be excluded from using the services due to unaffordability. Moreover, e-scooter companies may decide to place less e-scooters in low-income and minority neighborhoods, resulting in lower availability and accessibility of e-scooter services in these neighborhoods and hence lower e-scooter use. To date, there has been limited empirical evidence that can shed light on these equity-related issues.

Considering the equity aspects of shared e-scooters has not been well studied, we address the following research questions in this study: Does dockless e-scooter program provide equitable services to neighborhoods? Are shared e-scooter services more equitable compared to the station-based bikesharing program?

We focus on Washington DC as the study area, where the bikeshare system (Capital Bikeshare) is one of the most popular in the U.S. and over 10,000 e-scooters are already permitted on its streets. We develop an analytical framework to examine how dockless e-scooter and station-based bikesharing differ regarding a set of equity-related outcomes (i.e., availability, accessibility, usage, and idle time) across block groups in different socio-economic categories, which will be discussed in detail below. We use block groups as the main unit of analysis in this study, and we categorize block groups by Equity Emphasis Area (EEA) status and by income levels and racial compositions according to the most recent census data.

The rest of the paper is structured as follows. The next section introduces the analytical framework, followed by a section that describes the data sources. The following sections summarize the results and discuss the implications. We conclude the study by summarizing key findings, suggesting policy implications, and noting the limitations.

ANALYTICAL FRAMEWORK

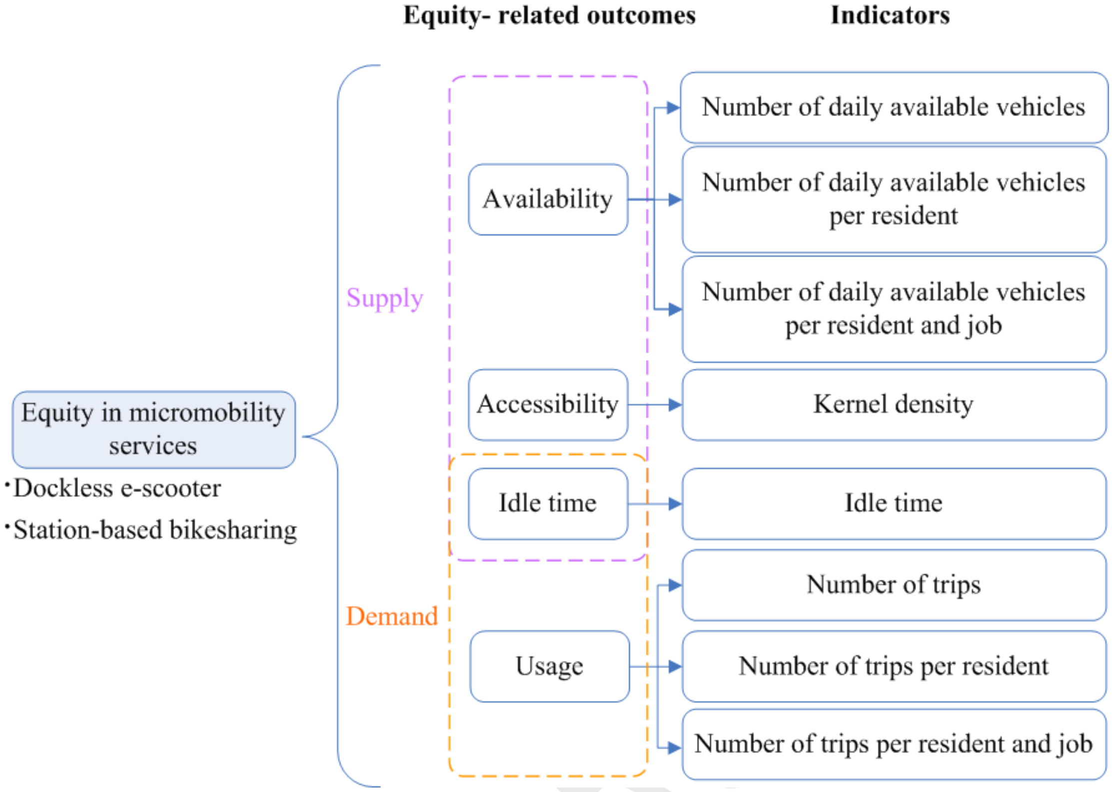


Figure 1. Analytical framework of equity in dockless e-scooter and station-based bikesharing

