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Is the widespread use of urban land for cycling promotion policies cost effective? A Cost-Benefit Analysis of the case of Seville

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ABSTRACT

Cycling promotion has without doubt been the most intensive policy seen in Seville in the 21 st century as far as the use of public land is concerned. In the current context, economic tools need to be applied to rigorously assess the efficiency and economic rationality of cycling infrastructure investments. This article provides a Cost-Benefit Analysis to estimate the economic and social returns on investments from the construction of a bicycle lane network in the city of Seville (Spain). This kind of studies tries to contribute to mitigating the degree of conflict associated with a land policy that breaks with the traditional status quo. The case study is especially relevant due to the successful public policy implemented in recent years to transform the Seville's urban mobility model into a sustainable system. Based on fieldwork with two survey campaigns conducted among the different cyclist profiles (private bicycle users and public bicycle sharing system users), we analyze two major effects: modal change and changes in journey time. Our robust findings, subjected to a sensitivity analysis, point to the remarkable economic benefits of the bicycle promotion policy in Seville, with significant savings in travel times, vehicle use and infrastructure maintenance, health, traffic accidents, and air pollution for both cyclists and society as a whole.

1. Introduction and prior research

Nowadays, the search for an efficient economy, i.e., that the social benefit produced compensates for the loss of well-being (Martínez-Paz et al., 2014; Munger, 2000; Schulze et al., 2016), is an essential requirement for any public intervention to be undertaken (Bateman, 2009; Jongeneel et al., 2012). Cost-Benefit Analysis (hereafter CBA) has come to be one of the most popular economic analysis tools for the rigorous assessment of public investments, especially in the area of transport infrastructure (Jones et al., 2014; Kelly et al., 2015; Lavee, 2015; Mouter et al., 2013), as not only does it enable the suitability of a scheme to be examined, but the various alternatives can also be ordered according to their ability to improve social well-being (Mishan and Quah, 2007).

Recently published articles in the field that have used CBA to assess transport infrastructure can be classified in three categories: first, studies that conduct a theoretical analysis of CBA and any possible difficulties for its application (Beukers et al., 2012; Boardman et al., 2010; Damart and Roy, 2009; Peer et al., 2012; Salling and Leleur, 2015; Van Wee, 2012); second, studies that compare CBA with other assessment methods (e.g., Eliasson and Lundberg, 2012; Gühnemann et al., 2012; Tsamboulas, 2007; Tudela et al., 2006); and finally, studies that apply CBA to assess the socio-economic benefits (economic effect, safety, environmental and health effects) of a specific transport scheme for both individual users and broad society, as Legaspi and Hensher (2015) explain.

Much more recent are CBA applications to evaluate strategies developed to promote sustainable means of urban transport, such as the bicycle. Following this line, this article applies CBA to estimate the economic and social returns on investments made in the city of Seville (Spain) to construct a bicycle lane network. This case

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study is especially relevant due to the success that was achieved[1] in progressively transforming Seville's urban mobility model into a sustainable system (see Castillo-Manzano and Sánchez-Braza, 2013a; Castillo-Manzano et al., 2014; Castillo-Manzano et al., 2015a; Marqués et al., 2015) by means of a number of public actions. Cycling promotion has without doubt been the most intensive policy seen in Seville in the 21 st century as far as the use of public land is concerned. Examples of this intensive land use include the construction of a 140 km bicycle lane network and the implementation of a public bicycle share system called SEVici (managed by the JCDecaux Company), with 260 docking stations, 2650 smart-bikes and 5163 individual bicycle racks. All this has required a major investment effort by local governments.

These efforts have resulted in Seville being evaluated as the Spanish city with the safest and most convenient bicycle lanes in a study carried out by the leading Spanish consumers' organization (OCU, 2013). In addition, international organizations such as the European Environment Agency (2013) have valued this policy with Seville being placed fourth in the Copenhagenize Index of the world's most bike-friendly cities (Copenhagenize, 2013). However, it has not all been praise. Intensive land use has led to serious disputes among citizens (see Castillo-Manzano et al., 2015b; Castillo-Manzano and Sánchez-Braza, 2013b), due to a widespread belief that the amount of land given over to bicycle lanes, docking stations for hire bikes and parking space for privately-owned bicycles hampered mobility and spoilt the city, especially the historical center, declared a World Heritage site by UNESCO in 1987. The anti-bike campaign degenerated into protests and demonstrations. In the worst cases, frequent and violent vandalism resulted in, for example, 213 of the on-average 2650 bicycles available during the September 2009 – September 2010 period, being stolen and 1442 vandalized, and, to give another example, 240 anchorage points also being put out of use.

