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Analyses of topical policy issues

Increasing the use of public bicycles: Efficiency and demand[☆]

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ABSTRACT

Millions of people travel every day by car in cities around the world, with daily mobility being one of the main contributors to CO_2 emissions. Bicycle-sharing systems are a mobility alternative to cars that may help to reduce CO_2 and GHG emissions. We analyze a public bike-sharing service (BIZI, in Zaragoza, Spain, May 2008–August 2019, 24 million uses), from the perspective of both efficiency and demand profiles, to determine whether the use of bicycles in the city can be increased. We study the evolution of the use of the BIZI service, showing that efficiency increased rapidly at first and reached an optimum value after the first two years. Using regression models, we characterize the groups that use this service the most and relate bicycle demand to factors such as weather conditions, number of bike lanes, and service extensions. Our analysis allows us to characterize the demand for BIZI as being subject, primarily, to weather conditions. This factor may reduce or boost the demand for this kind of service, which may help bike-sharing firms to decide on possible locations.

1. Introduction

Millions of people travel every day in cities around the world, from home to work, from home to school, and on other journeys. The Resolution of the European Parliament, of December 2, 2015, on Urban Mobility (2014/2242, INI) notes that the mobility of the European population is mostly based on the use of private vehicles (50% use private vehicles daily, while 16% use public transit and only 12% use bicycles). The same Resolution also acknowledges that daily mobility generates around 25% of CO_2 emissions in Europe. Thus, local and national governments are asked to take the necessary measures to promote alternative and sustainable modes of mobility, because the use of public transit and physical modes of transport have been shown to be important in CO_2 and Greenhouse Gas (GHG) reduction (Chapman, 2007; Gossling and Choi, 2015; Holian and Kahn, 2015). In this context, the implementation of bike-sharing systems may represent a mobility alternative to private cars that will help to reduce CO_2 and GHG emissions, and local governments/city halls in cities worldwide have implemented bike-sharing systems.

One such case is the bike-sharing service of the city of Zaragoza (Spain), called "BIZI", a public bicycle rental service which the Zaragoza City Council makes available to users. It is an economical, comfortable, and sustainable means of transport, and was launched in May 2008 with the aim of increasing the use of the bicycle in the city. Since then, there have

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been significant changes in the city. Extensions have been made in the number of bicycle stations available, going from 30 stations in 2008 to 130 in May 2011. In addition, the Zaragoza city council has dedicated resources to the development of bike lanes throughout the city, with the aim of allowing safe circulation throughout the city. Additionally, all one-way streets have a maximum speed limit of 30 km/h, which facilitates coexistence between cyclists and motor vehicles. All these actions are aimed at improving and increasing the use of bicycles in the city, and a greater and better use of the service.

Within this framework, we analyze daily data for the BIZI service from May 2008 to August 2019, which provides information on more than 24 million uses by citizens. Data on the service over time allows us to analyze the efficiency of the system, considering the normalized difference between dockings and undockings (picking up and leaving the bicycles at the station), and we find that efficiency (adjustment between demand and supply of the service) increased rapidly until reaching an optimum value after two years. This two-year period serves as a reference value for other cities considering similar bike-sharing systems.

The level of detail of the data, that records the number of uses at the calendar-day level, allows us to relate the number of uses of the BIZI service to the number of stations and the distance (in kilometers) of bike lanes available in the city. We analyze whether the expansion of the number of stations, and the increase in kilometers of bike lanes, are related to a greater number of uses of the service, and to a decrease in the time required for the actual journeys. We find that the expansion of the system through new stations is related to an increase in the number of uses and a decrease in the average travel time of each use. The expansion of bike lanes is also related to a decrease in the duration of trips. This analysis is of interest, as it shows that good planning and a greater availability of stations and bike lanes can boost the use of bicycles in the city, to the detriment of other modes of transport, such as the private car.

We link the day of use with the weather conditions on that day. Zaragoza has a semi-desert, continental Mediterranean climate, typical of the Ebro valley, which gives weather conditions in Zaragoza enough variation over the year to be a natural experiment into how weather affects the demand for the bike-sharing system.[1] We find that higher average temperatures, volume of rain, average wind speed, stronger gusts of wind, and the greater number of hours of sunshine are all negatively related to the number of uses of the service, while higher minimum and maximum temperatures during the day are all related to greater use. Regarding the duration of trips, a lower average temperature and stronger gusts of wind are related to a shorter duration of trips, while higher minimum and maximum temperatures, volume of rain, and average wind speed are all related to a longer duration of trips. These results may be helpful for bike-sharing firms trying to decide where to locate their services, since in locations with comparatively worse weather conditions the demand for bike-sharing services may be relatively low, which may be detrimental to investing in such systems.

We contribute to the literature on the evaluation of the efficiency of bike-sharing systems (Hyland et al., 2018; Hong et al., 2020; Caggiani et al., 2021). Our analysis allows us to analyze its efficiency, showing how much time the service needs to reach optimal efficiency. Second, we contribute to the literature on how planning and infrastructure is related to the use of bike-sharing systems. Prior research has analyzed strategic planning, and infrastructures related to cycling (Rietveld and Daniel, 2004; Doran et al., 2021), and to sustainable transport in general (Knowles, 2021). We acknowledge the importance of planning and availability of bike lanes and docking stations as a way to boost use. Third, we contribute to the literature on the relationship between weather conditions and the use of bicycles, with a focus on the use of bike-sharing services. Existing studies have shown that climatic conditions are related to the individual use of bicycles (Shannon et al., 2006; Guo et al., 2007; Cools et al., 2010; Flynn et al., 2012; Böcker et al., 2013; Lee and Pojani, 2019) and factors such as rain, wind, and heat are related to reduced use of this and other active means of transport.