Figure 1 illustrates the analytical framework of our study. We examine the following equity-related outcomes. First, we evaluate the supply of micromobility services across space with measures of *availability* and *accessibility*. Availability is defined as the number of available micromobility vehicles in a geographic unit, and in this study we use census block groups as the geographic unit of analysis. Accessibility quantities the number of micromobility vehicles reachable from a given location, which complements the availability measure by not excluding micromobility vehicles at a reachable distance from the block group boundary. Second, we evaluate the demand aspect of micromobility services, that is, we measure micromobility usage with number of trips. Third, we further examine *idle time*, which indicates the time duration when a micromobility vehicle is not used, i.e., the time interval between the end timestamp of a trip and the start timestamp of a following trip. Idle time is a measure of operational efficiency, as it is jointly shaped by the supply of and demand for micromobility services. It can also help inform the effectiveness of enhancing supply on increased micromobility use; when low use is coupled with long idle time, measures that increase supply can be ineffective.

To further explore the geographic equity of micromobility services, we analyze how these above equity measures vary across different block groups. We divide block groups by Equity Emphasis Area (EEA) status and by income levels and racial compositions according to the ACS 2014-2019 5-year estimates. The EEA status is defined by the National Capital Region Transportation Planning Board *(10)*, which considers the concentrations of the following four population groups: low-income, African American, Asian, and Hispanic or Latino. Figure 2 shows the block groups that fall within the EEA. Moreover, we classify block groups by quartile of household median income, block groups with a median household income of $49,222 or below as low-income, those with a median household income of between $49,223 and $130,614 as middle-income, and those with a median household income of $130,615 or above as high-income. Also, we classify a block group as “X-Majority” if more than 50% of the residents identify themselves as a single race of X. Block groups without a single race representing more than 50% of the population are categorized as "No majority."

Finally, after conducting the equity analysis for both the e-scooter services and the station-based bikesharing system, we compare which of the two micromobility systems is more equitable.

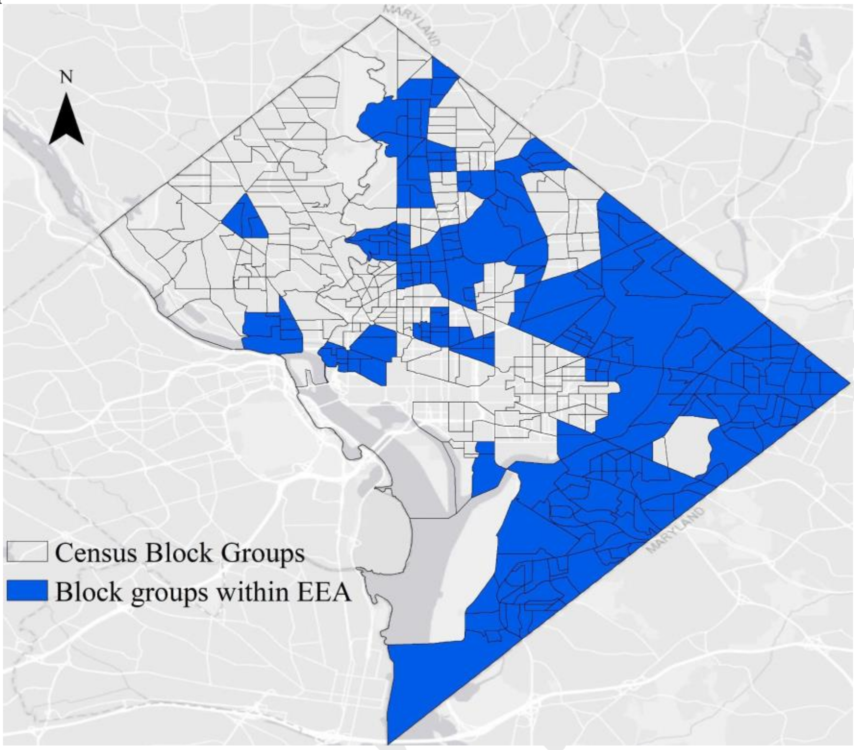


Figure 2. Distribution of EEA in DC.

DATA

The main data sources for this study include the following: e-scooter data, docked bikeshare data, and socio-demographic and employment data.