Regarding the prior literature on this topic, we find a range of studies that use CBA to conduct a direct or indirect assessment of public policies to promote bicycle use. In this context we find articles that use CBA to assess the construction of bicycle lane networks (Krizek, 2006; Wang et al., 2005); the cost effectiveness of investment required to promote them (Gotschi, 2011; Korve and Niemeier, 2002; Li and Faghri, 2014; Lind et al., 2005; Meletiou et al., 2005; Rahul and Verma, 2013); the bicycle's public health effects (Rutter et al., 2008; Sælensminde, 2004); the introduction of certain types of bicycles in specific contexts (such as Morey et al., 2002; for mountain bikes); the social costs of the bicycle compared to other modes of transport (Gössling and Choi, 2015) expressed, e.g., in terms of the value of the time saved by bicycle users (Börjesson and Eliasson, 2010); the analysis of the bicycle's influence on traffic and road traffic accidents (Elvik, 2000; Veisten et al., 2007); and the evaluation of public programs to promote helmet use by cyclists (Farley et al., 1997; Russell et al., 2011). Authors such as Krizek (2007) and Litman (2014) even draw up methodological guidelines to evaluate bicycle infrastructure.

This article contributes to the prior literature in a number of ways. First, it is an umbrella study of the effects of the construction of a city-wide 140 km long bicycle lane network in Seville, in southern Spain. Second, this article uses information collected in two survey campaigns specifically designed to estimate two major effects of the policies to promote bicycle use in cities: modal change and changes in journey time. The responses to these surveys have enabled these impacts to be estimated on the basis of real stated behaviors as opposed to extrapolations from other studies. Third, the study distinguished between two cyclist profiles: private bicycle users and SEVici bicycle users. Finally, it should be highlighted that costs and benefits have been calculated in great detail in order to enable this study to be replicated easily in any of the many cities that have developed, or are developing, similar policies.

In short, from a practical approach we think that this kind of study, based on an evaluation of the economic and social returns of public investments in cycling promotion, may also be helpful to alleviate the resistance generated in certain communities as a consequence of intensive land use for the implementation of urban bicycle facilities, as commented above.

The paper is structured as follows: after this introduction, Section 2 sets out the empirical framework, with a detailed analysis of the sources used; Section 3 presents the results in terms of the scheme's impacts on bicycle users and on society as a whole; Section 4 provides a discussion of these findings and a sensitivity analysis to confirm the stability of the results. Finally, the conclusions are given, followed by a References section.

2. Empirical framework

2.1. Data collection

For this CBA, personal face-to-face interviews were conducted of SEVici public cycle hire users (1400 interviews) and private bicycle users (504 interviews) in Seville in March and April 2014 (see Castillo-Manzano et al., 2016).

The journey points of origin and destination given by the interviewees were coded by the census tracts of Seville in which they were located. In 2014 there were 108 census tracts or neighborhood (see Fig. 1) divisions in Seville. A central point was established for each of the census tracts in order to code the length of journey, and the distance was calculated in kilometers as the shortest route by motorized vehicle (car or motorcycle), the distance in kilometers of the shortest route on foot, and the shortest route by public transport. In the case of public transport, the route was expressed as two components: time taken traveling on the public transport itself, and the distance that had to be covered on foot to arrive at the journey's point of origin and/or destination.

2.2. Estimation of changes in demand for modes of transport due to the bicycle promotion policy

For this CBA, the assessment period runs from the year before work began to construct the bicycle lanes in Seville (i.e., 2006) to 25 years afterwards.

Once the assessment period had been decided, one of the key aspects of a CBA of a bicycle promotion scheme is to determine the impact that said policy might cause or has caused on both: (i) bicycle use, and (ii) demand for other modes of transport.

In the case of Seville, the most reliable measurement unit used to estimate the change in bicycle use (i) due to bicycle promotion policies is the number of bicycle journeys made. The estimation technique was first used by Marqués et al. (2015) to determine the evolution of bicycle trips in Seville for the 2006–2011 period and later applied in SIBUS (2014)[2] and SIBUS (2016) to calculate the number of bicycle trips for 2013 and 2015, respectively.

Specifically, the estimation procedure consisted of: first, the annual figures from a range of sources were used to estimate the number of journeys per year: Seville City Hall for the 2006–2009 period (Ayuntamiento de Sevilla, 2006, 2010; Sigma Dos, 2007);

[1] As an example of this success, it is sufficient to cite the European Cyclists Federation, for example, which points to an increase from 6000 to 66,000 cyclists per day in Seville between 2006 and 2010, with a rise from 0% to 6.6% of mechanized journeys in only 4 years (see Castillo-Manzano et al., 2015a, 2015b).

[2] SIBUS is the University of Seville's Integrated Bicycle Scheme.

