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Research paper

E-scooters and public transport – Complement or competition?

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ABSTRACT

The rapid deployment of shared electric scooters (e-scooters) has resulted in much attention from the public and regulators. In this paper we look at what role e-scooters have in the mobility system in Oslo, Norway.

Previous research suggests that e-scooters fill three main functions: first by serving areas underserved by other modes; second that they replace public transport (PT) trips where the generalised costs of PT are relatively high; and third that they can play an important role as first/last mile mode. In this paper we look at the interaction between e-scooters and PT. We ask: do shared e-scooters compete with or complement public transport?

We analyse competition between e-scooters and other modes by combining four data-sources: *trip data* from e-scooter trips; *travel planner data* for alternative modes; a *survey* conducted among e-scooter users collected for the purpose of the study; and the *regional travel survey*, obtained from the PT authority in the greater Oslo area.

We find that e-scooters are both competing with and complementing PT. For most e-scooter trips, the PT alternative would take twice as much time, or more. A sizable share of e-scooter trips are indeed access and egress to/from PT.

1. Introduction

Shared electric scooters (e-scooters) were first introduced in their present form in the autumn of 2017, when Bird was launched in California. E-scooters offer motorised mobility at a low cost by presenting a new combination of a series of pre-existing technologies, most notably the kick-scooter, electric motor, the Global Positioning System (GPS), geographic information systems (GIS), smartphones, online payment, cloud computing and digital hailing. As with dock-less bikes and ride-sourcing, these new combinations have resulted in new services that have rapidly expanded into new geographic markets (Dudley et al., 2019; Fearnley, 2020). Their rapid growth places e-scooters at least in partial conflict with existing service offerings, such as taxi, city bikes, and public transport (PT). However, there is limited research on how e-scooters interact with other modes.

Previous studies looking at this interaction include Luo et al. (2021) who, using e-scooter trip data in Indianapolis, model demand overlaps with the PT system and find that about 27 percent of e-scooter trips could potentially be made by PT, and that less than one percent are potential first/last mile trips. Ziedan, Shah, et al. (2021) use e-scooter trip data in combination with economic data on PT services in Nashville, and Louisville (Ziedan, Darling, et al., 2021). They find that e-scooters cause both reductions and increases in PT ridership. Therefore, they conclude that the net effect is close to zero and not a major cause of a decline in bus patronage. Yan et al. (2021) who uses open data for Washington DC and compare with PT and docked bike sharing, find both intermodal competition and complementarity. Liu and Miller (2022) using hypothetical trips derived from real trips conducted in Columbus, Ohio, identify e-scooters as a potential accessibility enhancer and find that this is unequally distributed across space. Using survey data from Portland, McQueen and Clifton (2022), found that e-scooters, in their present form, were unlikely to be a preferred option to private cars. Zuniga-Garcia et al. (2022) develop a modelling tool to highlight the places where e-scooters and PT interact, using Austin data. All these studies use US cities as cases. Their findings are different from expectations form surveys conducted in European settings, where one typically finds higher PT ridership in the period prior to e-scooter introduction. The European surveys are mostly examples of 'grey literature' (Wang et al., 2023). In Europe, Nawaro (2021) found that e-scooters may be complimentary to PT in Warsaw, but that surveys likely overstate this effect. This paper investigates the emergence of e-scooters in a new context that has been understudied.

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Previous research on the role of e-scooters and micromobility in the mobility system in a European setting (Fearnley, 2020; Fearnley, Berge, & Johnsson, 2020) suggests that e-scooters fill three main functions. First, they serve areas that are underserved by conventional PT in densely populated areas. This is exemplified by high usage in areas of the cities where the distance to rail-based PT is long, such as along the waterfront. Second, they seem to replace PT for trips where the generalised cost of PT is comparatively high such as trips requiring transfers between lines. Third, they can function as first and last mile mode in combination with PT, and thus increase the catchment area of a PT service. This is exemplified by e-scooters being used in combination with ferry services and heavy rail (Fearnley, Johnsson, & Berge, 2020). To expand on these findings from preliminary research we ask: How do e-scooters compete or complement public transport? In recognising that the answer to this is likely to be context dependent, we focus on the experience in Oslo, Norway. In selecting Oslo as our case city, we are expanding on previous research by adding new data sources and new data from existing sources, in a previously studied location. This allows us to have a more in-depth understanding of the case, and to some extent, compensate for the biases in earlier research.

