Electric bike-sharking services mode substitution for driving, public transit, and cycling

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Abstract

In hopes of reducing traffic congestion, air and noise pollution, and energy consumption, bike sharing is becoming increasingly popular around the world. Underlying many of the benefits attributed to bike sharing is an assumption that bike share journeys replace a significant proportion of trips previously made by car. This paper examines factors correlated with the use of an electric bike-sharing system in Tricity, Poland. We use the double hurdle estimation approach on data from two matched surveys: before and after the implementation of the system. Our analyses indicate that electric bike rides did not act as a substitute for car trips. Shared e-bikes were used by residents as a substitute for public transportation or as a first/last mile of transport to/from public transportation stops. We examined the use of e-bikes for various types of trips and identified factors encouraging and discouraging people from usage of bike-sharing and cycling in general.

Keywords: E-bike; Bike sharing systems; Car use; Passenger behavior; Urban mobility; Public bicycles

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1. Introduction

In the last decade, many cities, countries, and regions across the globe introduced a variety of policies to promote sustainable transportation (Semenescu et al., 2020; Sun et al., 2018). Bicycles are widely recognized as environmentally friendly (Turoń et al., 2020), economically cost-effective (Zhang et al., 2015), and a healthy (Fishman et al., 2015a; Wang Y. et al., 2018) mode of transportation. Implementation of bike-sharing systems (BSS) has been linked to wide economic benefits, better public health, and time savings (Bullock et al., 2017). Therefore, many city and local governments around the world support and fund BSSs to encourage more people to cycle. Still, the performance and impacts of these new services are not well understood and authors call for further research on the subjects (Emberger et. al., 2020; Laa and Emberger, 2020).

This article investigates effects of the implementation of the electric bike-sharing system (e-bike BSS) in Tricity, Poland. Previous research on BSSs mainly focused on regular, non-electric systems (for literature reviews, see Eren and Uz, 2020; Fishman, 2016; Médard de Chardon et al., 2017; Sun et al., 2019). Although there is some previous literature on electric BSSs (Cherry, 2010; Guidon et al., 2019; Meireles et al., 2013; Thomas et al., 2015), it is mostly theoretical or performed in the cities where the standard, non-electric BSS has been already in operation. Astegiano et al. (2019) predicted growth of electric bikes' use until 2050 and called for research "investigating how the use of the e-bike might interact with car (and bike) sharing programs" (p. 170).

More frequent use of traditional bike-sharing systems was seen at public transportation stations that had more scheduled bus trips nearby (Sun et al., 2018). And Yang et al. (2018) postulated that BSSs can decrease the average trip time of passengers and increase the efficiency of an urban public transport network. Thus, e-bike BSSs can potentially improve access to public transit nodes such as bus, tram, or railway stations. Another possibility is that e-bike BSSs may become a competitor of public transportation as the distance range of e-bikes overlaps with the distance ranges of buses and trams (Bigazzi and Wong, 2020; Guidon et al., 2019; Kroesen 2017). Electric bicycles, as opposed to regular bikes, are thought to be more available for older people, ensuring inclusiveness of the system for all citizens.

In 2019, the metropolitan area of Gdansk, Gdynia, and Sopot (i.e., Tricity) introduced the first BSS in Poland using electrical bicycles only. Implementation of the BSS in Tricity (called MEVO) was a part of the strategy to achieve sustainable urban mobility and reduce car trips. Additionally, the metropolitan area authorities hoped that the e-bike BSS would lead to an increase in the use of public transportation because the e-bikes would serve as a first/last mile solution, making public transport services more available. The main premise for the introduction of the electric, instead of the standard BSS, was large differences in ground levels in Tricity that may discourage many people from cycling (Sun et al., 2018; Chen et al., 2017; Faghih-Imani et al., 2017; Fishman, 2016). Electric bicycles were supposed to enable and encourage all people to use the bike-sharing system. This presented a unique opportunity to research the e-bike BSS in a big urbanized area. This study aims to examine if the implementation of the electric BSS achieved expected goals intended by the policymakers. The data for the present study were collected using a survey answered by the same individuals before and after the introduction of the system.

We contribute to the BSS literature in the following ways. First, we explore the extent e-bike BSSs displace travel by other modes of transportation: cars, public transportation, and private bikes. Second, we explore factors discouraging and encouraging the use of electric bicycles and biking in general, in particular, the necessity of traveling high hills. Additionally, we examined these relationships for various types of trips (e.g., trips to/from bus stops, work, shopping, health, fun). The results of this study may provide useful guidance for policymakers and transportation agencies on the implementation of an e-bike BSS.

2. Literature review

2.1. Standard, non-electric bike sharing systems

Numerous studies have argued that the implementation of standard BSSs does not result in the massive reduction of car usage. Shared bicycles became substitute for public transportation and walking, rather than a private car (Ricci, 2015). For example, in the city of Dublin (Ireland), most people used the BSS for very short distances instead of walking (45%) or as a substitute for other sustainable modes of transport like buses or trains (34.6%), and only a small number used it as a substitute for a car (19.8%) (Murphy and Usher, 2015). Similarly, in Taiyuan (China), the BSS reduced the demand for walking and bus rides rather than private car trips and was a more popular choice for leisure trips rather than commute trips (Li and Kamargianni, 2018). In a recent literature review on traditional BSSs, Eren and Uz (2020) found that multiple studies show that bicycles are more likely to replace shorter bus trips that require little effort and short-term exposure to unfavorable weather conditions and that BSSs can be successfully integrated with public transportation as a first/last mile solution. The latter was confirmed in other studies reporting that well-designed BSSs can reduce the use of motor vehicles to access train stations (Böcker et al., 2020; Martin and Shaheen, 2014; Pucher and Buehler, 2009). In another review, using data from five cities across three continents, Fishman et al. (2014) found evidence of low car-mode substitution rate by BSSs and even an increase in car use due to a larger level of motor vehicle support servicing bikes. Other studies focused on car ownership and found BSS users to have higher levels of car ownership than non-users (e.g., in Chinese cities of Beijing, Hangzhou and Shanghai as reported by Fishman et al. (2013) or in France as reported by Jahanshahi et al. (2019)).

The BSS's usage patterns were found to be influenced by socio-demographic factors, such as age, sex, income, or pro-environmental attitudes. Younger age, male gender, and higher income were associated with more BSSs membership (Böcker et al., 2020; Fishman et al., 2015b; Fishman 2016; Nikitas, 2018; Wang K. et al., 2018). BSSs adoption intention was related to perceived green societal values and strengthened by personal pro-environmental attitudes (Bai et al., 2020; Wang Y. et al., 2018). BSSs were also found to have positive health impacts especially for men and for older users (Woodcock et al., 2014).

2.2. E-bikes

Since the 2000s, the popularity of electric bicycles (e-bikes) has grown rapidly in China, and over the last decade started gaining popularity in Europe and North America (Bigazzi and Wong, 2020; Fyhri and Fearnley, 2015; Kroesen, 2017; Fishman and Cherry, 2016; Cherry et al., 2009). Compared to regular bikes, electric bicycles are generally considered to have greater range, speed, and overall enhanced performance (Bai et al., 2020; Fyhri and Sundfør, 2020; Fyhri and Fearnley, 2015; Fishman and Cherry, 2016; Rose, 2012; Cherry et al., 2009). Challenging topography, trip distance, high temperature, poor air quality, and other factors associated with physical exertion act as barriers to bicycling (Campbell et al., 2016; Fishman, 2016). Therefore, "e-bikeshare offers the potential to increase the attractiveness of bikeshare to those who may not have previously seen it as an option" (Fishman, 2016, p. 108).