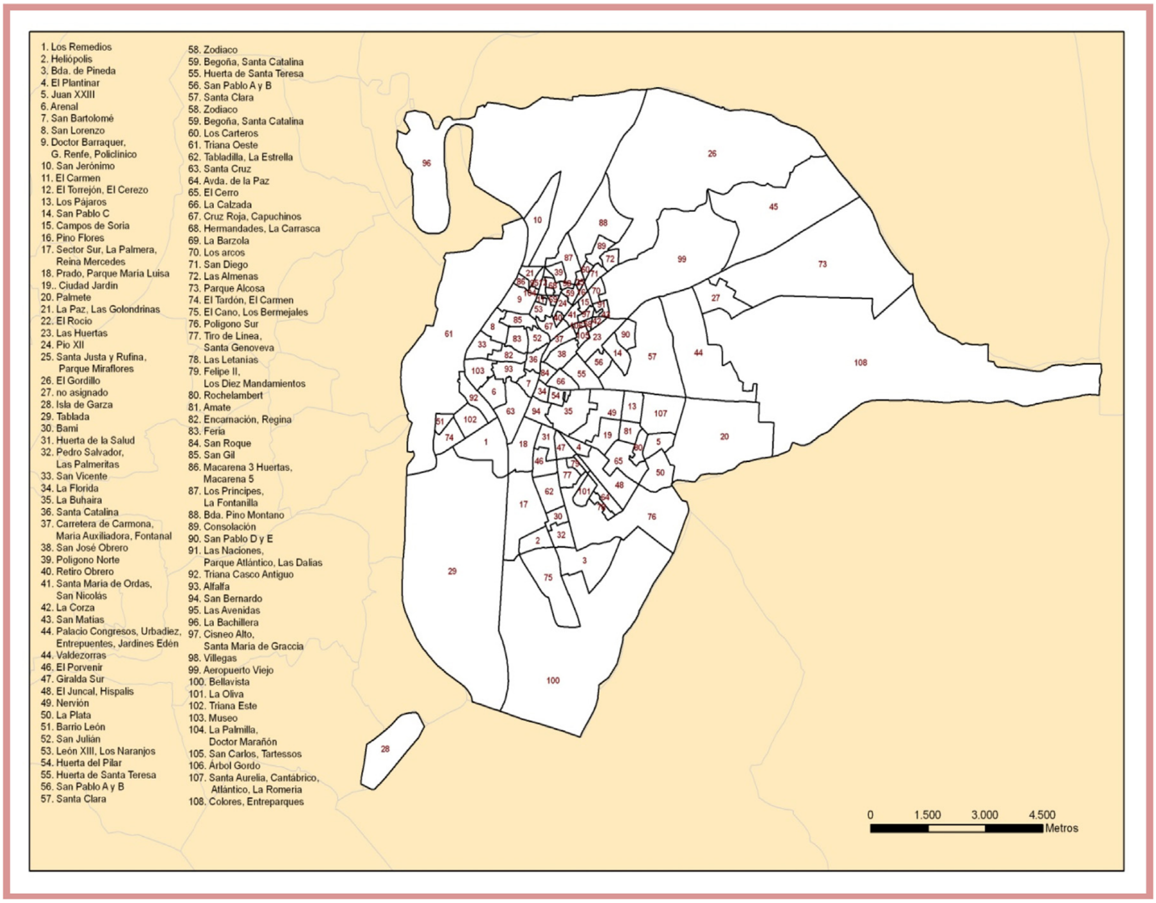

Fig. 1. City of Seville: Census tracts.

Source: Prepared by authors.

Marqués et al. (2015) and SIBUS (2014) for 2011 and 2013; and the ecocounter records (Ayuntamiento de Sevilla, 2013a, 2013b, 2014); ecocounters are devices located at certain points along the bicycle network that automatically count the number of bicycles that go past.

The number of private and SEVici bicycles are counted at each point to obtain an estimate of the percentage of all journeys made by SEVici bicycles. Using these percentages and the number of SEVici hires recorded during the counting period (sourced from Seville City Hall, 2012 and 2013) an estimate is subsequently obtained of the number of journeys made per day and also the number of journeys made per annum with and without a scheme in place (see Fig. 2).

Second, estimates were made for the situation with the scheme in place during the 2006–2013 period by homogenizing the various counts according to the number and location of the counter points and the time of day. As the counting was not done in the same months, the ecocounter records for 2013 were used so as to adjust for the seasonal component. Homogenization enables the inter-annual variation rates in the number of journeys to be calculated. Due to the lack of information for 2010 and 2012, the number of journeys was estimated as the mean of the number of journeys in the immediately preceding and following years. For years after 2013, annual journeys were estimated by applying successive projected population growth rates for Seville province (IECA, 2012) to the 2013 estimate.