E-scooter Data

E-scooter data from Jun 19, 2019 through Jul 10, 2019 are collected from real-time public APIs provided by each operator, and the obtained data are in General Bikeshare Feed Specification (GBFS) format. We infer e-scooter trips from the GBFS data for four operators: Spin, Lime, Bird and Lyft (the available data for other operators such as Helbiz cannot be used to infer trips). For the Lime and Spin data, each scooter trip record contains the trip's start date and time, end date and time, trip duration, trip distance, start and end location, and vehicle ID. The data has been processed to remove trips lasting less than 3minutes or longer than 90 minutes. In total, the Spin and Lime data contains a total of 31,570 trip records. For the Bird and Lyft data, we are only able to infer unlinked trips; that is, we know the trip origins and destinations but do not know how they are linked. During the study period, we estimate around 222,427 and 220,246 trips that started and ended in the study area, respectively. Therefore, we use data from all four operators when studying trip counts but use data for Spin and Lime only when examining trip characteristics such as duration and distance. To explore the availability and accessibility of shared e-scooters, we use the GBFS data scrapped at 6:00 am, which is the start of the day when e-scooter operators start to provide services.

Docked Bikeshare Data

Data for the Capital Bikeshare system can be accessed freely through the following URL: https://www.capitalbikeshare.com/system-data. The trip data is available in a CSV format and the availability data can be scrapped from real-time public APIs. Each trip's record including duration of trip, start date and time, end date and time, start and end station, bike's ID number and member type. We only kept trips with duration within 3 to 90 minutes, which resulted in a total of about 576,000 trips for analysis. Similar to shared e-scooters, we use the GBFS data scrapped at 6:00 am to analyze availability and accessibility.

Sociodemographic and Employment Data

We accessed demographic and employment data from the American Community Survey (ACS) and the Longitudinal Employer-Household Dynamics (LEHD) (https://lehd.ces.census.gov/) Database. The ACS is a demographics survey program conducted by the U.S. Census Bureau and provides a wide range of demographic data including education,employment, income, population and many other important statistics about the nation and its people. The main unit of analysis in this study is block groups, which are generally defined to contain between 600 and 3,000 people. Specifically, we obtain population, median household income and race data from the ACS 2015-2019 5-year estimates at block groups level. These data allow us to examine equity-related outcomes across block groups of different sociodemographic characteristics. We collect the 2018 employment data from the LEHD Origin-Destination Employment Statistics, which provide data on employment count at the block level.

ANALYSIS AND RESULTS

This section discusses equity analysis of the dockless e-scooter and station-based bikesharing services in Washington DC following the analytical framework presented in Section 3, and the results are summarized in Table 1 and Table 2.

Table 1. E-scooter accessibility, availability and idle time across block groups

	Availability						**Accessibility**		**Idle Time (hours)**	
	No. Daily Available E-scooters		**No. Daily Available E-scooters Per Resident**		**No. Daily Available E-scooters Per Resident and Job**		**Kernel Density**			
	Median	**Mean**	**Median ($\times10^{-2}$)**	**Mean ($\times10^{-2}$)**	**Median ($\times10^{-2}$)**	**Mean ($\times10^{-2}$)**	**Median ($\times10^{3}$)**	**Mean ($\times10^{3}$)**	**Median**	**Mean**
Block groups divided by EEA status										
EEA	9.46	23.68	0.62	1.66	0.56	0.97	412.58	1,123.65	3.9	5.19
Non-EEA	15.48	36.84	1.31	2.4	0.90	1.27	802.65	1,679.40	4.43	5.39
Block groups divided by median household income[a]										
Low	6.26	20.18	0.40	1.52	0.37	0.95	281.79	748.53	4.69	5.34
Middle	16.78	37.11	1.20	2.36	0.86	1.18	860.79	1,759.48	4.09	5.27
High	14.70	26.03	1.26	1.83	0.87	1.15	747.64	1,320.35	4.36	5.47

Block groups divided by racial compositions[b]										
White	18.78	43.59	1.50	2.72	1.00	1.21	1,284.54	2,000.12	4.36	5.33
Black	5.96	15.64	0.47	1.18	0.40	0.87	255.87	588.59	4.47	5.63
No-Majority	13.39	21.80	1.35	2.66	1.02	1.74	1,947.70	2,304.05	3.69	5.1
Average	13.35	30.10	0.95	2.02	0.71	1.12	585.07	1,395.35	4.33	5.35