The use of e-bikes is seen as an attractive way to reduce the emissions of greenhouse gasses and as one of the factors contributing to the decline of car modal share (Astegiano et al., 2019; Bigazzi and Wong, 2020; Fyhri and Sundfør, 2020; McQueen et al., 2020; Fishman and Cherry, 2016). Bai et al. (2020) reported that in China, e-bikes consume 90% less energy and generate 86–95% fewer pollutants than private cars, have a 60–93% lower carbon dioxide emission rate than private cars, and have a carbon dioxide emission rate comparable to public transit. The total environmental impact of e-bikes is valid to the extent that they displace car, bus, or motorcycle use, but not regular bicycle use (Cherry et al., 2009). Fyhri and Sundfør (2020) found that people who purchased an e-bike increased their bicycle use on average from 2.1 to 9.2 km per day, representing a change in bikes as a share of all transport from 17% to 49%. Fyhri and Fearnley (2015) reported that, in Norway, when participants were given an e-bike, they increased e-bike cycling trips from 0.9 to 1.4 per day, distance from 4.8 km to 10.3 km, and, as a share of all transport from 28% to 48%. Sun et al. (2020) found that after e-bike adoption, conventional bike use reduced significantly. Although car use reduced less strongly, a net environmental gain was still reported after e-bike adoption. In Norway, when kindergarten parents were provided with access to bikes and e-bikes with trailers, they increased cycling and decreased car usage for trips to work and kindergarten, even during winter, and the effects were greater for e-bikes (Bjørnarå et al., 2019). More experimental research in Brighton (UK) that loaned participants e-bikes for 6–8 weeks resulted in the overall reduction in car mileage by 20%. However, there was also reduction in bus trips and walking (Cairns et al., 2017). De Kruijf et al. (2018) reported mixed environmental, congestion, and public health effects after the implementation of e-bike monetary incentives in the North-Brabant province of the Netherlands. Although e-bike trips increased from 0% to 73% after half a year of participating in the program, half substituted car trips and the other half conventional cycling trips. In a recent meta-analysis, Bigazzi and Wong (2020) reported e-bike mode substitution to be the highest for public transit (33%), followed by conventional bicycle (27%), automobile (24%), and walking (10%).

Studies on demographics of e-bike users from three continents suggest that they are popular among older adults. A North American Survey of Electric Bicycle Owners of over 1700 cyclists found that just under half of them were aged 55 years or older (MacArthur et al., 2018). A National Australian study of 478 e-bike owners indicated that 70% of them were 50 years old or older (Johnson and Rose, 2015). Furthermore, a survey of 217 e-bikers from the Netherlands found that 73% were 55 years old or older (Lee et al., 2015). Qualitative study on the potential of e-bikes to support mobility among older adults found that they increase convenience and reduce physical exertion and reliance on a car (Leger et al., 2019).

The reviewed above studies on private use of e-bikes may imply that the implementation of e-bike BSSs could potentially substitute car trips and be popular among older-adults.

2.3. E-bikes Bike Sharing Systems

Most BSSs use traditional bikes. However, as e-bikes become increasingly popular, “it is likely that the next generation of bike share could be driven by e-bikes” (He et al., 2019, p. 3). Examples of cities that adopted full or partial e-bike BSSs include, in Europe, Stuttgart (Germany), Milan (Italy), Copenhagen (Denmark), Tricity (Poland); in the U.S., University of Tennessee-Knoxville (Tennessee), Birmingham (Alabama), Baltimore (Maryland), San Francisco (California), San Diego (California), Summit County and Park City (Utah), Seattle (Washington); and in China, Tengzhou, Liaocheng, and Yangzhou (Galatoulas et al., 2020).

There are some concerns with e-bike BSSs that include safety, disruption to traffic, high cost, and operational complexity (Campbell et al., 2016; Cherry and He, 2010; Schleinitz et al., 2016). However, despite these concerns, the popularity of e-bikes and some support that e-bikes replace car trips suggest that e-bike BSSs may be a valuable option to add to a regular, non-electric BSSs. There are reasons to expect that the e-bike BSS may be more effective than the traditional BSS in competition with private cars. Electrically assisted bikes are quicker, enable longer trips, and are easier over hilly routes, making this mode of transportation more attractive by reducing some barriers to bicycling (Fishman, 2016). Perceived convenience and functionality were found to significantly predict regular BSSs adoption intention (Wang Y. et al., 2018; Hazen et al., 2015). Compared to rush-hour driving and public transportation, the e-bike offers competitive travel speed (Fyhri and Fearnley, 2015; Sun et al., 2020).

Since most BSSs are traditional, there is very little research related to the new, electric BSSs. An e-bike BSS pilot project in the University of Tennessee (with 93 enrolled users), found that 11% of all e-bike trips would have previously been made using cars but no regular bicycle trips displaced car trips. However, only 22% of users accounted for 81% of the trips and walking was the mode most displaced by the system (Langford et al., 2013). The University of Tennessee experiment also demonstrated that costs associated with operating, battery charging, and distribution management are crucial for system reliability (Ji et al., 2014). The study of the e-bike BSS in the hilly terrain of Park City, Utah (U.S.) revealed that demand for e-bikes was higher at stations near public transit, recreational centers, bike trails, and in areas with a higher population density (He et al., 2019). People used e-bikes more for longer trips, on the weekends (as opposed to regular bikes), and in summer months. Only 15% of the e-bike trips were made by regular users. Authors concluded that "Park City attracts more casual users to its e-bike share system than regular users who commute to their workplaces" (He et al., 2019, p. 16). This result was different for the e-bike BSS in Zurich, Switzerland, which also has big terrain elevation differences. Guidon et al. (2019) concluded that a large proportion of the e-bike BSS's trips were for commuting since most rental start locations were in the main business district, rentals had a distinct morning and afternoon peak, and there was a 37% reduction of trips on weekends. E-bikes were one of the fastest urban transportation options in Zurich and the distance range of e-bike-sharing trips overlapped with the distance ranges of traditional public transportation and taxi services (Guidon et al., 2019). Guidon et al. (2020) found that the most important predictors for e-bike BSS demand are employment, population, bars and restaurants, and distance to a central location. Finally, Campbell et al. (2016), using a survey conducted in the four main urban districts of Beijing, modeled factors influencing user choice to change from existing mode to shared bike or shared e-bike. They found that an e-bike BSS tends to attract users as a bus replacement. Compared to the traditional BSS, the e-bike BSS demand was much more tolerant of trip distance, high temperatures, and poor air quality, though precipitation was also a highly negative factor. E-bike BSSs appealed more to young to middle age males with low income and education levels.

As the emerging studies reviewed above suggest, e-bike BSSs may have different effects on ridership than traditional BSSs: E-bikes may be used for longer distances, may replace bus trips, and target different demographics.

3. Characteristics of MEVO BSS and regional context

The metropolitan area of Gdańsk, Gdynia, and Sopot (called Tricity) has a population of over 1 million people. The three cities are situated adjacent to one another in a row on the coast of Gdansk Bay (Baltic Sea) in northern Poland. The topography of Tricity is very unique as it is situated on moraine hills (Figure 1). Large differences in ground levels have been identified as an important barrier for the development of bicycle transport (Sun et al., 2018). To overcome this obstacle, metropolitan authorities decided to develop a BSS with a large fleet of electric bicycles that would enable older and less physically able people to ride bicycles on an everyday basis despite significant changes in elevation. Tricity was one of the few cities in the world that adopted a public, fully electric bike rental system.

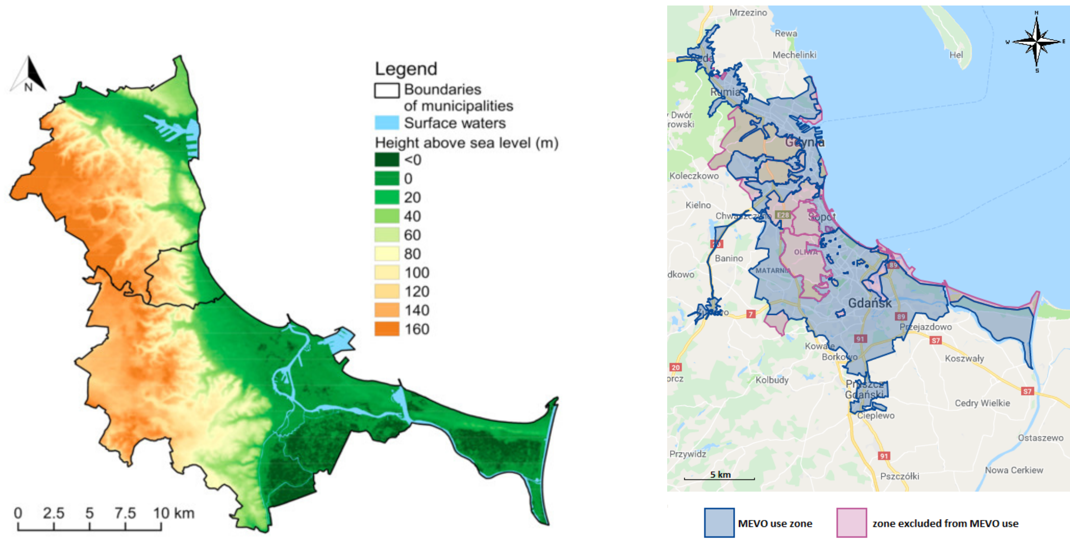

Fig. 1. Topological map of Tricity (left) and MEVO use zone (right)[2].