The rest of the paper is organized as follows. In Section 2, we describe the data, present analysis of the number of uses and the duration of journeys, and present the efficiency analysis. In Section 3, we show our analysis of the factors affecting the use and duration of bike trips, and Section 4 outlines our main conclusions.

2. The BIZI service and its efficiency

The data for the BIZI service in the city of Zaragoza (Spain) were obtained through the #OpenUrbanLab, the Zaragoza Open Source R&D laboratory, which is a physical and digital space for urban innovation that allows the downloading and use of a range of data (https://openurbanlab.com/). The BIZI service data used here covers the period from the start-up in May 2008 to August 2019, and includes 24,346,082 separate uses, covering each day of the period considered. We have information about the day of use, the origin and destination stations, the duration of the journey, and the time of day. Additionally, information is available on the users' year of birth (grouped into 5-year cohorts) and gender.

Fig. 1 presents the number of total uses of the service for each day of the period considered. We can observe the evolution of the number of daily uses of the BIZI service. We include an adjustment function of a locally adjusted regression, to reduce the variability of the number of uses (Cleveland, 1979). At the beginning of the period there was

[1] Zaragoza is characterized by great contrasts between the seasons, since in winter it is very cold with strong frosts, and in Summer it is quite hot, often exceeding 35 Celsius degrees, and sometimes as high as 40 or more. Being a semi-desert climate, it does not receive the influence of the sea and rain is scarce throughout the year, being concentrated during spring and autumn (May is usually the wettest month, statistically speaking). In addition, the presence of the "cierzo", a northwesterly wind that blows with differing intensity, is characteristic of the city. In winter, 'el cierzo' provides a sensation of cold (the so-called 'wind chill') much greater than that indicated by a thermometer, while in summer it produces the opposite effect, cooling from the suffocating heat.

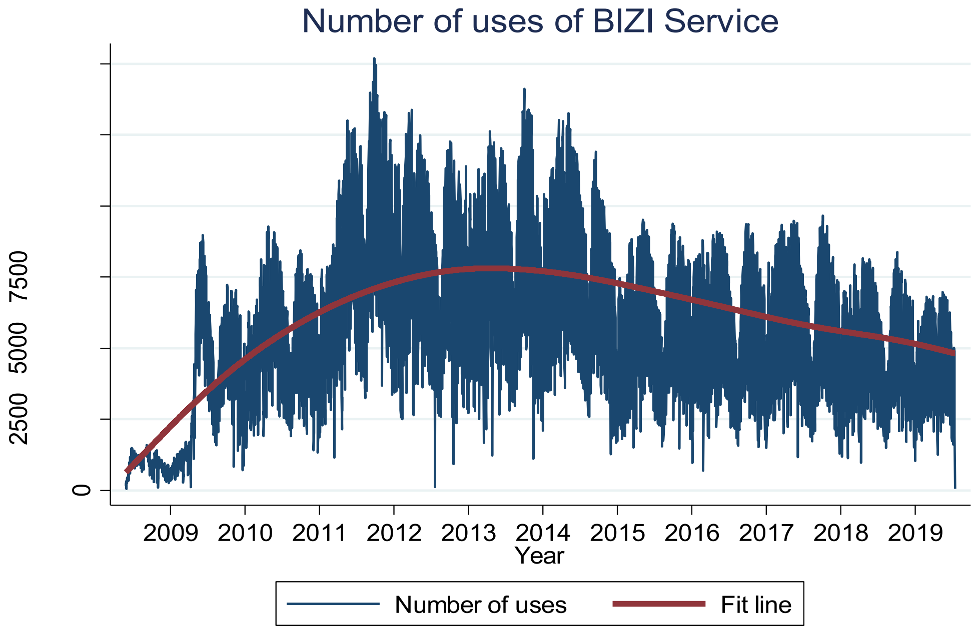

Fig. 1. Evolution in the number of uses. Notes: The number of uses refers to the May-2008 to August-2019 period, and are available in the Open Urban Laboratory. The number refers to the number of total daily uses. We use a connected line graph.

a large increase in the daily use of the service, going from around 1300–1500 uses per day in 2008 and early 2009 to around 15,000 daily uses by late 2011 and early 2012. A significant surge in the number of daily uses in the middle of 2009 probably corresponds to the expansion of the number of stations, from 30 to 70 stations.[2] The number was expanded again in October 2009 and May 2011, which could explain the accumulated increase in the number of uses in that period.

However, since the peak years of 2011 and 2012, the number of daily uses has been falling gradually, to the point that, at the end of the period (2019), daily uses fell to around 6000–6500. This decline could reflect a change in the city in terms of mobility, representing an advance in terms of sustainable mobility — the inauguration of the tram on April 19, 2011, and its second phase in March 2013. In fact, the adjustment function shows that the maximum number of daily uses of the tram was reached in 2013 and the daily uses of the BIZI service have followed a decreasing trend since then. Furthermore, the BIZI service has evolved in the context of other, similar services of bike-sharing, and/or e-scooter sharing, which have more recently been implemented in the city, and could also explain the decreases in the number of uses of the BIZI service.