We have chosen to look at Oslo for several reasons. First, Oslo represents an early introduction of the services. Commercial e-scooter services were introduced in Oslo in May 2019 by Voi and TIER, which was relatively early both in a European and global context. Second, the services operated in a mostly unregulated market until 10 September 2021, providing an interesting context for studying the interplay between unregulated e-scooters with highly regulated PT. During this period, e-scooter operators were not obstructed by previously established mobility actors in the city. Third, Oslo is a city where we have access to data form various sources; the questions we ask are, therefore, less bound by the availability of data. Fourth, Oslo has the highest level of PT use in Norway (Lunke et al., 2022) and as of July 2021, the highest density of shared e-scooters per capita in Europe (Fluctuo, 2021); according to the Municipal Government, there were 25,734 e-scooters on the streets of Oslo in July 2021 (Bugge, 2021).

There have been two well-documented survey studies on e-scooter use in Oslo. First, an early study based on a survey collected in 2019 (Fearnley, Berge, & Johnsson, 2020). This study found that e-scooter users state that they chose e-scooters because they are quick, flexible and fun, and that a majority of e-scooter trips were made in combination with other modes, predominantly PT modes. If an e-scooter were not available for their most recent e-scooter trip, 23 percent of respondents stated that they would have used PT.

A more recent study, mainly using a survey from 2021 (Fearnley et al., 2022), identified some notable developments. Two years after the first study, the proportion of e-scooter trips that were made in combination with other transport modes had fallen to just over 20 percent, down from 57 percent in 2019 (Fearnley, Berge, & Johnsson, 2020). Again, these trips were mostly in combination with PT. Among those who used e-scooter as their main mode of transport (as opposed to using e-scooter to/from another mode), the share that would have used PT if the e-scooter were not available had risen to 32 percent. In other words, the developments suggest that e-scooters are decreasingly used in combination with PT and increasingly substitute PT trips. This observation is part of the motivation behind this current study.

Compared to 2019 the context surrounding mobility also changed as a consequence of the Covid-19 pandemic. There were several restrictions on the use of PT in Oslo in the period March 2020 to May 2021. Even though we use data from when there were no restrictions - apart from suggested mask use on crowded PT services - overall PT demand was affected by these measures and other factors linked with the pandemic (Ruter, 2021). This prevents us from estimating the direct effects on PT ridership as done by (Ziedan, Shah, et al., 2021). Instead, we have looked at the hypothetical options (as suggested by the Open Trip Planner (OTP)) for the specific trips that were conducted with shared e-scooters.

There is data suggesting that the uptake of shared mobility, and in particular shared micromobility, is affected by the pandemic. There has been an increase in the use of some forms of car-sharing, at least in part explained by the restrictions imposed on international travel (George & Aarhaug, 2022). Other shared modes, such as docked shared bikes, have experienced reduced demand (George & Aarhaug, 2022). Presently, little is known on the interaction between different shared modes, although Reck et al. (2022), show that this is an interesting potential line of enquiry.

The remainder of the paper is structured as follows. Section 2 presents our data material and methods. Section 3 briefly presents the theory used. Section 4 presents our results. In section 5 we discuss our findings and section 6 presents our conclusions.

2. Material and methods

This paper draws mainly on two datasets. A trip observation dataset that has been combined with OTP data, and a user survey. These two data sources are supplemented by the market information survey (MIS), which is a regional travel survey, conducted by Greater Oslo public transport authority (PTA) Ruter.

2.1. Trip observation data combined with travel planner data

The core trip observation data is a dataset of 130,698 e-scooter trips made in June 2021. The data has been provided by one of the shared e-scooter operators in Oslo. At the time the dataset was created, there were eight operators in Oslo. The selected operator was one of the major operators. However, exact market shares cannot be shared for confidentiality reasons. To use data from one, as opposed to several operators was based on a preliminary investigation, which suggested that the operators who were willing to share data had similar use profiles. Data structure was a key criterion for selecting from among these – the selected data set provided more suitable indicators for measuring actual trip distance, and was also easier to combine with other data sources for subsequent analysis. Larger datasets were available, but inconvenient due to computer processing times. The chosen dataset includes the exact time and location for start and stop of each trip, distance travelled by the e-scooter, and time elapsed. To analyse these, we have combined them with data from hypothetical travel alternatives and map data using a Python script.

The actual e-scooter trips have been matched with travel alternatives by alternative modes using the OTP. The PT data have been scraped from the Entur national travel information service. The OTP data include total travel time, access and egress time, on-board time, distance, and number of transfers for the PT alternative. The walking option includes route and time, this is also the case for cycling and car use.