The demography of Tricity is complex and varies by neighborhood. However, as in many other European cities, there is gradual ageing of the society. In 2018, the median age in the Pomorskie Voivodship, where Tricity is located, was 39.6 years and it increased by 4.3 years from 2005. The population aged 65 years and older has been increasing yearly. In the Pomorskie Voivodship, there were 382,000 people 65 plus years old at the end of 2018, 3.8% more than in 2017 and 45.7% more than in 2005. The share of elderly people in the total population in 2018 was 16.4% and has increased by 0.5% and 4.5% from 2017 and 2005, respectively (GUS, 2019).

A survey among residents of the region revealed positive attitudes toward shared mobility services regardless of the age of participants (Suchanek and Szmelter-Jarosz, 2019). In order not to exclude citizens who do not use smartphones and mobile applications, the e-bike BSS

[2] Sources: Bieliński et al. (2020) and MEVO Watchdog Facebook: https://www.facebook.com/mevowatchdog/photos/293840808012793

accepted RFID (radio-frequency identification) proximity cards. Even though the system was designed to enable people of all ages to cycle, Nextbike Polska (2019), the system operator, reported that 56% of all registered users were 13-30 years old (nearly 94,000 people), 43% were 30-65 years old (71,500 people) and only 1% were seniors older than 65 (1,600 people). This does not match results reported by Fyhri and Fearnley (2015) who argued that e-bikes tend to be more popular with older age groups. Renting MEVO bicycles was quite complicated, as users needed to register online and use electronic forms of payment to activate their accounts. Although it was possible to rent an e-bike without a smartphone (using RFID card), the procedure was even more complicated. Instructions were available only at very few stations in the whole system. Most information about the system (including location of available bicycles) was available only online. These obstacles could discourage many senior citizens from using shared bicycles. As opposed to public transportation, there were no discounts or incentives for seniors to use MEVO. Additionally, there is no cycling culture among the older generation in Poland, and there was no other bike or scooter sharing system available in Tricity before 2019.

Electric bicycles did not make the system more accessible to women, who accounted for 44% of users. This matches results reported by Leister et al. (2018) who analyzed 23 traditional BSSs and revealed that, on average, 44.13% of trips are made by women.

The e-bike BSS, called MEVO, was launched in Tricity on March 26, 2019. Despite the problems with the full implementation and maintenance, MEVO bicycles have become very popular among residents of the metropolitan area. By September 27, 2019, after 185 days, the system reached 2.06 million trips, with 167,000 registered users, who in total cycled 6.6 million km. The average time of one trip was 24 minutes, and the average distance was 4.2 km (Nextbike Polska, 2019). This has made MEVO the most efficient BSS in Poland, with 9.1 trips per day per bicycle (TDB), a frequent measure of BSS efficiency (Fishman et al., 2014a; Médard de Chardon et al., 2017). In comparison, in Poland in 2018, the highest values of regular non-electric BSS's TDB were registered in Poznań (4.89 TDB) and Wrocław (4.88 TDB) (Bieliński et al., 2019). It is also much higher than TDB observed in the review of 75 BSS case studies across the world (0.22–8.4) (Médard de Chardon et al., 2017) and 69 Chinese case studies (0.7–9.5) (Zhao et al., 2014). This phenomenon may be associated not with the genuine efficiency of the Tricity's e-bike BSS but with the low number of bicycles provided to the large number of citizens. Only 1/3 of the planned bicycle fleet was actually provided. In Poland, in most BSSs, the first 15-20 minutes of usage were free of charge. MEVO could be rented for 0.1 PLN per minute (PLN is Polish zloty, the official currency of Poland), or on a subscription basis with 10 PLN per month or 100 PLN per year (with 90 minutes of usage every day and free of any additional charges). For reference, the price for a regular one-ride bus or tram ticket was 3.80 PLN, 1-hour ticket 4.40 PLN, and 24-hour valid ticket on all lines 14 PLN[3].

MEVO was a hybridized type of BSS, which means that it was not purely station based. Bicycles could be left outside of the station with an additional charge of 3 PLN. There was also a self-rebalancing mechanism (2 PLN premium to users who took an e-bike back to the station).

After seven months of operation, MEVO stopped operating on October 29, 2019 (Korolczuk, 2019). Managing the implementation of an e-bike BSS proved to be more complicated than a traditional BSS. MEVO was managed by Nextbike, the leading company in the bike-sharing market in central and eastern Europe. Initially, the system was supposed to include 4,080 electric bicycles, which would make it the largest BSS of this type in Europe (www.gdansk.pl, 2018a, 2018b). Unfortunately, from the launch of the system until the end of

[3] https://exploregdansk.info/transportation/public-transport-in-gdansk/

September 2019, Nextbike managed to deliver only 1,224 e-bikes. Lack of experience in handling electric bikes caused operator problems with fast charging of bicycles' batteries and other technical problems resulting from the type and weight of the devices (e.g., disconnecting batteries or parts that do not support the weight of the device).

4. Data and methods

4.1. Data

Data from two surveys were used in the analyses: one before the introduction of MEVO e-bikes and one after the introduction. The same respondents answered both surveys and data were matched appropriately. Data are from three cities: Gdansk, Gdynia, and Sopot. The first survey was collected between August and December 2018. Data collection has been carried out by the MRC Consulting company using the Computer-Assisted Personal Interviewing technique (CAPI) on a random sample of 4,081 respondents. Out of this number, 1,794 people signed up for participation in the second survey and provided their email addresses. After the introduction of the MEVO system, the second survey was conducted. Between August and September 2019, a total of 1,794 questionnaires were sent. After two reminders, 488 responses were collected (27% response rate). The first questionnaire included 16 questions and the second 15 questions. Both questionnaires consisted of different types of closed-ended questions, such as single choice questions (including dichotomous, ordinal-polytomous), multiple choice questions, and rank questions (with 1-10 ranking scale). The questionnaires consisted of questions about transport behavior of respondents, their modal choices, and reasons encouraging and discouraging from the usage of the MEVO system and cycling in general.

4.2. Econometric modelling strategy

The data on the use of MEVO e-bikes by respondents include a large number of zeros since many of the residents did not use MEVO e-bikes. The ordinary least squares regression results would not yield consistent estimates when the dependent variable is zero for a substantial proportion of the population (Greene, 2007). The Tobit model (Tobin, 1958) is also very restrictive by assuming variables that determine the probability of using the bikes (participation) also determine the level of participation. However, the Cragg's independent model (Cragg, 1971), which is a double-hurdle model, relaxes the Tobit model by allowing separate stochastic processes for the participation and level of participation decisions (Heckman, 1979; Yen and Huang, 1996). We use the double-hurdle model that focuses on the participation decision in the first stage and assumes that consumers who pass the participation hurdle have a positive level of participation. Thus, we use a double-hurdle model consisting of two stages. The first hurdle is a selection mechanism in which a respondent decides to use a MEVO e-bike. In the second hurdle, the respondent chooses the level of participation. The model first estimates if the participant decides to use MEVO e-bikes, and next, it estimates how often the participant uses MEVO e-bikes. The double-hurdle model allows us to efficiently estimate the parameters by means of the maximum likelihood principle. It jointly estimates the likelihood of participation and the amount of participation. A similar model was used recently in business literature by Frid et al. (2016) and Kwapisz and Hechavarria (2017). In our scenario, this model is more appropriate than the zero-inflated count model since different mechanisms may govern the selection decision (if the bike was rented) and the amount decision (how many times it was rented). In simple terms, first, the individual decides whether to rent an e-bike and, second, decides how many times to rent. In this way, the double-hurdle model overcomes the restriction of the zero-inflated models that any variable which increases the probability of *nonzero consumption* of MEVO also must increase the mean of *positive consumption* of MEVO, which is not reasonable in our scenario (Lin and Schmidt, 1984). A different dependent variable is used to model each stage, with the first part modeling discrete choice of whether to rent an e-bike with a specification similar to that of a logit model, and the other part modeling the positive number of rentals using a specification similar to a censored regression. The specification of the generalized double hurdle model is as follows:

$$y = \begin{cases} x'\beta + \nu \; if \;\; z'\alpha + u > 0 \;\; and \; x'\beta + \nu > 0 \\ 0 \; otherwise \end{cases} \text{ and } \begin{bmatrix} u \\ \nu \end{bmatrix} = N\left\{0, \begin{bmatrix} 1 & \rho\sigma \\ \rho\sigma & \sigma^2 \end{bmatrix}\right\}$$

where y is the number of rentals, z and x are variables determining the participation and the level of participation in MEVO, respectively; u and ν are residual terms from the two processes, with a correlation coefficient ρ; and α, β, and σ are parameters for estimation. In our model, we use one set of explanatory variables for both processes, $x = z$, as these variables represent all of the relevant information available in the data which may be related to both processes.

5. Results

5.1. Descriptive statistics

The descriptive statistics and definitions of variables used in the analysis are listed in Table 1. The results show that 54% of respondents reported using MEVO e-bikes, 22% reported using e-bikes a few times a year, 22% a few times a month, 8% a few times a week, and only 2% as a daily type of transportation.

Table 1. Definitions and Descriptive Statistics (n=488).

Variable	Definition	Mean	StDev
IfMEVO	If used MEVO e-bikes (1=yes; 0=no)	0.54	-
FreqMEVO	MEVO e-bike use frequency: 0 (never) - 4 (every day)	0.99	1.1
Binary indicators if used MEVO to commute to/from (1=yes; 0=no):			
MEVO Work	work, school, or university	0.38	--
MEVO Bus	public transportation stops	0.39	--
MEVO Shop	shopping	0.26	--
MEVO EatOut	restaurant, bar, coffee shop	0.31	--

MEVO Service	services (e.g. hairdresser, doctor, gym)	0.27	--
MEVO Meet	social meetings (family, friends, work)	0.37	--
MEVO Rec	recreation places (e.g. beach, forest)	0.31	--
MEVO Health	to keep healthy and feel good	0.14	--
MEVO Fun	for fun, without the destination	0.17	--
Frequency of transportation mode from Survey 1 on the scale: 0 (never), 1 (few times a year), 2 (few times a month), 3 (few times a week), 4 (every day):			
UseBikeFreq1	Bike use frequency	2.66	1.27
UseBusFreq1	Public transportation use frequency	2.37	1.17
UseCarFreq1	Car use frequency	2.67	0.97
Change in the frequency of transportation mode from survey 1 (before MEVO) to survey 2 (after MEVO); Change=Freq Survey 2- Freq Survey 1; 0=no change, Positive number = increase in use, Negative number = decrease in use			
BikeChange	Change in the frequency of using own bike	-0.05	0.86
BusChange	Change in the frequency of using public transportation	-0.03	0.76
CarChange	Change in the frequency of using own car	-0.05	0.74
Binary indicator for the main reason discouraging MEVO use (1=yes; 0=no):			
TooFewMevo	too few MEVO e-bikes	0.51	--
OwnBikeNoMevo	owning their own bike, no need for MEVO	0.32	--
Other	other reasons	0.17	--
Ranking of reasons discouraging biking in general on the scale from 1 (no influence on the decision to bike) to 10 (maximum influence on the decision to bike) from Survey 2:			
NoBikePaths	lack of bike paths	4.81	3.13
CrazyDrivers	lack of respect for bikers from drivers	5.39	3.05
NoWeather	bad weather	4.82	2.94
Safety	not feeling safe in traffic as a biker	4.88	3.04
TooFar	need to travel too far	4.22	3.24
Groceries	need to carry groceries/loads too heavy for a bike	4.17	3.08
Shower	no shower facilities at the place of work	4.18	3.39
Hills	too high hills	4.18	3.20
Ranking of reasons encouraging biking in general on the scale from 1 (no influence on the decision to bike) to 10 (maximum influence on the decision to bike) from Survey 2:			
Health	better for my health	8.44	2.08
Green	concern about climate	7.34	2.97
Money	save money	6.94	3.19
Time	save time in traffic	6.75	3.06
Weight	lose weight	5.89	3.32
BikePaths	good system of bike paths in my neighborhood	5.73	3.04
Controls:			
LessTraffic	Biking reduces traffic (1=yes; 0=no)	0.73	--
Male	1=Male; 0=Female	0.52	--
Work	1=If work; 0=otherwise	0.90	--
Age	Respondent’s age	34.76	9.63

The e-bike BSS in Tricity appeared to complement public transport. Almost 40% of respondents reported using MEVO e-bikes to commute to/from public transportation stops (Figure 2). This is similar to the results by Campbell et al. (2016) in Beijing who reported the utility of shared e-bikes as transit feeders to be positively related to the adoption of e-bike BSSs (though the result was at the low significance level). Recently, Bai and Jiao (2020) showed that better access to transit positively correlated with higher e-scooter ridership in Austin (TX) and Minneapolis (MN) in the U.S. Regular bikes BSSs were found to be the choice of transport in the first/last mile solution to access train stations by Böcker et al. (2020), Martin and Shaheen (2014), and Pucher and Buehler (2009).

The MEVO e-bikes may also be a substitute for other forms of transportation as 38% of respondents reported using e-bikes to go to work, school, or university; 37% to go to social meetings; and 31% to eat out (Figure 2). This is similar to the results reported for e-bike BSSs by Guidon et al. (2019) in Zurich. The most prevalent travel purpose in a traditional, non-electric BSS in New York City was to travel to eat out, followed by shopping and transferring to other public transport services (Bao et al., 2017). In Lyon, commuting to work or school during peak hours was the main reason to use public regular bikes by long-term BSS users (Tran et al., 2015). Commuting during peak hours and for entertainment purposes during non-peak hours and on the weekends were identified as the most common purposes of shared transportation in the literature review conducted by Sun et al. (2019).

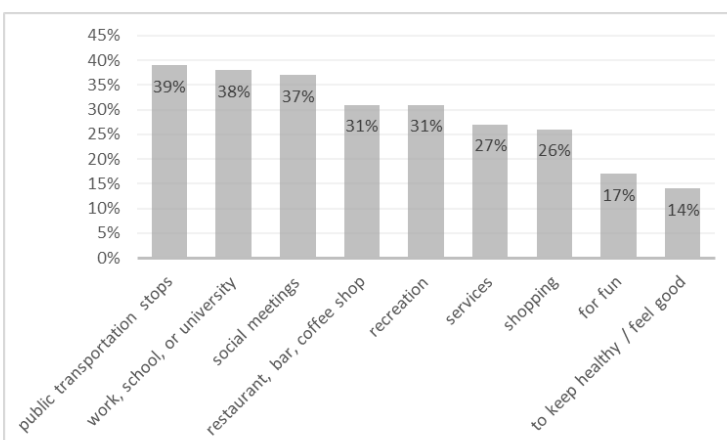

Fig. 2. Reasons to use MEVO

Respondents were asked about their mode of transportation and frequency of use in both surveys: before and after the BSS MEVO introduction. Two sets of variables were constructed. The first set reports frequency of using car, public transport, or bike in the first survey, before MEVO e-bikes were available. The second set is the change in the frequency of using car, public transport, or bike from Survey 2 to Survey 1. Therefore, zero denotes no change, a positive number indicates the increase in the frequency of using a given type of transportation, and a negative number indicates the decrease. There were no significant changes in the means of these variables for cars, bikes, and public transportation between before and after the introduction of the MEVO e-bikes.