Fig. 2 shows the evolution of the average time of journeys of the BIZI service.[3] We also include in the figure a locally fitted regression to reduce the fluctuations of the duration variable. Here we observe a decreasing trend in the duration of the journeys. Thus, while in 2009 the average duration was around 12 min, at the end of the period, the average duration of the journey was around 10 min. The adjustment function clearly reflects this decreasing trend in journey times. The expansion in the number of BIZI stations is obviously a factor, since the distance between available stations — and therefore the time needed to go from point A to point B is reduced. The development of bike lanes in the city (see Fig. 3 for a description of the Km of bike lanes available in the city) can also be a key factor, since these lanes prioritize cyclists and improve efficiency in terms of bicycle traffic, reducing travel times.[4]

We next analyze the personal characteristics of the users of the BIZI service. Here, we recognize that the information available is scant, since data is only available on gender (male or female) and age (measured in cohorts of 5 years). Table 1 presents the distribution of gender and age, on average, over the years and for each year. The birth cohorts have been

[2] Table A.1 in the Appendix presents the dates of the extensions, as well as the number of stations available in each phase. There are three distinct phases: implementation, in which the first 30 stations were established; expansion, which ended in April 2009 with the commissioning of 40 more stations; and extension, in May of 2011, which added 60 more stations.

[3] It is necessary to point out that an annual fee is paid for the use of the BIZI service (the current annual fee is €36.93), which gives the right to use bicycles for journeys of a maximum of 30 min. From there, an increase of 52 cents per half-hour of use is charged, up to 2 h, after which time there is a penalty of €3.16 euros per hour, up to a maximum of €200 if 24 h elapse. It appears that users of the BIZI service have adjusted well to the 30-min limit.

[4] It should be noted that the strong increase has occurred throughout the study period, since the number of kilometers available has been expanded by more than 100%, compared to the beginning of the analysis period, despite having several years in which the increases were practically nil. The bike lane data is presented annually, without specifying the specific day on which it could begin to be used, so that the extension is understood to have taken place on January 1 of each year.

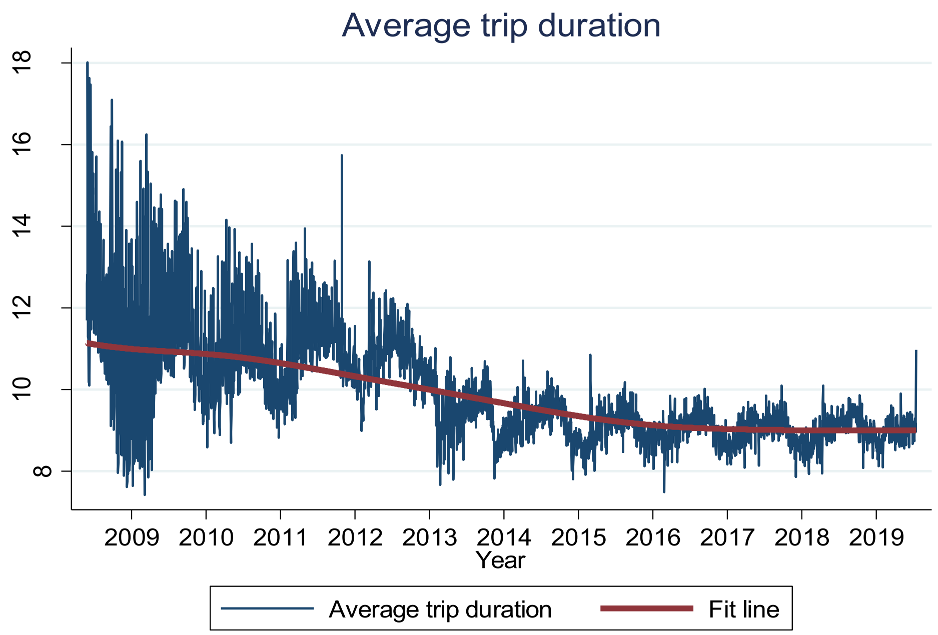

Fig. 2. Evolution of the duration of BIZI trips. Notes: The analysis data refer to the May-2008 to August-2019 period, and are available in the Open Urban Laboratory. The duration is based on the difference between the pick-up time and the drop-off time of the bike at the station. We use a graph of connected lines.