For the situation when the scheme was not in place, the basis used was a previously obtained estimation of bicycle journeys for 2006. The estimations of journeys for other years were obtained by

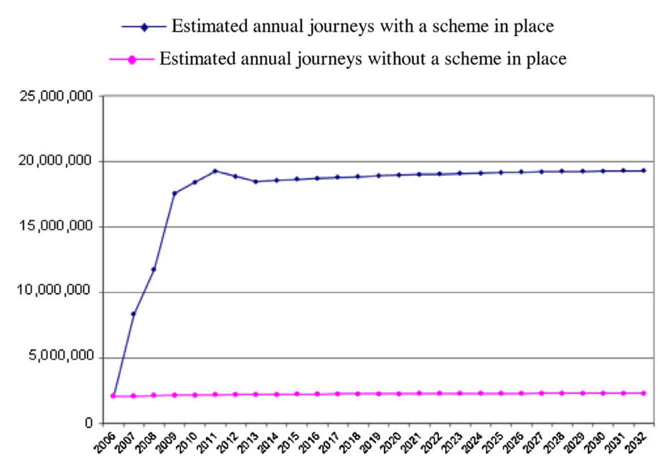

Fig. 2. Estimated annual no. of bicycle journeys.
Source: Prepared by authors.

applying real growth rates and projected population growth rates for Seville province.

The estimation of the number of journeys made using the various modes of transport (ii) was made on the basis of the results of the survey of private and SEVici public hire bicycle users in Seville.

A comparison of the estimations obtained in the current paper with the previous source used to calculate the number of bicycle trips (Marqués et al., 2015) show that the results essentially agree, with the only exception of a slight discrepancy for 2006. Bearing in mind that this was the year before the cycle network was built, this discrepancy may be explained by the use of different sources and limited available count data. Be that as it may, this slight difference does not affect the validity of our results, as this is the first year considered and, as Fig. 2 shows, the estimated number of annual trips with a scheme in place is equal to the estimated annual trips without a scheme in place. Therefore, the estimated net annual number of bicycle trips is zero.

The most relevant aspect is the increased percentage of bicycle journeys made to the detriment of the numbers of journeys made by car and motorcycle. In the case of journeys made using some kind of public transport (subway, bus), it is assumed that the costs of public transport in Seville do not vary with the increase in the number of bicycles, due to their high fixed costs and the fact that they are public. Only 73 and 42 (5.21% and 3%) of the 1400 SEVici users surveyed stated that they would make their journeys by car or by motorcycle, respectively, if they did not make them by bicycle. These figures are 42 and 13, respectively (8.33% and 2.58%) in the case of the 504 surveyees with private bicycles. Some previous estimations (see Marqués et al., 2015) give higher values for these substitution percentages for private motor vehicles (around 30%), due to the different survey methodology applied. Nevertheless, we consider that it is appropriate to use the most conservative estimate in the context of a CBA analysis. Notwithstanding, Section 4 examines the sensitivity of results to any changes in these values.

Additionally, it can be mentioned by way of illustration that the percentages obtained for pedestrian and public transport substitution were 27.07% and 37.71%, respectively, for SEVici users, and 19.84% and 28.37% for private bicycle respondents.

3. Results

This section gives a valuation in monetary terms of the main impacts on both cyclists and the community as a whole that result from the scheme being developed.

3.1. Economic valuation of the impacts on cyclists

3.1.1. Economic valuation of the costs of vehicle use and maintenance

The valuation of this impact only focuses on bicycle journeys that substitute car journeys. For this, first net journeys were estimated for each year of the evaluation as the difference between estimated journeys for the scenario with and without a scheme in place. Said net journeys were then used to calculate the economic valuation of the impact by applying the following formula:

$$MVMC_t = NJ_t \times SC \times AKC \times DC \quad (1)$$

where $MVMC_t$ is the monetary valuation of avoided vehicle use and maintenance costs for the year t; NJ_t are the estimated net journeys by bicycle for the year t; SC is the percentage of bicycle journeys substituting car journeys; AKC is the average distance in kilometers of avoided car journeys; and DC is the difference of cost per kilometer of car versus bicycle. As deduced from the formula above, SC, AKC and DC values remain constant and do not depend on the year.

The survey enables the percentage of bicycle journeys substituting car journeys and the number of car kilometers avoided by this substitution to be estimated for both SEVici and private bicycle users.

Of the 1904 cyclists interviewed, 73 SEVici users and 42 private bicycle users would have used the car for these routes. The sum total of car kilometers avoided by the 73 SEVici users is 264.69 km, whereas for private bicycle users it is 251.35 km. By adjusting these figures by the percentage of population that makes journeys by SEVici and by private bicycle over the total number bicycle journeys estimated by Marqués et al. (2015) for Seville (27% of bicycle journeys in Seville are made using SEVici and the remainder private bicycles), a mean percentage is obtained of 7.49% car journeys avoided due to bicycle journeys, and a mean distance of 5.539 km if these journeys had been made by car.