Notes: a. Income level is defined by quartile, with the middle representing the middle 50% of median household incomes at block group level: low, ≤$49,222; middle, $49,223–$130,614; high, ≥$130,615.

b. Race with a dominant population (≥50%) within a block group.

c. An outlier is captured in the availability results at block group level. The residents population in a block group is very few while many available dockless e-scooters are deployed here to meet the travel demand of floating populations such as workers, which lead to a significantly higher number of daily available e-scooters per resident. This outlier raises the statistical results of corresponding block groups obviously and conceals most of the characteristics presented by the results, so we removed this outlier for dockless e-scooter services analysis.

Table 2. Bikeshare availability, accessibility and idle time across block groups

	Availability			Accessibility		Idle Time (hours)	
	No. Daily Available Bikes	No. Daily Available Bikes Per Resident	No. Daily Available Bikes Per Resident and Job	Kernel Density			
	Mean	Mean ($\times 10^{-2}$)	Mean ($\times 10^{-2}$)	Median ($\times 10^{3}$)	Mean ($\times 10^{3}$)	Median	Mean
Block groups divided by EEA status							
EEA	3.80	0.26	0.18	99.93	192.76	1.91	3.32
Non-EEA	6.16	0.41	0.23	149.06	279.21	1.27	2.56
Block groups divided by household income[a]							
Low	3.02	0.22	0.16	71.75	128.69	1.1	2.73
Middle	6.06	0.40	0.23	168.17	280.20	1.4	2.66
High	4.67	0.32	0.19	141.25	251.80	1.74	2.98

Block groups divided by racial composition[b]							
White	7.26	1.27	0.21	293.81	330.28	1.28	2.59
Black	2.99	0.22	0.18	70.50	118.29	2.44	4
No Majority	5.75	0.39	0.27	222.24	337.58	1.78	2.99
Average	4.95	0.33	0.20	124.38	235.02	1.42	2.74

Notes: See information provided in Table 1.

Equity in Service Availability

We measure the availability of micromobility services at the block group level with three indicators: number of daily available vehicles, number of daily available vehicles per resident, and number of daily available vehicles per resident and job. The first indicator is a baseline measure, and normalizing it by the residents population indicates the level of availability on a per resident basis. Considering that some visitors such as commuters are also micromobility users, we further use the residents plus jobs population to normalize the base indicator.

As shown in Table 1, block groups within Non-EEA have more available dockless e-scooters than those in EEA. Middle-income block groups have the most daily average of available e-scooters (37.1), followed by the high-income block groups (26.0), and lastly the low-income block groups (20.2). The availability disparity between block groups classified by racial compositions is even larger: White-majority block groups have the highest number of daily available e-scooters, which is nearly three times as many as that in Black-majority block groups. The median number of daily available e-scooter in middle-income block groups (13.4) is very close to the regional average baseline (13.4). Regarding the number of available e-scooters per resident, we obtain similar results except when block groups are divided by median household income. High-income block groups now rank top in terms of median value of daily available e-scooters per 1000 residents (12.6), more than three times that of low-income groups (4.0). This finding is consistent with a prior study of dockless bikesharing that shows that higher-income neighborhoods have greater micromobility availability *(9)*. We further examine if the results change when we normalize the number of daily available e-scooters by accounting for not only resident population but also employment count (a proxy for activities and traveler flows). Again, the results are largely the same except when block groups are classified by racial compositions: No-majority block groups (instead of White-majority block groups) now have the most daily available e-scooters per capita (jobs plus residents).

Regarding the bikesharing system, results in Table 2 suggest that less bikes are available in EEA block groups (3.8) than in non-EEA block groups (6.2). Low-income block groups have the least number of daily available bikes (3.0), followed by the high-income block groups (4.7); and the middle-income block groups have the highest number of daily available bikes (6.1). This finding is similar to a previous study of the bikesharing system in DC *(4)*. We also find significant racial disparities in the availability of shared bikes across block groups: the number of daily available bikes in White-majority block groups (7.3) is 2.4 times that in Black-majority block groups (3.0); the number of daily available bikes in block groups without a racial majority is 5.8, still almost twice as large as that in Black-majority block groups. When we normalize the number of daily available bikes by taking into account the resident population, we get similar results. This indicates that less shared bikes are placed in low-income and Black-majority neighborhoods and that residents of these neighborhoods are also disadvantaged in terms of bikeshare availability on a per resident basis. When further taking workers into consideration, we get similar results if block groups are divided by EEA status and by median household income but not by racial composition. The disparity between block groups across different categories is narrowed slightly. No-majority block groups (instead of White-majority block groups) now have the most daily available bikes per capita (jobs plus residents), about 1.5 times that of Black-majority groups.