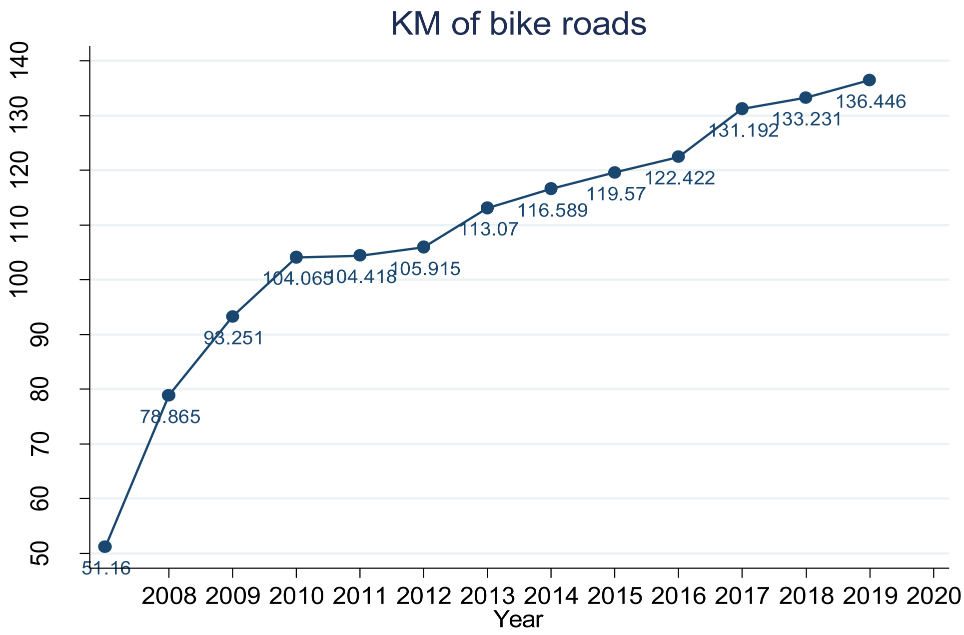

Fig. 3. KM of bike lanes in Zaragoza.
Source: Self-made from information available at Zaragoza City Hall.

pooled for those born between 1900 and 1950, between 1950 and 1990, and 1990 onward. We observe that the users of the service are mostly (62.25%) men. There is no clear trend in terms of use by men or women, so we cannot say that use of the service has increased among either gender during this period. Regarding the age of users, they mostly belong to the group born between 1950 and 1990. However, a trend is observed in which the use of this service has decreased among users born before 1990, and has increased among those born after 1990, indicating a relative increase in the number

Table 1
Gender, age, and duration, by year.

	Men (vs. Women)	Cohort 1900–1950	Cohort 1950–1990	Cohort 1990–2010	Trip duration
Average	62.25%	7.29%	79.05%	13.67%	11.48
2008	61.77%	10.08%	88.28%	1.64%	14.75
2009	60.70%	9.58%	88.01%	2.41%	13.41
2010	61.53%	9.04%	87.32%	3.64%	12.63
2011	60.69%	8.23%	84.58%	7.19%	12.75
2012	62.16%	8.11%	82.31%	9.58%	12.44
2013	62.51%	7.54%	79.66%	12.79%	11.01
2014	62.90%	7.00%	76.96%	16.04%	10.80
2015	64.71%	6.78%	75.77%	17.44%	10.55
2016	63.22%	6.06%	74.26%	19.68%	10.54
2017	62.85%	5.79%	72.77%	21.44%	10.48
2018	61.37%	5.34%	71.00%	23.66%	10.50
2019	61.34%	5.25%	71.30%	23.45%	10.40
Observations	24,346,082		24,346,082		24,346,082

Notes: The analysis data refer to the May-2008 to August-2019 period, and are available at the Open Urban Laboratory. Duration is based on the difference between the pick-up time and the drop-off time at the station.

Table 2
Statistics of the weighted degree distributions.

	Weighted out-degree	Weighted in-degree	Weighted degree
Mean	188,625	188,625	377,250
Standard error	8384	9069	17,358
Median	171,666	178,283	346,473
First quartile	113,528	108,519	213,337
Third quartile	236,463	239,289	475,025
Variance	9,138,927,330	10,693,165,555	39,170,704,956
Standard deviation	95,598	103,408	197,916
Kurtosis	1.321	2.292	1.822
Skewness	1.021	1.136	1.087
Range	505,950	608,651	1,114,601
Minimum	44,994	30,381	75,375
Maximum	550,944	639,032	1,189,976
Sum	24,521,275	24,521,275	49,042,550
Count (stations)	130	130	130

Notes: The columns correspond to the weighted out-degree (number of undockings at the station), in-degree (dockings), and degree (total number of uses of the station), respectively.

of users born after 1990, to the detriment of those born before 1990.[5] The average duration of journeys, is 11.48 min, although a steady decrease is observed in this average from 14.75 min in 2008 to 10.40 min in 2019 (consistent with Fig. 2).

We now analyze the efficiency of the system. To that end, we show in Fig. 4 the degree of distribution of the system, where blue columns correspond to the weighted degree (*i.e.*, the number of trips that either began or ended at the corresponding station), and the red line represents the (weighted) in- minus out-degree (*i.e.*, the number of trips finished at the station minus those that started from it), which constitutes a measure of the station's bicycle surplus. The lower the absolute surplus, the more efficient the station. High absolute bicycle surpluses imply (i) a lower availability for users, and (ii) a higher cost associated with the redistribution of the bicycles by the concession company. Note that there is no significant correlation between the degree and the absolute value of the surplus (Pearson's correlation coefficient $\rho = 0.24$), indicating that the most-used stations have better performance than those with less demand. Table 2 presents the descriptive statistics of the weighted degree distributions, which turns out to be heterogeneous: a relative median of 0.29 times the maximum value indicates the existence of a few highly connected nodes (hubs) and a majority of secondary nodes.