The difference of cost per kilometer is 0.237 € (Euros of 2009) (Fleetdata, 2009; Autopista, 2012). The value is 0.219 € (Euros of 2006) if the amount is calculated for the beginning of the period considered[3] (2006). The results are set out in Table 1, column [1].

3.1.2. Economic valuation of the changes in bicycle users' journey times

To value this impact, we estimated the mean monetary value of the change (positive or not) in the journey time experienced by the 1904 surveyees along their routes as a result of switching to the bicycle.

The survey data was used to calculate the distance (in km.) that each individual would have to cover should s/he wish to make the journey for this route by car or on foot; the distance that s/he would have to go to get to the most convenient public transport, and the time spent traveling on said public transport. In this case, the distance by bicycle between the journey point of origin and destination has been considered as being equivalent to the journey on foot, given the great freedom of movement in journeys that bicycles enable. All these distances were expressed as journey hours at an assumed speed of 20 km/h., 5 km/h. and 30 km/h., for the bicycle, the pedestrian and the car/bus, respectively. An extra 0.2 parking hours was also added to the mean journey time by private car. An extra amount of time was included for each journey by public transport calculated on the basis of generic estimations of waiting time given by the Google transit tool included in Google maps for individual cities.

In order to obtain a mean journey saving value in economic terms, time savings were subsequently valued in monetary terms for each cyclist using the following formula:

$$MVJTS_i = (JTm_i \times EVLTSm) - (JTb_i \times EVLTSb) \quad (2)$$

where $MVJTS_i$ is the monetary valuation of the journey time saving for individual i; JTm_i is the journey time for the route for individual i using mode of transport m (where m may be bus, car, bicycle or on foot); $EVLTSm$ is the economic valuation of leisure-time savings for mode of transport m; JTb_i is the journey time for the route for individual i using the bicycle as the mode of transport; and $EVLTSb$ is the economic valuation of leisure-time savings made by using the bicycle.

The values used for the economic valuations of leisure-time time savings in Spain for passengers were: 7.11, 9.9 and 4.95 (Euros of 2002) per hour (adjusted for purchasing power parity) for bus, car and bicycle/foot journeys, respectively. The first two values (bus and car) were obtained from Bickel et al. (2006) for the case of Spain. As this study does not provide values for journeys by bicycle and on foot, the last value was obtained from Navrud et al. (2006) using the proportions of the values for these modes of transport and the car given by Litman and Doherty (2009). These values were recalculated as Euros of 2006. Notwithstanding, Section 4 will examine the sensitivity of our results to any changes in valuations of time savings by car and public transport, which, to a certain degree, will be equivalent to changes in the speed of the modes of transport.

The surveys were used to compute changes in time savings for the two samples, SEVici cyclists and private bicycle users. Adjusting for the population values of both types of cyclist, a mean journey saving of 1.98 € was obtained. This value was multiplied by estimated net annual bicycle journeys to obtain an estimation of the

[3] All monetary amounts in this paper were calculated at 2006 values using the Spanish Statistics Institute (INE, 2015) web page.

Table 1
Monetary valuation of the scheme's main impacts (Euros of 2006).