There were two main reasons discouraging the use of MEVO e-bikes. First, reported by 51% of the respondents, there was too few MEVO e-bikes available. This may be related to the popularity of bicycles but also to a relatively low number of bicycles available to the large number of citizens (and the mentioned above operators' problems that delivered only 1/3 of the planned bicycle fleet). The second was owning a personal bike (32%). Our results are similar to those obtained in a Gothenburg (Sweden) study (Nikitas, 2019), where the two most important reasons for not using traditional bike-sharing frequently or at all were "I have my own bike" (41.1% of respondents) and "lack of bike-sharing and cycling infrastructure" (30.9%).

Respondents were also asked to rank on the scale from 1 (no influence) to 10 (maximum influence) factors that discourage their decision to ride a bike in general. Median ranks of reasons discouraging biking in general are presented in Figure 3. Lack of bike paths, lack of respect for bikers from drivers, and bad weather were the biggest discouragements (median ranked 5 on the 1-10 scale). These results are in line with previous studies where rainy and cold weather, hilly terrain, and road safety were also the top reasons not to use bike-sharing (Sun Z. et al., 2019; Sun et al., 2018; Nikitas, 2019; Boss et al., 2018; Schepers et al., 2014; Wadud, 2014). For example, in a study of 1,064 cyclists from 20 different countries, perceived crash risk (17%), adverse weather conditions (17%), and lack of safety (16%) were found to be the most relevant factors discouraging cycling (Useche et al., 2019).

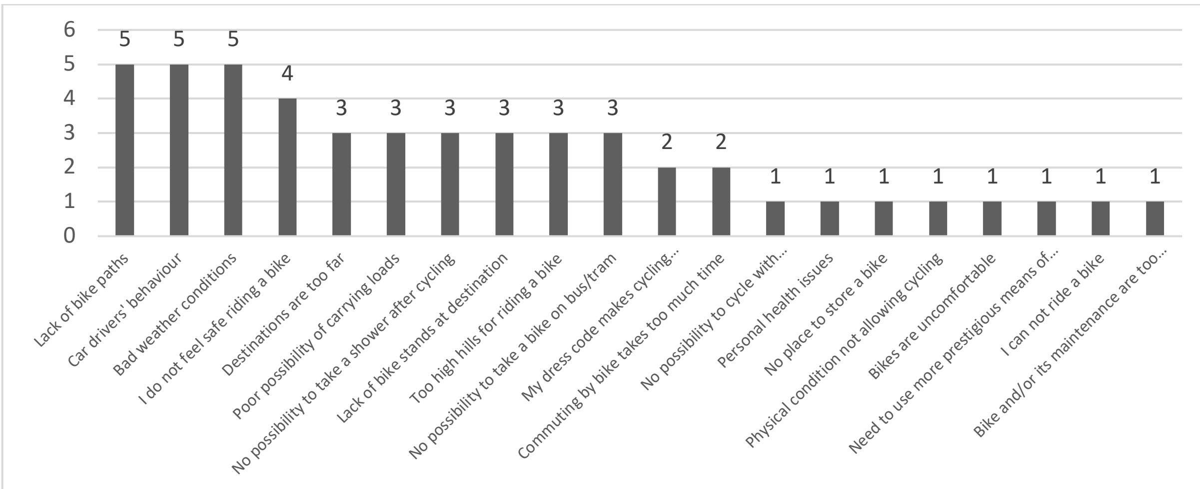

Fig. 3. Median (scale 1-10) ranks of reasons discouraging biking in general.

In the same manner, respondents ranked factors encouraging biking in general (Figure 4). The top reason reported as encouraging biking was good effect of biking on health (median 9 on 1-10 scale), followed by concerns about the environment and saving money (median 8), saving time (median 7), losing weight (median 6), and good system of bike paths in the neighborhood (median 6). Similar factors were listed as the most encouraging to cycling in Useche et al. (2019): physical health and fitness (38%), contribution to environmental sustainability (14%), economy (13%) and time saving (10%).

Respondents were also asked about their age (mean 35), sex (52% male), and work status (90% currently work), and their opinion of if biking reduces traffic (73% agreed).

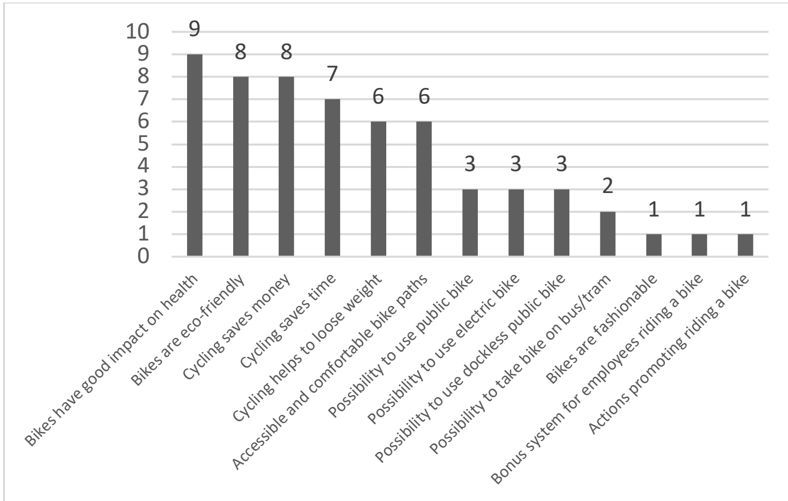

Fig. 4. Median (scale 1-10) ranks of reasons encouraging biking in general.

5.2. Regression results: Overall Use of MEVO e-bikes

The double-hurdle regression model was used to identify factors correlated with the likelihood of renting a MEVO e-bike and, among those who did rent MEVO e-bikes, factors correlated with the frequency of MEVO e-bikes' use. The interpretation of results is given only in general terms, according to the direction (positive or negative) and relative strength of effect sizes because of the manner by which the double hurdle model calculates coefficients in the probit and truncated models simultaneously (Cragg, 1971; Frid et al., 2016).

Two double-hurdle models were performed: one using the frequency of using car, bike, and public transportation before the introduction of MEVO e-bikes (Table 2) and the second using the change in the frequency of use from before to after the introduction of MEVO e-bikes (Table 3) as independent variables. The first set of probit and truncated regressions (Table 2) jointly test for the effects of previous frequency of using car, bike, and public transportation on the likelihood of renting MEVO e-bikes and subsequent frequency of renting MEVO e-bikes. The second set of probit and truncated regressions (Table 3) jointly test for the effects of the increase of use of car, bike, or public transportation on the likelihood of renting MEVO e-bikes and subsequent frequency of renting MEVO e-bikes. Both sets of regressions test for the effect of factors encouraging the use of bikes and discouraging the use of MEVO and bikes in general as well as the set of controls (only reasons with median 3 and above were included).

Table 2. Double hurdle estimation results of the likelihood of renting a MEVO e-bike and the frequency of use – previous transportation mode use (n=488).