2.2. User survey

During the period October–November 2021, a survey was sent to registered users in Norway, aged 16 and above, from five shared e-scooter companies (N = 3576) as part of the Norwegian MikoReg project (Fearnley et al., 2022). As the e-scooter companies do not disclose their number of customers, the response rate for the survey is unknown. For this study, responses from the city of Oslo (N = 1921) have been used.

The survey covered several topics, including accidents, use patterns, trip purpose, parking, and substitution/complementarity with alternative travel modes, in addition to background variables.

3. Theory

In this paper we draw on a conventional transport economics framework of utility maximising consumers and transport as a derived demand (Button, 2010/2014). We look at relative travel times as an indicator of disutility associated with the alternative modes. We acknowledge that a generalised cost (Lunke et al., 2021, 2022) would be a more precise approach, however we do not have access to enough cost data to present accurate generalised cost arguments. In particular, we cannot link e-scooter trips to survey answers. Consequentially, we do not know how much each e-scooter user paid, nor their access to period tickets on PT. Making such a study would be an interesting case for further research.

In the case of e-scooters, the assumption of travel as a derived demand can be problematic, as a significant proportion of the trips are made for other purposes than travelling from A to B. Many e-scooter trips, especially in the summer, seem to be made as joyrides – trips taken for the sake of taking a trip, not to get from A to B. In order to control for joyrides, we have used the difference in travel distance between the open trip planner's suggestion for a bicycle trip and the actual distance the e-scooter has been travelling. This has been used to exclude joyrides from the dataset for the relevant analysis, as elaborated upon in the next section.

4. Results

4.1. Trip data

In aggregate, the trips made by e-scooters averaged a distance per trip of 1769 m, with the median distance being 1331 m. The shortest distance in the dataset was 0 m and the longest was 22 km.

In order to identify e-scooter trips that were not made for travelling purposes, we created a dummy variable that selected trips where the e-scooter distance was between 50 and 180 percent of the trip planner map distance for bicycle. This variable includes 80.1 percent of the trips in the dataset. The cut-off points were set to include trips that used unmapped shortcuts, and take into account the fact that the average bicycle trip is approximately 20 percent longer than the travel planner trip in the Oslo case (Flügel et al., 2019; Lunke et al., 2018). This observed deviation is explained by preferences relating to avoiding adverse conditions, such as heavily trafficked roads, road works, tram lines etc. In this we assume that e-scooter and bicycle users have similar preferences for route choice.

Further, we define an e-scooter trip as parallel with PT when the origin and destination are near each other (cut off set at 250 m), and in the case of PT involves the use of the same mode, implying that it does not include transfers. The share of e-scooter trips being conducted in parallel with the PT network, is 63.9 percent in the gross dataset. Using this method, we get a parallel trip share between e-scooters and PT that is likely to be an overestimation. It is likely that PT was not a real alternative for all these trips. Our number for parallel trips is higher than the number of trips where the travel planner came up with a viable PT alternative. Reasons may include that the e-scooter trips were made at a time of day when PT was not in operation, or is operating at a low frequency.

Combining these two variables, 50.5 percent of the trips in the dataset satisfy the criteria for both trips made for travelling purpose and trips made in parallel with PT.

In 55,832 cases (42.7%), the OTP came up with a PT alternative to the conducted e-scooter trip. We do not have access to the specification of the selection criteria used in the travel planner. However, a logit regression on the observed data (Table 1) suggests that the probability of getting a PT trip as an alternative to the e-scooter trip in the dataset increases with travel distance and proximity to PT stops, and decreases at night.

In line with expectations, this regression suggests that the travel planner excludes PT as an alternative where PT is either impossible (no service) or improbable. This includes short PT travel options, where walking the full distance would be faster than using PT and so on.

The shorter trips also have greater variance and typically higher relative travel times (PT/e-scooter) than longer distances (Fig. 2). The lower probability of getting PT as an option at night is also in line with expectations, with the PT system being reduced at night.

Fig. 1 is a scatterplot of binned mean relative travel time (PT/e-scooter), by travel distance (in 10 groups each containing approximately 10,000 observations, with 99% confidence interval of the mean plotted. This plot suggests that e-scooters for the average trip use half the travel time compared to PT. This is even the case for e-scooter trips of more than 2.5 km. This suggests that relative travel time is an important factor in preferring e-scooters over PT.