Year	Impacts on bicycle users			Impacts on the community as a whole			Net monetary balance
	[1]	[2]	[3]	[4]	[5]	[6]	
	Savings in car use and maintenance costs	Savings in journey time	Changes in cyclists' health	Cost of scheme infrastructure and maintenance	Change in accidents	Environ-mental impact	
2006	0	0	0	−17,150,613	0	0	−17,150,613
2007	568,953	6,201,441	9,878,013	0	32,445	29,654	16,710,506
2008	876,366	9,552,164	15,215,236	0	−198,108	44,461	25,490,118
2009	1,401,303	15,273,853	24,329,072	−10,930,262	−680,110	69,171	29,463,028
2010	1,477,457	16,103,902	25,651,221	−243,272	−657,590	70,882	42,402,600
2011	1,553,866	16,936,749	26,977,828	−502,976	−228,121	72,362	44,809,709
2012	1,516,380	16,528,162	26,327,008	−232,602	−194,068	68,471	44,013,351
2013	1,479,044	16,121,207	25,678,785	−112,359	−537,505	64,697	42,693,869
2014	1,486,306	16,200,356	25,804,859	−262,712	−396,938	62,913	42,894,784
2015	1,492,949	16,272,764	25,920,195	−262,712	−399,389	61,079	43,084,887
2016	1,499,121	16,340,034	26,027,346	−262,712	−401,665	59,205	43,261,328
2017	1,504,712	16,400,978	26,124,421	−262,712	−403,728	57,287	43,420,957
2018	1,509,804	16,456,477	26,212,824	−262,712	−405,606	55,332	43,566,119
2019	1,514,522	16,507,907	26,294,744	−262,712	−407,347	53,346	43,700,459
2020	1,518,753	16,554,028	26,368,208	−262,712	−408,908	69,348	43,838,718
2021	1,522,524	16,595,129	26,433,676	−262,712	−410,299	66,618	43,944,937
2022	1,525,979	16,632,788	26,493,661	−262,712	−411,573	63,868	44,042,011
2023	1,529,051	16,666,266	26,546,986	−262,712	−412,706	61,099	44,127,983
2024	1,531,753	16,695,724	26,593,910	−262,712	−413,703	58,311	44,203,283
2025	1,534,235	16,722,774	26,636,997	−262,712	−414,619	55,514	44,272,189
2026	1,536,445	16,746,865	26,675,370	−262,712	−415,434	52,705	44,333,239
2027	1,538,395	16,768,115	26,709,219	−262,712	−416,154	49,887	44,386,750
2028	1,540,192	16,787,704	26,740,420	−262,712	−416,816	47,064	44,435,851
2029	1,541,783	16,805,045	26,768,041	−262,712	−417,403	44,236	44,478,989
2030	1,543,189	16,820,367	26,792,449	−262,712	−417,922	52,845	44,528,216
2031	1,544,497	16,834,630	26,815,167	−262,712	−418,405	52,910	44,566,088
2032	1,545,674	16,847,452	26,835,590	−262,712	−418,839	52,970	44,600,134

Source: Prepared by authors.

monetary value of this impact for each year. Finally, the "rule of half" Litman and Doherty (2009) was applied (see Table 1, column [2]).

3.1.3. *Economic valuation of changes in health*

Taking a conservative view, we have only considered the effect of the physical exercise that comes from bicycle use in terms of mortality, according to the simplification recommended by Cavill et al. (2008). For this the formula developed in Cavill et al. (2008) was used to estimate the fall in the mortality rate among habitual cyclists as a result of the greater physical exercise done:

$$RMRHC = 1 - \left[\frac{DBAS}{DBC} \times (1 - 0.72)\right] \quad (3)$$

where *RMRHC* is the relative mortality risk for habitual cyclists; *DBAS* is the distance covered by bicycle in the area of study (Seville in this case); *DBC* is the distance covered by bicycle in Copenhagen, and value 0.72 is the relative risk for all causes of mortality of all regular bicycle users between the ages of 20 and 60 compared to the general population, estimated for the city of Copenhagen. In this formula, the distance covered in Copenhagen per cyclist per year is 1512 km. On the basis of the survey data the distance covered per cyclist per year in Seville is estimated at 883.14 km.

Comparing the above formula with these data, the relative mortality risk of habitual cyclists compared to non cyclists was 0.836, which is equivalent to 0.164 risk protection.

The mortality risk in Seville for the general population between the ages of 20 and 64 (population used in Cavill et al., 2008) was 0.23%. This risk was estimated on the basis of the number of deaths (IECA, 2014a) and the population in the 20–64 year age range in the municipality of Seville in 2011 (Caja España-Duero, 2012).

Once the mortality risks had been obtained for the habitual cyclist and non cyclist collectives in Seville, the next step was to determine the number of habitual cyclists in Seville for each year. Given how difficult it was to determine this figure, a reference value for each year was obtained by dividing the net number of weekly journeys for each year (net annual journeys/52) by the mean weekly frequency per mean cyclist (estimated as 5.87 journeys according to the survey data). The relative mortality risk for the general population was applied to this population of habitual cyclists in order to estimate the number of deaths in said collective that did not do the physical exercise.

The previously estimated protection risk was applied to this number of deaths to obtain the number of deaths avoided in the collective by virtue of the exercise that they do as habitual cyclists. From 2010 on, these numbers are in the order of 20 deaths avoided per year. This value is in line with the 24.17 deaths avoided per year estimated by Marqués et al. (2015) for the same case study, and also in qualitative agreement (order of magnitude) with the values reported in Rojas-Rueda et al. (2011, 2012) for different bicycle use scenarios in Barcelona. These "avoided" deaths were valued in monetary terms using a statistical life value of 1,122,000 € (Euros of 2002), which is the value stated in Bickel et al. (2006). When recalculated as Euros of 2006 the value was 1,279,080 €. The results using this figure to value "avoided" deaths in each year in monetary terms are given in Table 1, column [3].

3.2. *Economic valuation of the impacts on the community as a whole*

3.2.1. *The costs of setting up, maintaining and operating infrastructure*

These costs were established using official data or data that were given to the authors in person on request. They are given in Table 1, column [4] in Euros of 2006.