	Probit Model – If rented MEVO			Truncated Model – Frequency of renting MEVO		
	Coefficient	p-Value	Signif. Code	Coefficient	p-Value	Signif. Code
Intercept	0.29	0.63		-0.48	0.05	**
Reasons discouraging MEVO use:						
TooFewMevo	0.76	0.00	***	0.06	0.47	
OwnBikeNoMevo	-0.65	0.00	***	-0.31	0.00	***
Reasons discouraging biking in general:						
NoBikePaths	0.01	0.84		0.02	0.13	
CrazyDrivers	0.01	0.77		-0.02	0.11	
NoWeather	0.03	0.31		0.00	0.70	
Safety	-0.05	0.04	**	0.01	0.37	
TooFar	-0.03	0.26		-0.03	0.02	**
Groceries	0.01	0.62		0.02	0.10	*
Shower	-0.03	0.10		0.00	0.71	
Hills	-0.01	0.79		0.02	0.09	*
Health	-0.02	0.58		0.00	0.99	
Reasons encouraging biking in general:						
Green	0.02	0.42		-0.01	0.49	
Money	-0.04	0.16		0.01	0.47	
Time	0.06	0.05	**	0.01	0.24	
Weight	-0.04	0.06	**	0.00	0.62	
BikePaths	0.00	0.94		0.01	0.18	
Controls:						
LessTraffic	0.15	0.35		0.06	0.41	
Male	-0.09	0.56		0.07	0.25	
WorkN	0.22	0.34		0.08	0.41	
Age	-0.02	0.01	**	-0.01	0.11	
Previous use of transportation modes:						
UseBikeFreq1	0.09	0.17		0.04	0.16	
UseBusFreq1	0.13	0.04	**	0.09	0.00	***
UseCarFreq1	0.03	0.75		-0.01	0.81	
Log-Likelihood	-374.54					
R^2				0.174		

***Significance at 1%; **Significance at 5%; *Significance at 10%

Results from our first double-hurdle model show that the metropolitan residents who used public transportation more frequently before the introduction of MEVO e-bikes were more likely to rent a MEVO e-bike and, among those who opt to rent MEVO e-bikes, used them more frequently (Table 2). Additionally, the results from our second double-hurdle model show a negative relationship between the change in using public transportation and the probability of renting a MEVO e-bike (Table 3). Thus, those who decreased their use of public transport were more likely to rent an e-bike. Therefore, some metropolitan residents substituted MEVO e-bikes for public transportation. Previous use or a change in use of cars or private bikes were not significantly related to the likelihood of renting or frequency of renting MEVO e-bikes. Therefore, users of the e-bike BSS were more likely to switch from public transportation but not from cars or regular bikes.

Table 3. Double hurdle estimation results of the likelihood of renting a MEVO e-bike and the frequency of use – change in the transportation mode (n=488).

	Probit Model – If rented MEVO			Truncated Model – Frequency of renting MEVO		
	Coefficient	p-Value	Signif. Code	Coefficient	p-Value	Signif. Code
Intercept	0.78	0.10	*	-0.14	0.48	-0.14
Reasons discouraging MEVO use:						
TooFewMevo	0.83	0.00	***	0.07	0.41	
OwnBikeNoMevo	-0.55	0.01	***	-0.30	0.00	***
Reasons discouraging biking in general:						
NoBikePaths	0.00	0.96		0.02	0.14	
CrazyDrivers	0.01	0.68		-0.02	0.08	*
NoWeather	0.03	0.33		0.00	0.81	
Safety	-0.05	0.05	**	0.01	0.31	
TooFar	-0.04	0.18		-0.02	0.02	**
Groceries	0.01	0.72		0.02	0.07	*
Shower	-0.03	0.18		0.00	0.87	
Hills	0.00	1.00		0.02	0.05	*
Reasons encouraging biking in general:						
Health	-0.02	0.64		0.01	0.67	
Green	0.03	0.32		-0.01	0.63	
Money	-0.04	0.16		0.01	0.63	
Time	0.06	0.04	**	0.02	0.18	

Weight	-0.05	0.04	**	-0.01	0.42	
BikePaths	0.00	0.94		0.01	0.26	
Controls:						
LessTraffic	0.17	0.30		0.06	0.38	
Male	-0.10	0.51		0.08	0.19	
Work	0.24	0.29		0.05	0.65	
Age	-0.02	0.01	***	-0.01	0.03	**
Change from previous transportation modes:						
BikeChange	-0.04	0.57		-0.04	0.14	
BusChange	-0.19	0.04	**	0.03	0.43	
CarChange	-0.04	0.65		-0.05	0.22	
Log-Likelihood	-380.00					
R^2				0.149		

***Significance at 1%; **Significance at 5%; *Significance at 10%

As expected, estimations of other coefficients are very similar in Tables 2 and 3, so we will discuss them together. Metropolitan residents who reported that the main reason discouraging them from the use of MEVO e-bikes is bike availability were significantly more likely to rent an e-bike. For those who actually rented a bike, the availability of bikes was not a significant factor in their frequency of using them. As expected, metropolitan residents who reported that the main reason discouraging them from the use of MEVO e-bikes is owning their own bike were less likely to rent MEVO e-bikes and, for those who did, rented them less frequently. Not feeling safe in traffic as a biker was a significantly discouraging factor in the probability of renting a MEVO e-bike but not significantly related to the frequency of renting for those who did. Metropolitan residents who needed to travel far were renting MEVO e-bikes less frequently. Those who rented MEVO e-bikes and were discouraged from biking in general because of the necessity of traveling high hills rented MEVO e-bikes more frequently. This confirms that e-bike BSSs are attractive services for people who are discouraged from cycling because of the necessity of traveling high hills.

As for the factors encouraging biking in general, those who scored saving time in traffic as a big encouraging factor were more likely to rent a MEVO e-bike. Finally, older people were less likely to rent a MEVO e-bike and, those who did, rented them less frequently (confirming findings by Fyhri and Fearnley (2015)).

5.3. Regression results: Specific use of MEVO e-bikes

We also investigated specific reasons metropolitan area residents rented MEVO e-bikes. Because of the infrequent use of MEVO e-bikes for various destinations, it was impossible to apply a double hurdle model, so the logistic regression was used. Therefore, the results report odds ratios for using a MEVO e-bike for transportation to a particular destination. We use the frequency of using car, bike, and public transportation before the introduction of MEVO e-bikes as independent variables. The results are reported in Table A1 in the Appendix.

The results show that metropolitan residents who more frequently used private bikes before the introduction of MEVO, were more likely to rent a MEVO e-bike to commute to work, a public transportation stop, to eat out, or to service places. Residents who more frequently used public transportation before the introduction of MEVO were more likely to rent a MEVO e-bike to commute to work, a public transportation stop, shopping, and service places, social events, and recreational places. These results again suggest that electric bike-sharing services are not only complementary, but also competitive to public transport. Finally, residents who more frequently used cars before the introduction of MEVO were not significantly likely to rent a MEVO e-bike to commute to any of the destinations, confirming our previous results.

6. Discussion and Conclusions

Many researchers studying traditional and e-bike BSSs have attempted to address the question of whether BSSs substitute travel by other transportation modes (Ricci, 2015; Murphy and Usher, 2015; Li and Kamargianni, 2018; Eren and Uz; 2020; Fishman et al., 2014). While research on traditional BSSs is growing very fast (for reviews see: Eren and Uz, 2020; Fishman, 2016; Médard de Chardon et al., 2017; Sun et al., 2019), the literature on e-bike BSSs is still in its infancy (Langford et al., 2013; Ji et al., 2014; Campbell et al., 2016; He et al., 2019; Guidon et al. 2019, 2020). E-bikes' popularity is growing exponentially, especially in China and Europe, and there is significant literature on the effect of private e-bikes and transport mode substitution (e.g., Astegiano et al., 2019; Bigazzi and Wong, 2020; Fyhri and Sundfør, 2020; McQueen et al., 2020; Fishman and Cherry, 2016). In general, e-bikes are faster, require less effort, and may cover longer distances. Therefore, e-bikes have greater potential to substitute for car trips than traditional bicycles as suggested in some results reported for privately owned e-bikes (Kroesen, 2017). However, the effects of the introduction of e-bike BSSs are still not fully understood and our study contributes to this literature.

The main contribution of the present study is to investigate the transportation mode change after the introduction of a fully e-bike BSS in a big metropolitan area. We use data on transportation mode use before and after the introduction of the system. Overall, the results suggest that the electric bike-sharing services are not competitive to the usage of private cars or private regular bicycles. Metropolitan area residents who reported using a car or bicycle before the system implementation were not significantly more likely to rent an e-bike. This result is similar to the literature on conventional BSSs that reported low car substitution (Ricci, 2015; Murphy and Usher, 2015; Li and Kamargianni, 2018; Eren and Uz; 2020; Fishman et al., 2014) but not on the use of private e-bikes that some studies found to substitute e-bikes for car trips (Sun et al., 2020; Fyhri and Fearnley, 2015; Bjørnarå et al., 2019; Cairns et al., 2017). The electric BSS was also not competitive to the usage of conventional private bicycles. Previous literature on private e-bike's use is not conclusive on the subject. For example, Fyhri and Sundfør (2020) found an increase in bicycle use, whereas Sun et al. (2020) found a slight decrease after obtaining an e-bike. Our results suggest that public authorities do not have to worry that the introduction of the e-bike BSS will be competitive to private bike use.