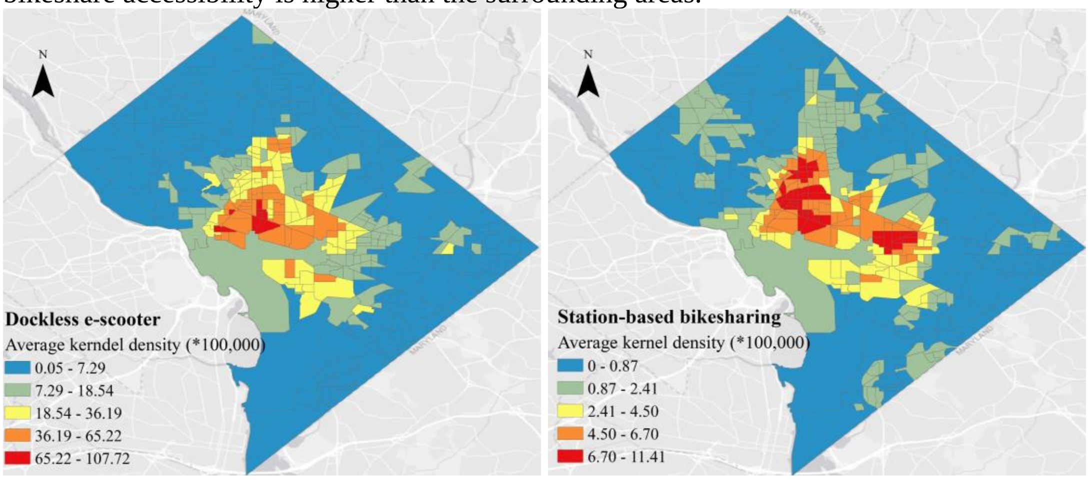
Compared to the station-based bikesharing system, the disparities in e-scooter accessibility between disadvantaged and advantaged block groups are larger. We further measure these disparities as the ratio of e-scooter accessibility in each type of disadvantaged block groups and that in their respective counterparts. We find that, compared with bikesharing, e-scooter services narrow down the accessibility gap between low-income and high-income block groups but widen the gaps for other comparisons between block groups.

In sum, we find that both micromobility systems have less available shared vehicles in block groups with an EEA status, low median household income, and a Black-majority population. We obtain similar results when the number of daily available vehicles is normalized by accounting for the resident population or by accounting for resident population plus total employment.

Equity in Accessibility to Micromobility Options

The availability measure may have a modifiable areal unit problem *(11, 12, 13)*, which is a type of statistical bias that occurs when point-based measures of spatial phenomena (e.g., location of available bikes or e-scooters) are aggregated into areal units (e.g., block groups). To address this issue, we also evaluate supply with an accessibility indicator, measured by kernel density of available micromobility vehicles. Kernel density is a commonly applied spatial analysis technique to indicate the accessibility of resources across space. After obtaining the kernel density estimation value, we further aggregate it to the block groups level.

The spatial distribution of e-scooter and bieshare accessibility is shown in Figure 3. E-scooter accessibility is highest in the central area of DC, which gradually declines outwards toward the city boundary. Similar to the dockless e-scooter system, the bikeshare accessibility is highest in the central area of DC where a large number of bikes are located. It gradually decreases as we move away from the city center, but there are pockets of areas where bikeshare accessibility is higher than the surrounding areas.



(a) Dockless e-scooter (b) Station-based bikesharing

Figure 3. Spatial distribution of e-scooter (left) and bikeshare (right) accessibility.

We further examine how bikeshare and e-scooter accessibility vary across block groups divided by EEA status, median household income, and racial compositions. Results are presented in Table 1 and Table 2. Block groups not within EEA have higher kernel density values, which mean higher levels of accessibility, than those in EEA. The level of accessibility in middle-income block groups is the highest (1,759,475), followed by high-income block groups. Low-income block groups have the least access to e-scooter services, and its kernel density value (748,533) is less than half of that in the middle-income block groups. When considering block groups categorized by racial compositions, we find that Black-majority block groups have the lowest accessibility, which is only a quarter of the average level of accessibility in No-majority block groups.