Fig. 2 is a map of central Oslo. The intensity of e-scooter use on the road segments are depicted using a colour scale, with red being most intense use. The PT network is illustrated by highlighting the stops with pictograms of the modes. The PT network can be deduced by connecting the dots and icons. As the number of bus stops is high, we have used dots for these, instead of icons. From Fig. 2 we observe a pattern where e-scooters are mainly used for trips within the densely populated parts of the city. In addition, knowing the frequencies of the underlying PT network, the map shows a higher number of e-scooter trips on road segments where PT is either not present, less frequent, or where the PT alternative likely requires interchange. This can be both a consequence of e-scooters connecting parts of the city that are not well connected with PT or that e-scooter riders avoid streets with heavy traffic, particularly busses and trams. The map also shows that a large amount of traffic either originates or ends at major PT hubs, such as the main rail and metro stations. A local will also recognise that e-scooters are most

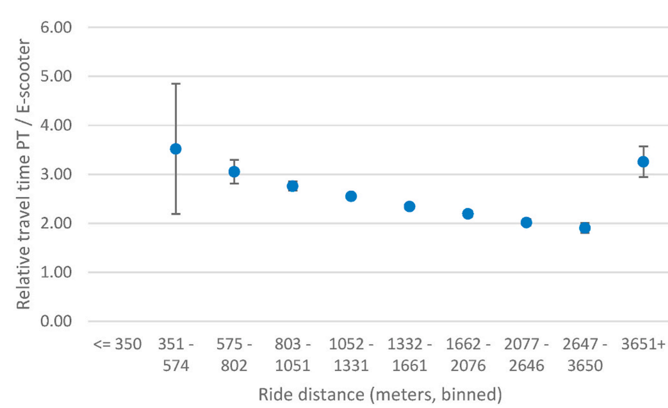

Fig. 1. Relative travel time public transport/e-scooter (means).

Table 1
Logit regression probability of having PT as an alternative to e-scooter.

	B	S.E.	Wald	df	Sig.	Exp(B)
weekend	0.105	0.018	34.952	1	0.000	1.110
night	−0.636	0.037	293.890	1	0.000	0.529
near_bus	0.639	0.039	273.594	1	0.000	1.895
near_metro	0.153	0.020	57.893	1	0.000	1.165
near_tram	0.274	0.017	269.021	1	0.000	1.315
euclidian_distance_meter	0.003	0.000	32897.512	1	0.000	1.003
Constant	−4.330	0.042	10475.073	1	0.000	0.013

Night = time of day 00:00 – 06:00; near bus/metro/tram = up to 250 m.

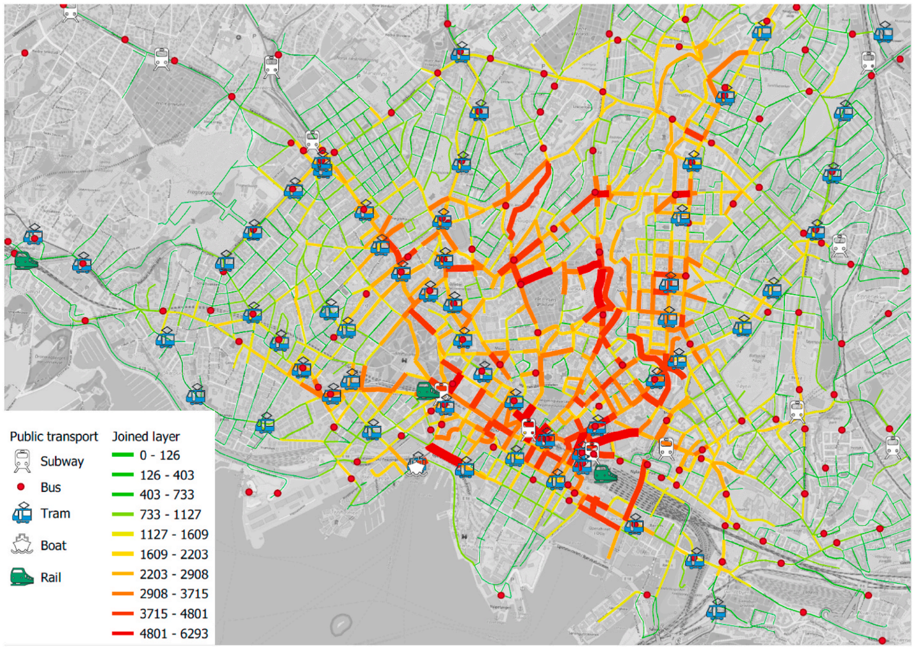

Fig. 2. Map, e-scooter rides per road segment and main PT-network in Oslo (trips).

heavily used in areas with a relatively young and wealthy population.