In contrast, the electric bike-sharing services proved to be used by the same population that used the public transportation system before the e-bike BSS introduction. Our regression results suggest that metropolitan area residents who reported using the public transportation system before the e-bike BSS implementation were significantly more likely to rent e-bikes and use them more often after the implementation. A significant number of residents switched from public transit to shared e-bikes. These results match results from the survey of people in Beijing by Campbell et al. (2016) who found that e-bike BSSs tend to attract users as a bus replacement. It is also consistent with the results from the recent meta-analysis by Bigazzi and Wong (2020) who reported private e-bike mode substitution to be the highest for public transit. Several factors may explain this result. First, travel time could be reduced using e-bike BSSs as many public transportation users need to make transfers to reach their final destination. Public busses, trams, and railway transport reach higher speed than e-bikes, but they need to halt at all stops to pick up and drop other passengers and, in some cases, are slowed down by traffic congestion. Additionally, passengers usually need to walk to the public transportation stops. This makes the e-bike BSSs more efficient and comfortable. MEVO bicycles could be picked up at 660 stations and dropped off either at one of them or at any available parking space (for a small additional fee). Another factor influencing the usage of MEVO instead of public transportation could be its price. Monthly subscription cost was only 10 PLN, which was cheap in comparison to the monthly public transport ticket, that could, depending on the fare, costs from 35 PLN (reduced price for students) to 104 PLN. Traveling by MEVO could also be more comfortable and reliable during the rush hours, when public transport is overcrowded, and some busses and trams do not drive according to their schedules. MEVO was the easiest way to commute to the new neighborhoods where public transport is still unavailable.

E-bike BSS was also used by many metropolitan citizens as a first/last mile transport to public transportation stops. In fact, commuting to the public transportation stops was the top reason for the usage of the e-bike BSS in Tricity. It was used as first/last mile transport by 39% of respondents. Taken together, the electric bike-sharing services proved to be similar to traditional bike-sharing services in transportation mode change: a substitute and/or a complement to public transportation rather than a private car (Ricci, 2015).

Electric bicycles proved to be useful in the hilly region of Gdansk, Sopot, and Gdynia metropolis. Citizens who ranked high being discouraged from cycling in general because of traveling high hills before the implementation of the system rented MEVO e-bikes more frequently than others. These results match previous research on e-bikes (Guidon et al., 2019). Citizens who ranked high biking as a way to save time in traffic were also more likely to rent e-bikes. Still, those who were concerned about safety in traffic as a biker and those who used bikes as a way to lose weight were less likely to rent e-bikes.

Our paper is the first to estimate the probability of renting an e-bike for specific reasons. Our results suggest that metropolitan area residents who used public transport before the MEVO introduction were more likely to rent an e-bike for commuting to work, public transportation stops, shopping, going to obtain services, and going to social events and recreation spots. However, these residents were not likely to rent an e-bike when going to eat out, to keep healthy and feel good, or just for fun, without a specific destination.

We also identified factors encouraging and discouraging people from the usage of BSS and cycling in general. The most important reasons for cycling were positive effects on health, environmental concerns and saving money, saving time, losing weight, and a good system of bike paths in the neighborhood. The main reasons discouraging people from using MEVO and cycling in general were associated with availability of shared bicycles and infrastructure (lack of bike paths), concerns about safety (and car drivers' behavior), and weather conditions. The electric bike-sharing system in the Tricity metropolitan area proved to be very popular among citizens. In terms of the trips per day per bicycle, this first fully electric bike-sharing system in Poland was more efficient than any other system in the country.

6.1. Policy implications

Our results imply potential changes in the mode share after the implementation of the e-bike BSS. The finding that e-bike BSSs substitute public transportation trips is consistent with other studies on regular bicycles. If used as a substitute for public transportation, the electric bike-sharing systems have potential to reduce the strain on the public transportation systems, making busses and trains less crowded during the rush hours. Additionally, during nights or weekends, when providing high quality (e.g., frequent, safe) public transportation is usually not cost efficient, an e-bike BSS may be an attractive solution to consider by public transportation providers. For example, dynamic pricing with differential rates for renting e-bikes at night or on weekends and in certain zones may further increase the substitution between these two transportation modes at desired times or places. It can also be an attractive mean of transportation during the pandemic, when people want to avoid public transportation in fear of infection (Wang and Noland, 2021). Development of electric bike-sharing systems can prevent the switch to cars from public transportation following the COVID-19 pandemic.

Governments may be attracted to the idea of the e-bike (vs. regular bike) BSS as a tool to reduce car trips since they solve reasons people give for not cycling (distance, hills, physically strenuous) and offer many of the same benefits as the car (range, flexibility, rush-hour speed) (Fyhri and Fearnley, 2015). However, our results suggest that an e-bike BSS may not be the tool to reduce the amount of motorized car travel since we found no substitution between cars and e-bikes. Therefore, if the city goal is to reduce car use, our results suggest that the adoption of an e-bike BSS may not be effective. However, city governments may try to leverage e-bike BSS's trips that integrate with public transit to improve urban mobility, and in the long-term, achieve the goals of reducing car trips. One way to do this is to introduce additional policy measures that include e-bikes/bikes-only zones in the city centers or around campuses. Caspi et al. (2020) showed that e-bikes are more popular on university campuses. Another possible solution for e-bike BSSs to achieve their full potential and be a truly competitive alternative to the car could be to focus on policies that aim to improve cycling conditions by smoothing the flow for cyclists by building infrastructure for e-bike riding, charging, and parking. Transportation planners could implement parking pricing for cars while providing free and preferential parking for e-bikes (Ding et al., 2019). Differential speed limits could be introduced. All these measures and a well-constructed advertising campaign may be necessary to encourage a mode shift from a car to an e-bike share.

If a city desires to increase e-bike BSSs usage, increasing the number of bikes close to public transportation stations may be a good strategy. We found that e-bikes were used as a first/last mile solution which underlines the importance of integrating e-bike BSSs with public transport in order to promote their complementary use. This finding may aid public transportation and bike companies to refine the public transportation network and relocate the shared bikes. Transportation planners could increase free parking spots for e-bikes or bicycles near public transportation stops. The appropriate e-bike BSS's infrastructure around public transportation stops together with an adequate public transportation service may be necessary conditions for the scalability of e-bike BSSs. Regular reallocation and visible (free) parking sites around public transportation stops at certain locations and during certain times (e.g., peak hours, night times, weekends) are desired policy implications.

Additionally, our results should inform education and promotion strategies that can enhance citizens' environmental awareness and, therefore, the demand for the development of a sustainable urban transport system. E-bike BSSs promotion policies could focus on the explanation of how to use the e-bikes and target specific age groups.

Finally, the Tricity experience of the introduction and subsequent collapse of the e-bike BSS suggests that policy makers should consider working with the BSSs industry associations to set market standards for the implementation of a BSS that matches the city's long-term transportation goals (Yin et al. 2019). Other policies may include subsidies or incentive programs for e-bike BSS companies.

Adapting these policy recommendations is challenging as cities struggle to provide different modes of transportation in finite space. There is always a question of to whom to give and from whom to take (Hess and Schubert, 2019). Our recommendations need to be taken as just one piece of the puzzle to help address the broader picture in which practices are performed.