To study the evolution of the system, we have performed a temporal analysis of the system, splitting the system N into slices *N(t)* of constant time lapse. Each slice *N(t)* consists of the same nodes as the original system N, the stations, while the weight of each link of *N(t)* is proportional to the number of trips from the origin to the destination, measured during the considered period. The final goal is to reveal possible self-organization processes that would involve a positive increment of efficiency. Let us define the inefficiency of the system in period t as the average normalized absolute value of the in-minus the out-degree (*i.e.*, the normalized difference between dockings and undockings) averaged over all the

5 We explore the number of users pertaining to each group in the years 2008 and 2019. While in 2008 there were 420 users born before 1990 and 159 users born after 1990, in 2019 there were 961 users born before 1990 and 590 users born after 1990. So, while those born before 1990 represent 72% (i.e., 420/(420+159)) of total users, in 2019 those born before 1990 represent 62% (i.e., 961/(961+590)) of total users.

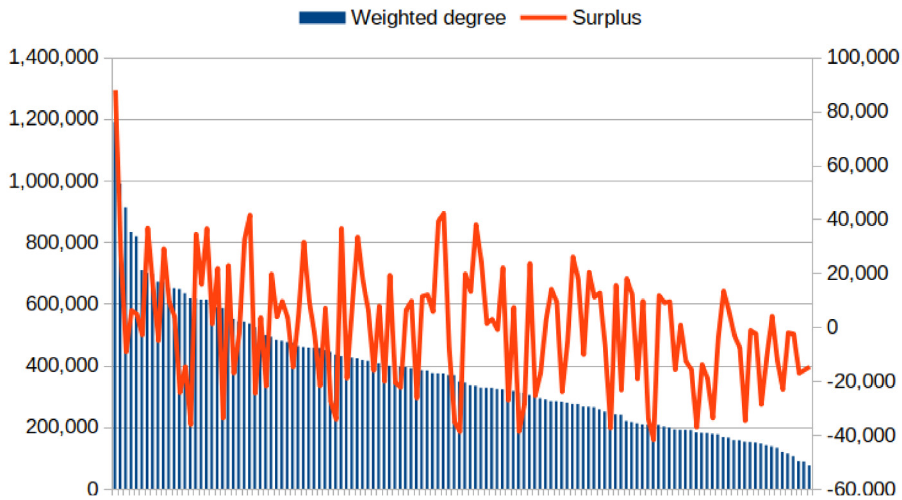

Fig. 4. Degree distribution. Notes: Stations are sorted according to their use, i.e., the total weighted degree of the nodes. Blue columns (left scale) correspond to the total weighted degree of the node, i.e., undockings and dockings. Red line (red scale) represents the difference between the weighted in- and out-degree, i.e., the number of dockings minus the number of undockings. . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

operative stations, during the course of a week. Inefficiency can take values from 0 to 1. We define the efficiency of the system as the complement to efficiency:

$$Efficiency\,(t) = 1 - \frac{\sum_i \left|\left(k_i^{in} - k_i^{out}\right)\right| / max\left(k_i^{in} - k_i^{out}\right)}{number\ of\ operative\ stations} \tag{1}$$

Fig. 5 displays the evolution of the efficiency for different period lengths, namely days and weeks. As shown, although efficiency fluctuates in all time scales, it exhibits a clear trend to increase over time until reaching an optimum value after two years, with this result being robust against the time scale choice. In the first month, the daily efficiency fluctuates around a mean value of 0.986 ($\sigma = 0.012$); from the second year, the mean efficiency is 0.998 ($\sigma = 0.0018$). Although the mean value increment is not so impressive, the significant decrease of the standard deviation over time indicates a clear reduction in the occasional imbalance between demand and use of the stations. That means that the system self-organizes toward an efficiency close to one. A plausible explanation is that some users adapt their trip schedules to the availability of bicycles at the stations throughout the day.

3. Factors associated with the number of uses and trip duration of the BIZI service

In this Section, we relate the use of the BIZI service to the following factors: extensions of the number of stations, kilometers of bike lanes in the city, socio-demographic characteristics of the population, and the weather conditions of the city. We have obtained the daily climatological variables of the city of Zaragoza from the Spanish Meteorological Agency (AEMET). These climatological variables are the maximum, minimum, and average temperature, the hours of sunshine, the maximum wind speed, and its average value, all in daily values for the city of Zaragoza. (We have daily information on these variables, and for reasons of space we do not show their values, although they are available on request.)

We want to analyze the factors related to both the number of uses (e.g., count of the number of uses per day) and the duration of the journey, so we must take into account that each variable is different, and the methodologies (econometric model used) will differ. Regarding the number of uses, we want a count data variable, as we are considering the number of uses per day. To that end, the model to be estimated is a binomial negative type of model, used to estimate regression models when the variable is a non-negative counting variable (Cameron and Trivedi, 2013). Said regression is a type of generalized linear model in which the response variable has a Poisson distribution, and the logarithm of its expected value can be modeled by a linear combination of unknown parameters; that is, the logarithm is the canonical link function. The binomial negative regression assumes that the dependent variable (e.g., y) has a Poisson distribution, and the expectation (and variance) of y given x is: $\lambda = E\,(y|x) = e^{x\prime\beta}$. Therefore, $log\,(E\,(y|x)) = x'\beta$.[6] This model is estimated with the following

[6] An alternative to the binomial-negative model, that is similar, is the Poisson model that assumes that the counting variable is generated by a process similar to a Poisson distribution, and its mean is equal to its variance. However, the application of the Poisson regression model can give rise to the phenomenon known as over-scattering, as in certain data sets, a variance higher than expected is observed, and in this case the Poisson model would not be adequate. To try to solve this problem, the negative binomial model assumes that the counting variable is generated by a process similar to Poisson, except that the variation is allowed to be greater than that of a true Poisson. The results when we use the Poisson model are robust to the results shown in Table 3.