5. Survey

In the survey we find that there is no one answer to the question of whether e-scooters substitute or complement PT. Table 2 shows the proportion of e-scooter trips that were made in combination with another transport mode and with e-scooter as main mode, respectively, and how that differs with trip purpose. 76.1 percent of all respondents used e-scooters as their main transport mode on their last e-scooter trip and 19.5 percent used e-scooter to or from another transport mode. There is a general tendency for e-scooters to be used as access/egress mode more frequently when trip purpose is work/school or business, and a tendency for e-scooters to be used as main mode of transport for leisure trips.

From Table 3 we see that a total of 83 percent of trips to/from another transport mode are combined with a PT mode (bus, metro, tram, train or ferry). We see some variation between user characteristics.

The 2021 user survey also brings evidence of e-scooters being

Table 2
Use of e-scooter as main mode or first/last mile mode according to trip purpose. (Percent[a]).

E-scooter used … Trip purpose	… to/from another transport mode	… as main transport mode	N
All	19.5	76.1	1617
To/from work/school	24.2	74.2	647
Business	23.1	75.6	82
To/from leisure activities	16.7	77.6	249
To from party, pub, restaurant	14.5	83.7	178
Visit friends/family	15.0	85.0	154
For the fun of it or to socialise	15.9	34.9	68
To/from other errands	16.1	80.7	286
Don't remember/will not answer	18.2	72.7	11

[a] For some of the categories, e.g. “For the fun of it or to socialise” a substantial share of respondents indicated that e-scooter was neither used to/from another transport mode, nor as a main transport mode.

substitutes for PT. Table 4 presents the proportion of respondents who would have used PT if an e-scooter were not available, i.e. the e-scooter replaced a PT trip. For around one in five trips where e-scooter was combined with another transport mode, the e-scooter replaced a PT trip – with the exception for users aged above 40 where only 11.7 percent of the trips replaced PT. Where e-scooter was the main transport mode, around one-third of the trips replaced PT. Here, inexperienced users and those aged above 40 replace PT to a lesser extent than experienced and younger users. For e-scooter trips at night, about one-quarter of the trips replace PT. Here, 33.8 percent of those who have only used an e-scooter up to 10 times before, used e-scooter as substitute for PT.

6. Discussion

Compared to PT, e-scooters are used for shorter trips, and more leisure trips (Ruter, 2021). In Oslo the MIS-survey (Ruter, 2021) shows that trips of similar distances to the most frequent e-scooter trips are mostly made by walking (70% of all trips shorter than 1 km). The modal share of walking drops rapidly for trips above 1 km (approximately 30% for trips between 1 km and 2 km, and less than 10% for trips between 2 km and 3 km). This points to e-scooters addressing a demand that is not well served by other modes – trips that would involve either a long walk or a short PT ride.

Using a national survey Fearnley (2022) found that in Norway, users stated a variety of reasons for why they chose e-scooters over PT. In the survey, statements such as e-scooter being the quickest, most reliable, cheapest, most flexible, and most accessible alternative were all significant reasons for choosing e-scooters over PT. He also found that e-scooters substitute PT to a larger degree the longer e-scooter trip was. These findings are supported in our study where we use a method triangulation of survey, trip data and travel planner data.

Building on these observations one can argue that e-scooters both compete with and complement PT. The relative travel times suggest that e-scooters were, on average, more than twice as fast as PT on the trips made for travelling purposes and where PT was an option in the trip planner. This highlights that the level of service offered to the public by PT is not good enough to be the preferred solution.

In mapping PT competitiveness versus the private car in Oslo, Lunke et al. (2021) show that the private car competes well and that the

Table 3
What transport mode did you use e-scooter to/from? (Percent).

	Bicycle	Bus	Metro	Tram	Train	Ferry	Sum PT[a]	Car	Taxi
All	6.2	28.8	28.8	5.2	18.6	1.6	83,0	10.5	0.3
Male	5.4	25.4	23.1	4.6	22.3	2.3	77,7	16.2	0.8
Female	4.4	31.9	31.9	3.5	21.2	0.9	89,4	6.2	0.0
Used e-scooter up to 10 times in total	2.5	27.5	17.5	0.0	20.0	2.5	67,5	30.0	0.0
Used e-scooter more than 10 times in total	6.8	28.9	30.5	6.0	18.4	1.5	85,3	7.5	0.4
Up to 40 years old	7.9	33.8	27.6	5.3	17.1	0.9	84,7	7.0	0.4
Over 40 years old	1.3	14.1	32.1	5.1	23.1	3.8	78,2	20.5	0.0

[a] Sum PT is sum of bus, metro, tram, train, and ferry.