In the case of the costs of maintaining the Seville bicycle lane network, official data were available for the 2009–2013 and 2014–2015 periods. These latter years were used to extend annual maintenance costs from 2015 to 2032.

3.2.2. Traffic accidents

For the monetary valuation of this impact, the information used initially was provided by the Spanish General Traffic Directorate (Dirección General de Tráfico, DGT) upon request from the authors as to the number of annual urban accidents in the city of Seville between 2002 and 2013 in which cyclists and passenger cars were involved. Data included in reports and yearbooks for 2012 and 2014 were also used (Dirección General de Tráfico, 2014a, 2014b).

A non-parametric Mann-Whitney comparison of the values for the 2002–2006 period (before the effects of the scheme were felt) and the values for the 2007–2013 period (after) showed differences significant at 5% between the values of the two periods.

As the data provided by the DGT did not state the severity of the accidents, the percentages of all accidents for cyclists and passenger cars, which were available on the national level, were applied to the data for Seville, providing an estimate of deaths, seriously injured and slightly injured for accidents involving cyclists and passenger cars. These categories were grouped together for the 2003–2006 and 2007–2013 periods and a new non-parametric Mann-Whitney comparison was performed. There are no statistically significant differences for bicycle deaths and seriously injured at 5%. However, there were seen to be significant differences in the numbers of slight bicycle and passenger car accidents. Only cases with significant differences were valued in monetary terms.

The monetary valuation of the increase in slight bicycle accidents was made using the estimate of the number of slight bicycle accidents for the 2006–2013 period. These estimations were temporarily extended for the situation with the scheme in place. For 2014 the average of the estimates for the preceding 4 years was calculated in order to obtain a mean value, and for the following years up to the end of the evaluation period it was assumed that this estimated mean value for 2014 would grow at the same rate as the projected growth in population for Seville. For the case of the situation without the scheme in place, the estimations for the various years were made using the 2006 estimate, and real growth rates and real projected population growth rates for the province of Seville were used. Estimates of changes in the number of slight bicycle accidents as a result of the scheme are given in Table 2.

In the case of passenger car accidents, although there is a significant difference in the number of accidents estimated in the years before and after the commencement of the scheme, all of the reduction cannot be attributed to this, as there are other factors that could also justify this decrease. The decision was therefore taken to obtain an estimate of the annual number of car accidents by car journey and to apply this value to the number of avoided car journeys each year as a consequence of the scheme. In this way an estimation of the number of car accidents avoided as a result of the scheme would be obtained.

The estimation of the number of passenger car accidents by car journey was made using data from Seville City Hall (Ayuntamiento de Sevilla, 2010), which provides information about the modal share of internal journeys in Seville for 2009, with data on the number of daily journeys and the modal share.

Once the number of car accidents by car journey in Seville (0.926×10^{-6}) had been estimated, the annual reduction in the number of car journeys as a result of the scheme was estimated. Said reduction was estimated by applying the previously mentioned car to bicycle switch percentage (7.49%) to annual journeys.

An estimation of the number of car accidents that were avoided was provided by multiplying the number of accidents per car journey by the reduction in the number of car journeys post scheme implementation.

The following step consisted of estimating the number of slightly injured, seriously injured and deaths that would have occurred each year as a result of the accidents that were avoided. This estimation was made for the 2007–2013 period by applying the proportions of slight and serious injuries and deaths recorded in car accidents on the national level to the number of estimated accidents. Slight and serious injuries and deaths were estimated for 2014 using the average of the preceding 4 years. For other years the 2014 values were considered to remain constant as the annual numbers of accidents avoided in these years were very similar (a difference of under 0.4 accidents). Estimates of changes in the numbers of slightly injured, seriously injured and deaths from car accidents as a result of the scheme are shown in Table 2.

Finally, changes in the numbers of slight and serious injuries and deaths were valued in monetary terms using the values of 1,122,000 €, 138,900 € and 10,500 € (Euros of 2002) stated in Bickel et al. (2006) for deaths and the serious and slight injuries, respectively. The corresponding total values recalculated as Euros of 2006 are given in Table 1, column [5].

3.2.3. Environmental pollution

For the valuation of these impacts, emissions data (gr/km) were used for the various pollutants envisaged by the Association of the Barcelona Metropolitan Area (2010) and provided by the Catalonian Energy Institute. The use of these data is justified by the fact that vehicle emissions have evolved (reduced) over time, and these data provided emission figures that are very close to the commencement date of the evaluation period (2006).

Once the various pollutant emissions had been determined for 2006, the evolution that said emissions would experience over the evaluation period was established. A decreasing path of pollution avoided has been considered, as motorized vehicles' environmental and energy efficiency increases and improves overtime, i.e., this evolution takes into account the European regulations that lay down permissible and acceptable limits for pollutant emissions from new vehicles sold in European Union member States.