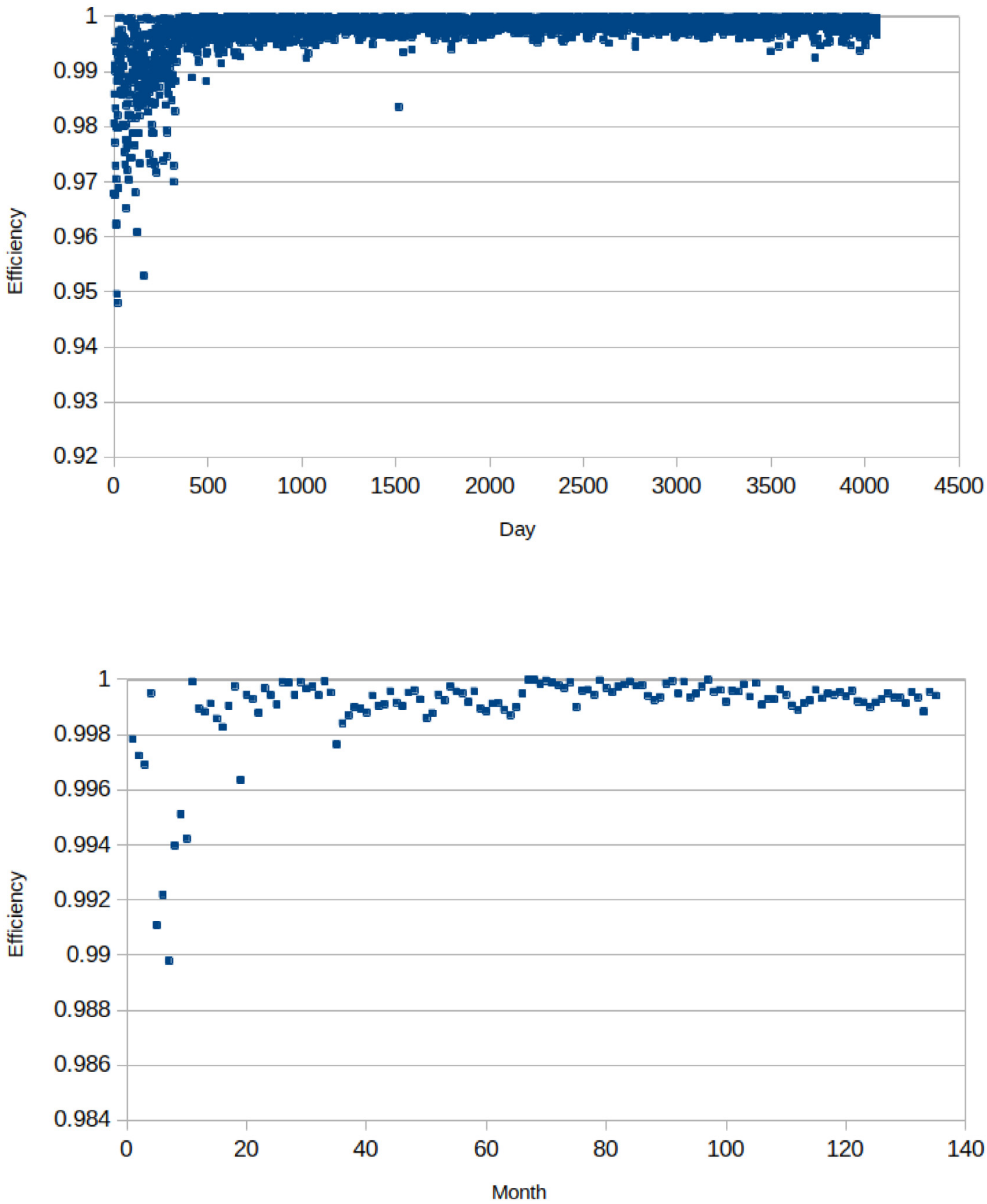

Fig. 5. Evolution of the efficiency of the system.

explanatory variables: male (1 if male, 0 if female), cohort 1900–1950 (1 if born between 1900 and 1949, 0 otherwise), cohort 1950–1990 (1 if born between 1950 and 1989, 0 otherwise), number of stations, number of kilometers of bike lanes in the city, and weather variables that collect the maximum, minimum, and average temperatures, the hours of sunshine, the maximum speed of the wind and its average value, the price of the annual subscription to the service, and the penalty fee for exceeding the 30-min limit established by the operator of the system.[7]

[7] The price of the annual subscription to the Service, and the penalty fees for exceeding the 30-min limit are shown in Table A.2 of Appendix. We include the price of the subscription to the Service because changes in prices could affect those who use the Service; for instance, a higher price may mean that potential users with lower relative incomes do not subscribe to the Service, who may be at the same time those in most need of the Service, since they cannot afford the alternatives (taxi, car, bus). Regarding the penalty fees, the average duration of the ride is often conditioned

Table 3
Factors associated with the use of the BIZI Service.