Table 4
Proportion of e-scooter trips that would have been made by public transport if an e-scooter was not available on last trip, according to trip characteristics. (Percent).

	Combined trip and would only change e-scooter leg	Used e-scooter as main mode of transport	E-scooter trip at night
All	19.2%	35.9%	24.2%
Male	17.8%	36.7%	23.5%
Female	18.4%	38.3%	24.3%
Used e-scooter up to 10 times in total	21.2%	26.7%	33.8%
Used e-scooter more than 10 times in total	18.9%	36.9%	23.6%
Up to 40 yo	22.3%	39.3%	25.5%
Over 40 yo	11.7%	28.5%	20.3%

tendency for choosing private car over PT increases as a function of other (dis)utility components such as bus transfers, rather than direct travel times. This suggests that the advantage in terms of utility for e-scooters over PT may be even higher than the difference in travel times indicate. Elements of this may be linked to the lack of flexibility in the PT service: PT takes you from a place you are not to a place you do not want to go to, at a different time than when you want to go, as opposed to a direct trip available on demand.

In addition, the zonal ticketing system in operation in the Oslo region may have unintended lock-out effects in addition to the intended lock-in effects (Fearnley & Aarhaug, 2019). The relative high price of single tickets contributes to making PT less competitive on shorter and occasional trips. The threshold for using PT is higher for persons without season tickets.

As shown by Lunke et al. (2022) the geography of origin and destination within the city is very important for how PT competes with other modes. Although the e-scooter trips in our dataset are mainly located within central parts of the city where PT services are generally perceived as being good, PT offers an inferior alternative to e-scooters in terms of travel time. The map in Fig. 2 illustrates that many of the most heavily used street segments are not well served by PT or they are served by a radial PT-service while the destination is along a different transport artery. An example which can be deduced from the map would be trips between major university campuses and areas of the city with large student populations.

In our data, we found that either 42.7 or 50.5 percent (depending on criterion) of the trips made by e-scooter had PT as a realistic travel option. This is much higher than the 27 percent found by Luo et al. (2021) and is possibly a result of the relatively high level of service offered by PT in Oslo compared with Indianapolis. Still, the travel time difference shows that replacing these e-scooter trips with PT would induce a significant disutility on the travellers. E-scooters are providing a quicker and more convenient service.

Approximately 20 percent of e-scooter trips are made in combination with another mode, mainly PT. This suggests that e-scooter complements some PT services and may have an impact in promoting shared modes. This line of argument points towards the integration of e-scooters into the PT services, possibly through integrated ticketing or travel information. Integrated ticketing would probably place e-scooters within the realm of the PTA as the ticketing authorities. This has numerous possible pitfalls, including the vested interests of PTAs in existing modes and the potential lack of market feedback. It is possible to imagine scenarios where e-scooters are excluded from the market in order to reduce competition within the PTAs offerings. On the positive side, integrating e-scooters into the PTA service may improve the user experience and simplify multi-modal travelling, increasing the overall attractiveness of the PTAs service.

Presently, e-scooters present a welfare improving mobility option in the inner city. This is an area where the PT service is rapidly losing its competitive edge with distance from the transport hubs. If PT is going to compete with e-scooters on travel time and attractiveness in these areas, that would require considerable improvements in service levels at a micro scale. Such an increase in service levels and stop patterns is neither advisable nor affordable.

However, at present, e-scooters are mainly catering to a relatively small segment of the population: young urbanites. And importantly, e-scooters are not used nearly as much in winter as in summer. While e-scooters can be an attractive alternative to PT on a dry summer day, the disutility of being exposed to the elements increases significantly with lower temperatures, precipitation, and higher winds (Bjørnarå et al., 2021). This is confirmed by lower mode shares of e-scooters, as is also the case for bicycling in winter months (Ruter, 2021).

This study suggests that e-scooters mainly complement PT. However, e-scooters are competing with PT in the sense that PT was a realistic travel option for just less than half of the observed e-scooter trips. E-scooters are not chosen over PT for longer trips, and to a lower extent on commuting trips than on leisure trips. On the trips where e-scooters were chosen, PT would have implied a significant increase in travel times, as would walking. This points to e-scooters being more of a complement to other non-car services than in competition with the existing modes. This finding is in line with Liu and Miller (2022) who find that e-scooters improve overall accessibility, but that this improvement is distributed unequally through urban space. Although there is a significant drop in PT patronage in the period where e-scooters have been available, this is probably mainly caused by policies for controlling the pandemic, and only to a lesser degree by the entry of shared e-scooters. That is not to say that e-scooters have not contributed to this development.