6.2. Limitations and further research

As any other research, our study has certain limitations that offer directions for future research. First, it was conducted only in one metropolitan area focusing on one system. Future studies should try to replicate our results to see if they can be generalized to other cities and countries. Transport mode substitutions by the e-bike BSS may depend on local circumstances and available transport alternatives. It is possible that in Tricity car use was already rather inconvenient and many people who could choose an alternative have, making it more difficult for BSSs to attract new trips from car users (Fishman et al. 2014). Time and cost savings of using BSSs may vary substantially depending on the local circumstances. Second, e-bike adoption is still in the early-adopter phase and most popular with younger people. Our results may not be reflective of the behavior of the people in the future when e-bikes become even more popular, especially among older ages. Research on the adoption of e-bike BSSs in different age groups is encouraged. The Tricity adopted the e-bike vs. the regular bike BBS to attract the older population, which turned out to be unsuccessful. Third, we do not study if the e-bike BSSs generated new trips that people would not have undertaken before it was provided. In the experiment conducted by Fyhri and Fearnley (2015), e-bike test users increased their bicycling substantially and significantly more than did the control group, but there is no evidence on the same effect for e-bike BSSs. We leave this question for future research. Fourth, the topic of bicycle infrastructure has been studied before, but we still do not know much about the effects of e-bike infrastructure. The lack of infrastructure and services may have been big reasons for the collapse of the e-BSS in Tricity. Fifth, future studies may want to address traffic accidents after the introduction of e-bike BSSs. E-bikes mix with usual traffic and do not use especially designated bike paths. Inexperienced users may easily rent an e-bike and cause accidents (Cherry et al. 2009). What follows is a possibility of an increase in traffic when a significant part of the population switches from public transport to e-bikes. Six, learning how to use an e-bike takes time (Fyhri and Fearnley, 2015; Fyhri and Beate Sundfør, 2020). It is possible that the long-term effects of introducing e-bike BSSs is different from the short-term that we addressed in this study. Seven, the environmental (including the manufacturing and disposal of e-bike batteries) and health impacts of e-bike BSSs need to be addressed in future studies (McQueen et al. 2020; Cherry et al. 2009). Finally, future research may use big data analysis by using data from mobile shared transportation apps to further understand mode transportation substitutions. For example, examining the timing of trips allows us to learn more about the purposes of trips: commuting or recreation. Overall, e-bike BSSs are a new mode of transportation with a potential to provide an environmentally friendly mode for a broad population, but more research on the subject is still needed.

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Appendix

Table A1: Logit estimation of reasons to rent MEVO e-bikes (n=454)

	MEVO Work		MEVO Bus		MEVO Shop		MEVO EatOut		MEVO Service	
	OR	p-Value	OR	p-Value	OR	p-Value	OR	p-Value	OR	p-Value
Intercept	0.07**	0.01	0.11**	0.04	0.14*	0.08	0.06**	0.01	0.05**	0.02
Reasons discouraging MEVO use:										
TooFewMevo	3.46***	0.00	2.85***	0.00	1.84*	0.07	2.85***	0.00	4.60***	0.00
OwnBikeNoMevo	0.47**	0.04	0.37***	0.01	0.24***	0.00	0.27***	0.00	0.32**	0.02
Reasons discouraging biking in general:										
NoBikePaths	1.03	0.48	1.03	0.43	0.99	0.79	0.96	0.39	1.02	0.68
CrazyDrivers	0.95	0.23	1.02	0.70	1.09*	0.09	1.07	0.17	0.99	0.85
NoWeather	1.05	0.25	1.03	0.54	1.05	0.31	1.04	0.46	0.99	0.84
Safety	0.92*	0.09	0.92*	0.08	0.92	0.11	0.96	0.41	0.97	0.57
TooFar	0.95	0.29	1.01	0.77	0.97	0.53	0.94	0.26	0.96	0.47
Groceries	1.04	0.34	0.98	0.59	1.01	0.79	1.07	0.14	1.07	0.15
Shower	1.01	0.81	1.00	0.89	0.90***	0.01	0.93**	0.05	0.97	0.39
Hills	1.04	0.40	0.98	0.62	1.03	0.47	1.04	0.41	0.95	0.31
Reasons encouraging biking in general:										
Health	0.92	0.23	1.04	0.61	1.04	0.58	0.93	0.35	1.08	0.35
Green	1.03	0.49	0.99	0.87	1.07	0.19	1.07	0.17	0.97	0.53
Money	1.04	0.46	1.03	0.57	0.95	0.34	0.97	0.60	0.99	0.84
Time	1.06	0.27	1.07	0.15	1.04	0.48	1.08	0.15	1.06	0.29
Weight	1.01	0.79	0.98	0.55	0.89***	0.00	0.96	0.35	0.97	0.55
BikePaths	0.98	0.64	1.02	0.59	1.12**	0.01	1.09*	0.06	1.05	0.26
Controls:										
LessTraffic	1.20	0.51	1.40	0.23	0.98	0.94	2.00**	0.03	2.00**	0.03
Male	1.04	0.87	0.99	0.98	1.31	0.31	0.90	0.69	0.94	0.82
Work	1.49	0.32	1.11	0.79	1.37	0.47	1.56	0.32	1.04	0.93
Age	0.98	0.17	0.97**	0.05	0.96**	0.02	0.97**	0.03	0.95***	0.00
Previous use of transportation modes:										
UseBikeFreq1	1.47***	0.00	1.22*	0.07	1.12	0.34	1.31**	0.02	1.40***	0.01
UseBusFreq1	1.28**	0.03	1.31**	0.01	1.25*	0.06	1.16	0.22	1.31**	0.03
UseCarFreq1	1.10	0.48	1.01	0.92	1.10	0.50	1.10	0.50	1.09	0.56
AIC	550.38		557.78		491.23		497.65		467.86	
Log-Likelihood	-251.19		-254.89		-221.62		-224.83		-209.93	

***Significance at 1%; **Significance at 5%; *Significance at 10%

Table A1 cont.: Logit estimation of reasons to rent MEVO e-bikes (n=454)

	MEVO Social		MEVO Rec		MEVO Health		MEVO Fun	
	OR	p-Value	OR	p-Value	OR	p-Value	OR	p-Value
Intercept	0.20	0.14	0.13*	0.06	0.07*	0.07	1.34	0.82
Reasons discouraging MEVO use:								
TooFewMevo	4.47***	0.00	2.50***	0.01	2.00	0.10	1.22	0.57
OwnBikeNoMevo	0.39**	0.02	0.34***	0.01	0.11***	0.01	0.16***	0.00
Reasons discouraging biking in general:								
NoBikePaths	1.03	0.54	1.07	0.12	1.03	0.63	1.05	0.33
CrazyDrivers	0.97	0.53	1.07	0.20	1.00	0.97	1.06	0.31
NoWeather	1.05	0.31	1.05	0.30	1.05	0.42	1.08	0.13
Safety	0.91*	0.06	0.93	0.12	0.99	0.93	0.92	0.13
TooFar	0.97	0.53	1.00	0.97	1.10	0.12	0.93	0.24
Groceries	1.08*	0.07	0.99	0.85	0.94	0.29	0.97	0.55
Shower	0.93*	0.07	0.92**	0.03	0.93	0.16	0.94	0.15
Hills	0.99	0.77	0.98	0.69	1.03	0.66	1.05	0.34
Reasons encouraging biking in general:								
Health	0.96	0.55	0.98	0.74	1.05	0.63	1.03	0.69
Green	1.10*	0.05	0.98	0.75	1.01	0.92	0.92	0.14
Money	1.00	0.98	1.04	0.50	1.03	0.71	0.99	0.86
Time	1.08	0.13	1.04	0.43	1.06	0.40	1.03	0.59
Weight	0.93*	0.05	0.94	0.11	1.00	0.98	0.99	0.80
Bike Paths	1.07	0.13	1.06	0.16	1.07	0.26	1.08	0.15
Controls:								
LessTraffic	1.52	0.16	1.54	0.14	0.93	0.84	0.82	0.56
Male	0.84	0.50	0.68	0.14	1.14	0.69	0.92	0.79
WorkN	1.13	0.77	1.30	0.53	0.63	0.37	0.63	0.30
Age	0.96***	0.01	0.98	0.19	0.98	0.21	0.95***	0.01
Previous use of transportation modes:								
UseBikeFreq1	1.29**	0.03	1.11	0.36	0.87	0.31	0.90	0.40
UseBusFreq1	1.31**	0.02	1.43***	0.00	1.24	0.15	1.23	0.13
UseCarFreq1	0.89	0.42	0.94	0.67	0.95	0.77	1.04	0.80
AIC	509.83		523.06		347.32		399.83	
Log-Likelihood	-230.91		-237.53		-149.66		-175.92	

***Significance at 1%; **Significance at 5%; *Significance at 10%