We get similar results for the bikesharing system. Non-EEA and middle-income block groups have a greater level of accessibility to bikesharing services. We also find significant disparities in accessibility between low-income and high-income block groups. The average kernel density value of bikesharing services in high-income block groups is nearly twice that in low-income block groups. This indicates that users in low-income block groups have a lower level of accessibility to bikesharing services. Similar to the results for e-scooter services, no-majority and White-majority block groups have higher levels of accessibility to bikesharing service, three times that in Black-majority block groups.

Equity in Micromobility Usage

We calculate three indicators to measure the usage pattern of micromobility services: number of trips, number of trips per resident and number of trips per resident and job. Descriptive results are summarized in Table 3 to show the number of bikesharing and e-scooter trips across different types of block groups.

We find that Non-EEA block groups have more e-scooter travel activities than in the EEA area. The middle-income block groups, which have greater e-scooter availability and accessibility, generate the most trips on average (1196.3) during the study period. Given the right-skewed distribution of results, we also examine the median values. High-income block groups have the highest median number of trips (290.0), almost ten times that of low-income groups (29.5). There appears to be significant racial disparities in e-scooter use: 45% of the block groups in DC are Black-majority, but they make up 5.4% of all e-scooter trips during the study period; by contrast, while 43% of the block groups are White-majority, they make up 68% of all e-scooter trips. When we normalize the number of trips by resident population, we get similar results. When we normalize the number of trips by further accounting for total employment, the results show slight change for block groups divided by household income. High-income block groups (instead of middle-income block groups) become the ones that have the most number of trips per resident and job.

The results for station-based bikesharing are largely similar to those for e-scooter services. Block groups within EEA make fewer trips than those not in EEA. Middle-income block groups have the highest number of bikesharing trips (1194) during the study period, accounting for over half of all trips, followed by high-income block groups. Again, there appears to be significant racial disparities in bikesharing use: the number of trips taken in White-majority block groups accounts for 62.6% of the total trips, ten times that in the Black-majority block groups which only accounts for 6.2% of the total trips. We get similar results when we normalize the number of bikesharing trips by accounting for the resident population or by accounting for residents plus workers.

There is one major difference between the usage pattern of e-scooter services and that of bikesharing services. After normalized by resident population and total employment, the median/mean number of e-scooter trips is highest in high-income block groups whereas the median/mean number of bikesharing trips is highest in middle-income block groups. These results indicate that e-scooter users are likely having a higher income than bikeshairng users.

Table 3. Statistics for e-scooter and bike-sharing trips characteristics.

Mode	E-scooter[a]						Bikesharing[e]		
Trip Characte-ristics	No. Trips[b]		No. Trips per Resident[c]		No. Trips per Resident and Job[d]		No. Trips	No. Trips Per Resident	No. Trips Per Resident and Job
	Mean	Median	Mean	Median	Mean	Median	Mean	Mean	Mean
Block groups divided by EEA status									
EEA	609.10	57.00	0.43	0.04	0.16	0.03	452.70	0.31	0.15
Non-EEA	1269.20	282.00	0.79	0.21	0.30	0.17	1270.00	0.78	0.32
Block groups divided by household income									
Low	325.67	29.5	0.18	0.02	0.09	0.02	236.83	0.13	0.07
Middle	1196.30	200.50	0.78	0.16	0.26	0.12	1194.00	0.75	0.32
High	1005.00	290.00	0.69	0.22	0.29	0.17	781.10	0.53	0.23
Block groups divided by racial composition									
White	1820.00	453.00	1.17	0.35	0.38	0.28	1597.00	1.00	0.36
Black	145.83	32.00	0.09	0.03	0.07	0.02	159.05	0.10	0.09
No majority	712.10	434.00	0.55	0.21	0.28	0.17	796.40	0.57	0.34
Average	931.00	152.00	0.61	0.11	0.23	0.09	851.10	0.54	0.23