The overall policy objectives in Norway and the city of Oslo is that the number of trips with private passenger cars should not increase in urban areas (the zero growth goal); any growth in traffic should be made by PT or non-motorised modes (Tønnesen, 2015). This policy objective pre-dates e-scooters by more than a decade, and frames the relevant competition as being between private cars and everything else. The large overlap between service offered by e-scooters and PT shows that this framing is too simple. E-scooters may well play a part in providing alternatives to the private car. Either as a stand-alone service or as a complement to PT.

Given the overall policy objective of reducing car dependency, competition between e-scooters and PT is a second order problem for policy makers. However, given the context of developing post-pandemic mobility systems, this question may be of crucial importance. Limited funding may result in competition for passengers being conducted in the policy sphere in addition to the present on-street competition. This study suggests that even though there are possibilities for regaining some PT patronage through imposing restrictions on e-scooter use, such policies would be welfare reducing. An obvious solution to the issues would be to integrate e-scooters with the PT services.

7. Conclusions

E-scooters both compete with and complement PT. The level of competition is higher in the Norwegian context than in American cities where earlier studies have been conducted. This probably reflects a higher PT modal share in Norway. Still, where e-scooters are chosen over PT, the PT alternative is usually clearly inferior in terms of travel times. This suggests that e-scooters offer a service for trips that are not well catered to prior to their entry into the mobility market. As approximately 20 percent of e-scooter trips are made in combination with other transport modes, mostly PT, there is also a level of complementarity. This complementarity also extends to trips serving origin and destination combinations that are not easily served, even in the relatively dense part of the city, by PT. This suggests that e-scooters are welfare increasing, for the users, and that a potential path forward for policy development is to further promote this complementarity.

CRediT authorship contribution statement

Jørgen Aarhaug: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Nils Fearnley:** Conceptualization, Investigation, Writing – original draft, Funding acquisition. **Espen Johnsson:** Formal analysis, Investigation, Visualization.

Declaration of competing interest

None.

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References

Bjørnarå, H. B., Berntsen, S., te Velde, S. J., Fyhri, A., Isaksen, K., Deforche, B., … Bere, E. (2021). The impact of weather conditions on everyday cycling with different bike types in parents of young children participating in the CARTOBIKE randomized controlled trial. *International Journal of Sustainable Transportation*, 1–8. https://doi.org/10.1080/15568318.2021.1999538

Bugge, S. (2021). Oslo nattestenger sparkesykler fra klokken 23. *E24*, 13 July 2021 https://e24.no/naeringsliv/i/6k3llL/oslo-nattestenger-sparkesykler-fra-klokken-23.

Button, K. (2010/2014). *Transport economics* (3rd ed.). Edward Elgar Publishing.

Dudley, G., Banister, D., & Schwanen, T. (2019). The dynamics of public participation in new technology transitions: The case of dockless bicycle hire in manchester. *Built Environment, 45*(1), 93–111.

Fearnley, N. (2020). Micromobility – regulatory challenges and opportunities. In A. Paulsson, & C. H. Sørensen (Eds.), *Shaping smart mobility futures: Governance and policy instruments in times of sustainability transitions* (pp. 169–186). Emerald Publishing Limited.

Fearnley, N. (2022). Factors affecting e-scooter mode substitution. *Findings, June*. https://doi.org/10.32866/001c.36514

Fearnley, N., & Aarhaug, J. (2019). Subsidising urban and sub-urban transport – distributional impacts. *European Transport Research Review, 11*(1), 49. https://doi.org/10.1186/s12544-019-0386-0

Fearnley, N., Berge, S. H., & Johnsson, E. (2020). *Delte elsparkesykler i Oslo: En tidlig kartlegging, 1748/2020* (Oslo).

Fearnley, N., Johnsson, E., & Berge, S. H. (2020). *Patterns of E-scooter use in combination with public transport*. Transport Findings. https://doi.org/10.32866/001c.13707. July.

Fearnley, N., Karlsen, K., & Bjørnskau, T. (2022). *Elsparkesykler i Norge: Hovedfunn fra spørreundersøkelser høsten 2021, 1889/2022*. Oslo: Transportøkonomisk institutt.