Variables	Number of uses Binomial negative	Duration OLS
Men (vs. women)	0.002***	−0.069***
	(0.000)	(0.000)
Cohort 1900–1950	−0.004***	0.224***
	(0.000)	(0.001)
Cohort 1950–1990	−0.003***	0.079***
	(0.000)	(0.000)
Number of stations	0.010***	0.001***
	(0.000)	(0.000)
Km of bike lanes	0.017***	−0.004***
	(0.000)	(0.000)
Average temperature in day	−0.004***	−0.013***
	(0.000)	(0.003)
Average rain in day	−0.001***	0.001***
	(0.000)	(0.000)
Minimum temperature in day	0.007***	0.007***
	(0.000)	(0.002)
Maximum temperature in day	0.001***	0.008***
	(0.000)	(0.002)
Average wind speed	−0.000***	0.001***
	(0.000)	(0.000)
Maximum wind speed	−0.001***	−0.001***
	(0.000)	(0.000)
Number of hours of sun	−0.001***	0.002***
	(0.000)	(0.000)
Year	0.082***	−0.009***
	(0.000)	(0.000)
Price of annual subscription	0.017***	−0.001***
	(0.000)	(0.000)
Penalty fee	0.002***	0.787***
	(0.000)	(0.005)
Constant	−161.550***	20.875***
	(0.138)	(0.439)
Number of observations	24,346,082	24,346,082
(Pseudo) R squared	0.217	0.065

Notes: Robust standard errors in parentheses. The analysis data refer to the May-2008 to August-2019 period, and are available at the Open Urban Laboratory. The duration is based on the difference between the pick-up time and the drop-off time at the station. * Significant at the 10% level ** Significant at the 5% level *** Significant at the 1% level.

Regarding the duration of the journey, the variable is a continuous variable that can take any positive value, and therefore we apply an Ordinary Least Squares (OLS) model, specified as follows:

$$T_i = \mu + \beta X + \varepsilon_i \tag{2}$$

where T_i represents the journey time for the "ith" observation. X is a vector of variables and includes the same explanatory variables that are included in the Poisson and Negative Binomial models. ε_i is the regression error term, and the standard errors are robust.

Column 1 of Table 3 shows the results of estimating the Poisson and Negative Binomial models, respectively. First, we observe that for men, the number of BIZI stations, the number of kilometers of bike lanes, and the maximum and minimum temperature of the day, are all related to a greater number of uses. Users born between 1900 and 1990 (compared to those born after 1990), the average temperature of the day, the average rainfall of the day, the average speed and gusts of wind, and the number of hours of sunshine are all negatively related to the use of the service.

Column 2 of Table 3 presents the results for the estimated OLS model. For men, the kilometers of bike lanes, the average temperature of the day, and the existence of gusts of wind is negatively related to duration. For users born before 1990, the average rainfall of the day, the maximum and minimum temperature of the day, the average wind speed and the number of hours of sunshine are all related to longer journey times. The results for the number of stations may be counterintuitive, since we find that a greater number of BIZI stations is related to longer travel times, although, logically, more stations should result in shorter travel times. We interpret this result as that those who previously did not use this service because there were no stations near them, began using the service as new stations appeared — especially to go from the center

on the pricing policy of the operator of the system. For example, in some countries, traveling up to 20 min is often free of charge (Kwiatkowski, 2021).

Table A.1
Number of BIZI stations.
Source: Self-made with information available at Zaragoza City Hall.

Extensions	Date	New stations	Total
Start	2008	–	30
First extension	April-2009	40	70
Second extension	October-2009	30	100
Third extension	May-2011	30	130

Table A.2
Price of annual subscription and penalty fee for uses of +30 min.
Source: Self-made with information available at Zaragoza City Hall.

	2008–2010	2010–2011	2011	2012–2014	2014–2022
Annual subscription	20.00 €	25.00 €	35.00 €	35.89 €	36.93 €
Penalty fee					
>30 min				0.51 €	0.52 €
>1 h				1.02 €	1.04 €
>1,5 h				1.53 €	1.56 €
>2 h				4.60 €	4.72 €
>3 h				7.67 €	7.88 €
>4 h				10.74 €	11.04 €
>5 h				13.81 €	14.20 €
>6 h				16.88 €	17.36 €
>7 h				19.95 €	20.52 €
>8 h				23.02 €	23.68 €
>9 h				26.09 €	26.84 €
>10 h				29.16 €	30.00 €
>11 h				32.23 €	33.16 €
>12 h				35.30 €	36.32 €
>13 h				38.37 €	39.48 €
>14 h				41.44 €	42.64 €
>15 h				44.51 €	45.80 €
>16 h				47.58 €	48.96 €
>17 h				50.65 €	52.12 €
>18 h				53.72 €	55.28 €
>19 h				56.79 €	58.44 €
>20 h				59.86 €	61.60 €
>21 h				62.93 €	64.76 €
>22 h				66.00 €	67.92 €
>23 h				69.07 €	71.08 €
>24 h				200.00 €	200.00 €

to the periphery of the city or vice-versa (https://openurbanlab.com/2020/07/14/visualizacion-zaragoza-bici/), which may be compatible with the increase in travel time.

The price of the annual subscription and the penalty fees are positively related to the number of uses. Furthermore, the price of the annual subscription is negatively related to the duration of the trip, while the penalty fee is positively related to the duration. These results may reflect the fact that demand for the Service has increased in recent years, which has led to an increase in the price of the annual subscription, and to a need to introduce a penalty fee in order to have a better control of the Service (note that the penalty fee was introduced in 2012).