a. The data source for e-scooter metrics is the four e-scooter platforms of Spin, Lime, Bird, and Lyft.
b. The sum of the number of e-scooter trips taken over the study period that begin and end at a block group.
c. The number of e-scooter trips taken over the study period per resident.
d. The number of e-scooter trips taken over the study period per resident and job.
e. The data source for station-based bikesharing trips is the Capital Bikeshare system.
Note: 1)The median values for bikesharing trips indicators are 0, since some block groups in DC do not have docking stations for bikes which means no bikeshare trips start or end here. Therefore, we only present the mean values in the table.
2) An outlier is captured in the usage results at block group level. The resident population in a block group is very few while it has a large number of floating populations such as workers, which generate a lot of trips in total. This leads to a significantly higher number of trips, which raises the statistical results of corresponding block groups obviously and conceals most of the characteristics presented by the results, so we removed this outlier for dockless e-scooter services analysis.

Idle Time Analysis

We calculate the idle time for each micromobility device and then aggregate the results at the block groups level. The results are shown in the last columns of Table 1 and Table 2. E-scooters are generally idle in shorter duration in block groups not within EEA, which indicates a latent demand for e-scooter use. The median idle time of e-scooters placed in low-income block groups is 4.7 hours, longer than that in middle-income (4.1 hours) and high-income block groups (4.4 hours). Moreover, e-scooters in Black-majority block groups (4.5 hours) have the longest idle time when compared with those placed in White-majority (4.4 hours) and No-majority (3.7 hours) block groups. In other words, the utilization rate of e-scooters in low-income and Black-majority is lower. Considered together with the findings on e-scooter availability/accessibility and usage, these results suggest that increasing supply alone is not likely effective in promoting e-scooter use in these neighborhoods.

The median idle time of shared bikes is about a third that of shared e-scooters, which indicates much greater utilization rate of the bikesharing system. We find significant differences between shared e-scooters and shared bikes regarding how their idle time varies across block groups. Different from the case of e-scooter services, on average shared bikes have a longer idle time in block groups within EEA but a shorter idle time in low-income block groups. In other words, although shared bikes are less frequently used in EEA overall, they have a very high utilization rate in low-income neighborhoods. This is likely attributable to the "Capital Bikeshare for All" equity program, which allows low-income individuals to use shared bikes for free (unlimited free rides for trips under 60 min) with an $5 annual membership fee. Finally, on average shared bikes have a longer idle time in Black-majority block groups than White-majority and No-majority block groups. This means that the bikesharing system is underutilized in Black neighborhoods, and a further implication is that the equity program has not benefited residents of Black neighborhoods as much as other low-income population groups.

DISCUSSION

E-scooter Services Increase Access to Shared Mobility Options in Disadvantaged Neighborhoods but Widen the Access Gap across Neighborhoods

For a station-based bikesharing system, users need to access and return shared bikes at fixed docking stations. This means that neighborhoods without docking stations have little or no access to bikeshare service. Dockless e-scooters, due to their free-floating nature and their ability to be deployed in large quantities, can be easily expanded to these neighborhoods and enhance mobility for the residents. Also, unlike station-based bikesharing, e-scooters users can often avoid the 'last mile' problem because e-scooters can be parked at their destinations. Flexible and low-cost e-scooters allow them to penetrate wherever they are needed. Based on our analysis, we find that on average, e-scooter availability and accessibility are 2.7 times and 4.7 times that of bikeshare availability and accessibility in D.C. neighborhoods. For instance, as shown in Table 1 and Table 2, the average accessibility of e-scooter services (588, 593) is about 5 times that of shared bikes (118, 294) in Black-majoirty block groups, which indicates that residents have better spatial access to e-scooters than station-based bikes.

However, we also find that e-scooters have exaggerated the existing disparities in spatial access to micromobility services. EEA, low-income, and Black-majority block groups in general have a lower level of spatial accessibility to both e-scooter and bikesharing services. Moreover, as discussed above, the arrival of e-scooters has widened these accessibility disparities.