Fluctuo. (2021). European shared mobility index - October 2021. https://european-index.fluctuo.com/.

Flügel, S., Hulleberg, N., Fyhri, A., Weber, C., & Ævarsson, G. (2019). Empirical speed models for cycling in the Oslo road network. *Transportation, 46*(4), 1395–1419. https://doi.org/10.1007/s11116-017-9841-8

George, C., & Aarhaug, J. (2022). *After the window closes: Car sharing in a post-pandemic urban mobility system Working paper* (Oslo).

Liu, L., & Miller, H. J. (2022). Measuring the impacts of dockless micro-mobility services on public transit accessibility. *Computers, Environment and Urban Systems, 98*, Article 101885. https://doi.org/10.1016/j.compenvurbsys.2022.101885

Lunke, E., Aarhaug, J., De_Jong, T., & Fyhri, A. (2018). *Cycling in Oslo, bergen, stavanger and trondheim*. Oslo: Institute of Transport Economics.

Lunke, E. B., Fearnley, N., & Aarhaug, J. (2021). Public transport competitiveness vs. the car: Impact of relative journey time and service attributes. *Research in Transportation Economics, 90*, Article 101098. https://doi.org/10.1016/j.retrec.2021.101098

Lunke, E. B., Fearnley, N., & Aarhaug, J. (2022). *The geography of public transport competitiveness in thirteen medium sized cities*. May 2022. Environment and Planning B-Urban Analytics and City Science. https://doi.org/10.1177/23998083221100265. Artn 23998083221100265.

Luo, H., Zhang, Z., Gkritza, K., & Cai, H. (2021). Are shared electric scooters competing with buses? A case study in Indianapolis. *Transportation Research Part D: Transport and Environment, 97*, Article 102877. https://doi.org/10.1016/j.trd.2021.102877

McQueen, M., & Clifton, K. J. (2022). Assessing the perception of E-scooters as a practical and equitable first-mile/last-mile solution. *Transportation Research Part A: Policy and Practice, 165*, 395–418. https://doi.org/10.1016/j.tra.2022.09.021

Nawaro, Ł. (2021). E-Scooters: Competition with shared bicycles and relationship to public transport. *International Journal of Urban Sustainable Development, 13*(3), 614–630. https://doi.org/10.1080/19463138.2021.1981336

Reck, D. J., Martin, H., & Axhausen, K. W. (2022). Mode choice, substitution patterns and environmental impacts of shared and personal micro-mobility. *Transportation Research Part D: Transport and Environment, 102*, Article 103134. https://doi.org/10.1016/j.trd.2021.103134

Ruter. (2021). *Market information survey (MIS) 2017-2021*. Personfil & Reisefil [Travel survey].

Tønnesen, A. (2015). Policy packages and state engagement: Comparing car-use reduction policy in two Norwegian cities. *Journal of Transport Geography, 46*, 89–98. https://doi.org/10.1016/j.jtrangeo.2015.06.006

Wang, K., Qian, X., Fitch, D. T., Lee, Y., Malik, J., & Circella, G. (2023). What travel modes do shared e-scooters displace? A review of recent research findings. *Transport Reviews, 43*(1), 5–31. https://doi.org/10.1080/01441647.2021.2015639

Yan, X., Yang, W., Zhang, X., Xu, Y., Bejleri, I., & Zhao, X. (2021). A spatiotemporal analysis of e-scooters' relationships with transit and station-based bikeshare. *Transportation Research Part D: Transport and Environment, 101*, Article 103088. https://doi.org/10.1016/j.trd.2021.103088

Ziedan, A., Darling, W., Brakewood, C., Erhardt, G., & Watkins, K. (2021). The impacts of shared e-scooters on bus ridership. *Transportation Research Part A: Policy and Practice, 153*, 20–34. https://doi.org/10.1016/j.tra.2021.08.019

Ziedan, A., Shah, N. R., Wen, Y., Brakewood, C., Cherry, C. R., & Cole, J. (2021). Complement or compete? The effects of shared electric scooters on bus ridership. *Transportation Research Part D: Transport and Environment, 101*, Article 103098. https://doi.org/10.1016/j.trd.2021.103098

Zuniga-Garcia, N., Tec, M., Scott, J. G., & Machemehl, R. B. (2022). Evaluation of e-scooters as transit last-mile solution. *Transportation Research Part C: Emerging Technologies, 139*, Article 103660. https://doi.org/10.1016/j.trc.2022.103660