4. Conclusions

The BIZI Zaragoza service is a public bicycle rental service which the Zaragoza City Council makes available to users as an economical, comfortable, and sustainable means of transport. The service was launched in May 2008, with the aim of increasing the use of the bicycle in the city. Given the daily use of this service, knowing the needs and demands of the users is essential for its proper functioning. We show that efficiency increased over time until reaching an optimum value after two years of operation. We find that being a man, the availability of BIZI stations, kilometers of bike lanes, and higher temperatures are all related to greater use of the service. In addition, younger individuals use the service more, and it is used less on rainy and windy days and with fewer hours of sunshine (i.e., winter). All of the above factors are negatively related to the duration of trips. Longer journey times are related to older users, the average rainfall of the day, the maximum and minimum temperatures of the day, the average wind speed, and the number of hours of sunshine.

Our results are consistent with prior studies analyzing the relationship between climatic conditions and bicycle use. Bike-sharing firms may use this information to decide their investments in different locations, where good weather conditions may drive such investments. Furthermore, local governments could also consider whether or not to subsidize bike-sharing firms in those cases where weather conditions may impose limits to investment.

Furthermore, knowing how the factors controllable by the city council are related to the use of this service is important from the point of view of sustainable mobility, since a greater number of BIZI stations and more kilometers of bike lanes are related to a greater use of this service, and therefore have greater importance in terms of sustainable mobility in the city of Zaragoza. The fact that the number of uses increased with the number of bike lanes calls for policy interventions aimed at boosting the use of such services, and posits infrastructure planning as a key factor toward sustainable mobility and, ultimately, growth. Knowing the socio-demographic characteristics of users can serve to guide the development and implementation of MaaS (Mobility as a Service) platforms, whenever a set of mobility services is offered (bicycles, car-pooling, bus, tram) at an economic price.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

See Tables A.1 and A.2.

References

Böcker, L., Prillwitz, y J., Dijst, M., 2013. Climate change impacts on mode choices and travelled distances: a comparison of present with 2050 weather conditions for the Randstad Holland. J. Transp. Geogr. 28, 176–185.
Caggiani, L., Camporeale, R., Hamidi, Z., Zhao, C., 2021. Evaluating the efficiency of bike-sharing stations with data envelopment analysis. Sustainability 13 (2), 881, https://doi.org/10.3390/su13020881.
Cameron, A.C., Trivedi, P.K., 2013. Regression Analysis of Count Data, second ed. Cambridge University Press, New York.
Chapman, L., 2007. Transport and climate change: a review. J. Transp. Geogr. 15, 354–367.
Cleveland, W.S., 1979. Robust locally weighted regression and smoothing scatterplots. J. Am. Stat. Assoc. 74 (368), 829–836.
Cools, M., Moons, E., Wets, G., 2010. Assessing the impact of weather on traffic intensity. Weather Climate Soc. 2 (1), 60–68.
Doran, A., El-Geneidy, A., Manaugh, K., 2021. The pursuit of cycling equity: A review of Canadian transport plans. J. Transp. Geogr. 90, 102927.
Flynn, B.S., Dana, G.S., Sears, J., Aultman-Hall, L., 2012. Weather factor impacts on commuting to work by bicycle. Prevent. Med. 54 (2), 122–124.
Gossling, S., Choi, A.S., 2015. Transport transitions in Copenhagen: Comparing the costs of cars and bicycles. Ecol. Econom. 113, 106–113.
Guo, Z., Wilson, N.H.M., Rahbee, A., 2007. Impact of weather on transit ridership in Chicago, Illinois. Transp. Res. Records 2034 (1), 3–10.
Holian, M., Kahn, M., 2015. Household carbon emissions from driving and centr city quality of life. Ecol. Econom. 116, 362–368.
Hong, J., Tamakloe, R., Tak, J., Park, D., 2020. Two-stage double bootstrap data envelopment analysis for efficiency evaluation of shared-bicycle stations in urban cities. Transp. Res. Rec. 2674, 211–224, https://journals.sagepub.com/doi/10.1177/0361198120918568.
Hyland, M., Hong, Z., de Farias Pinto, H.K.R., Chen, Y., 2018. Hybrid cluster-regression approach tomodel bikeshare station usage. Transp. Res. Part A 115, 71–89, https://www.sciencedirect.com/science/article/pii/S0965856417304676.
Knowles, R.D., 2021. The mismatch between strategic planning and sustainable transport: The case of Greater Manchester's Spatial Framework 2019. J. Transp. Geogr. 92, 102990.
Kwiatkowski, M.A., 2021. Regional bicycle-sharing system in the context of the expectations of small and medium-sized towns. Case Stud. Transp. Policy 9 (2), 663–673.
Lee, Q.Y., Pojani, D., 2019. Making cycling irresistible in tropical climates? Views from Singapore. Policy Des. Pract. 2 (4), 359–369.
Rietveld, P., Daniel, y V., 2004. Determinants of bicycle use: do municipal policies matter? Transp. Res. Part A 38 (7), 531–550.
Shannon, T., Giles-Corti, B., Pikora, T., Bulsara, M., Shilton, T., Bull, F., 2006. Active commuting in a university setting: Assessing commuting habits and potential for modal change. Transp. Policy 13 (3), 240–253.