Compared to Bikesharing, Shared E-scooters Have a Higher Level of Spatial Accessibility but an Equivalent Number of Trips and Longer Idle Time

Similar to the results for e-scooter supply (availability and accessibility), we find significant disparities in e-scooter use between disadvantaged and advantaged block groups. E-scooter use is significantly lower in EEA, low-income, and Black-majority block groups when compared with their respective counterparts. Notably, although the average number of daily available e-scooters is over 5 times that of daily available bikes, the number of e-scooter trips is similar to that of bikeshare trips. This implies that on average, shared bikes are much more frequently used than shared e-scooters. The same conclusion can be reached by comparing the average idle time of shared e-scooters with that of shared bikes: the former is about twice that of the latter in most block groups. In block groups where the average idle time is particularly long, which indicates that the available e-scooters exceed the demand for e-scooter use, the operators should consider reducing the number of e-scooters placed there. A long idle time may lead to more cases of improper parking and vandalism activities of shared e-scooters.

The middle-income block groups have the highest accessibility to both microbility systems among block groups of all income levels, where the mean idle time for shared e-scooters and bikes is also the lowest. This indicates that the users from middle-income block groups have a strong demand for micromobility service. This finding can help operators explore expansion of service scope to other areas with potential markets for micromobility use. Accessibility to both e-scooter and bikeshare services in high-income block groups is high, but the average idle time of both micromobility vehicles is also quite long.

Bikeshare's Equity Program Appears to be More Effective Than E-scooters' Equity Programs

The low-income block groups have the lowest level of e-scooter and bikeshare availability and accessibility. The average idle time of shared e-scooters in low-income block groups is longer than that in high-income or middle-income block groups; however, the average idle time of shared bikes in low-income block groups is relatively short, close to that in middle-income groups. These results are likely due to the effects of micromobility equity programs. The equity program for bikesharing provides a much larger discount to low-income travelers compared to those offered by e-scooter companies. Qualified individuals can enjoy unlimited 60-min free bike rides at a $5 annual membership fee. By contrast, discounts offered by e-scooter companies range from waiver of the $1 unlock fee to unlimited 30-min trips with a $5 membership fee per month. Moreover, e-scooter companies may have not promoted these equity programs as much as Capital Bikeshare.

The averaged idle time of shared bikes in Black-majority block groups is considerably higher than that in non-Black-majority block groups. The same finding holds true for shared e-scooters, which on average have an idle time of 5.67 hours in Black-majority block groups. Considered together with the fact that micromobility accessibility and availability are lower in Black-majority block groups, these results suggest that the demand for micromobility use is weak. Therefore, it is quite likely that increasing vehicle supply alone would not lead to higher micromobility use; other coupling strategies such as promoting the enrollment of equity programs and reducing access barriers to micromobility services are also necessary.

CONCLUSION

This study conducts a comparative analysis of geographic equity (including spatial access and usage distribution) between dockless e-scooters and station-based bike share systems across neighborhoods of different socioeconomic categories. It fills a major research gap regarding the equity of shared e-scooter services. An important finding is that the dockless e-scooter system provides higher accessibility and more daily available vehicles compared to station-based bikesharing. Additionally, we find that compared with station-based bikeshare, e-scooters improve the absolute accessibility levels for underserved areas and low-income groups; however, e-scooters also widen the accessibility gaps between advantaged and disadvantaged block groups. We also observe that the average idle time of shared e-scooters is longer than that of shared bikes. Advantaged block groups make more trips in both station-based and dockless service and considerably gap in trips volume among various race majority groups; for instance, Black-majority block groups account for 45% in DC groups but only made 6.2% of bikesharing trips and 5.4% of e-scooter trips.

Our findings suggest that more shared bikes should be placed in low-income neighborhoods, considering that bikeshare accessibility is low but shared bikes in these neighborhoods have relatively short idle time compared to those in higher-income neighborhoods. This can be achieved by increasing the size of the bicycle fleet, moving some existing bikes from other areas to the target areas, or more rebalancing efforts to maintain the level of intended supply. To promote micromobility use in Black-majority neighborhoods, policymakers should think of strategies beyond managing micromobility supply. One possible strategy is to enhance the biking infrastructure to make travelers feel safer to use micromobility. Also, micromobility operators should accommodate the needs of individuals who are not tech savvy or lack access to smartphones by lifting access restrictions to the service platforms. Finally, both public entities and micromobility operators should make efforts to reduce existing financial and physical barriers for underserved groups.

A limitation of this research is that we do not know the socio-economic attributes of users. For example, the low-income groups mentioned in the research refer to users who started/ended the e-scooter trip in the low-income block groups. It is hard to determine the real income levels of these users. Future research will require developing survey instruments to study individual-level travel behavior among low-income populations.

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