Naturally, these regulations are considered to affect the manufacture of new vehicles, and not the car fleet that exists in any given year, which means that reductions in pollution levels take many years to fully take effect.

It was decided to assume in the present article that by 2030 the total number of cars in Seville would reach a per vehicle mean (diesel and gasoline) equivalent to the limit imposed by the European Union for the different pollutants in new vehicles (diesel and gasoline) for 2014 (Euro 6) (DOUE, 2008). The value of CO_2 established for 2030 was 95 grs./km., as set by the European Union for the manufacture of cars as from 2020 (DOUE, 2009). The evaluation of emission levels was assumed to be linear between 2006 and 2030. For years subsequent to 2030 emission levels were taken to be the same as for 2030.

The differences between emission levels for gasoline and diesel cars required the share of these two types of car in the total number of cars in Seville to be known (IECA, 2014b). For 2006, the ratio of gasoline vehicles was considered equal to that of 2007. The proportion of gasoline vehicles in Seville was estimated for the post 2013 years by estimating a 0.02 decrease rate based on the existing trend in the 2007–2013 period.

Once the emissions data (grs./km.) for diesel and gasoline cars and the proportion of each in Seville had been obtained, the monetary valuation of the environmental impact for each year t ($MVEI_t$)

Table 2
Estimates of the number of slightly injured, seriously injured and deaths as a result of the scheme.

Year	Change in number of slight bicycle accidents	Change in number of deaths from car accidents	Change in number of seriously injured from car accidents	**Change in number of slightly injured from car accidents**
2006	0.000	0.000	0.000	0.000
2007	2.790	0.014	0.117	2.490
2008	24.910	0.021	0.157	4.014
2009	69.960	0.029	0.254	6.718
2010	67.710	0.026	0.201	7.375
2011	31.970	0.024	0.216	7.526
2012	28.790	0.022	0.208	7.520
2013	57.220	0.020	0.199	7.579
2014	45.810	0.023	0.206	7.500
2015	46.010	0.023	0.206	7.500
2016	46.200	0.023	0.206	7.500
2017	46.370	0.023	0.206	7.500
2018	46.530	0.023	0.206	7.500
2019	46.680	0.023	0.206	7.500
2020	46.810	0.023	0.206	7.500
2021	46.920	0.023	0.206	7.500
2022	47.030	0.023	0.206	7.500
2023	47.120	0.023	0.206	7.500
2024	47.210	0.023	0.206	7.500
2025	47.280	0.023	0.206	7.500
2026	47.350	0.023	0.206	7.500
2027	47.410	0.023	0.206	7.500
2028	47.470	0.023	0.206	7.500
2029	47.520	0.023	0.206	7.500
2030	47.560	0.023	0.206	7.500
2031	47.600	0.023	0.206	7.500
2032	47.640	0.023	0.206	7.500

was calculated by applying the following formula:

$$MVEI_t = \left[KCM_t \times G_t \times \left(\sum_p GE_{pt} \times GMC_{pt} \right) \right] + \left[KCM_t \times (1 - G_t) \times \left(\sum_p DE_{pt} \times DMC_{pt} \right) \right] \quad (4)$$

where *KCM* are the kilometers of car or motorcycle journeys avoided; *G* is the percentage of gasoline vehicles over the total number of vehicles in Seville, whereby (1-*G*) equals the percentage of diesel vehicles over the total; *GE* and *DE* are emissions data for gasoline and diesel vehicles respectively; *GMC* and *DMC* are the estimated monetary costs of the pollutants emitted by gasoline and diesel vehicles; *p* is a subscript that represents the various pollutants considered, and subscript *t* refers to the year in question. The emissions are measured in tonnes/km, monetary costs (measured in Euros of 2006/tonne) of each pollutant come from Maibach et al. (2008) duly recalculated, and the kilometers avoided are calculated using the formula:

$$KCM_t = NJ_t \times SCM \times AKCM \quad (5)$$

where *NJ* is estimated net journeys for each year; *SCM* the percentage of bicycle journeys substituting car or motorcycle journeys; and *AKCM* average kilometers of car or motorcycle journeys avoided. The percentage of journeys that had previously been made by car or motorcycle, and the mean number of kilometers of said journeys, were obtained from the survey (10.18% and 4.97 km, respectively). The results are expressed in Euros of 2006 in Table 1, column [6].

4. Discussion of results and sensitivity analysis

Table 1 shows the net monetary valuations (in Euros of 2006) of the different impacts of the bicycle promotion policies in the case of Seville explained in the foregoing sections. The negative values are a reflection of the scheme's costs, while the positive values are the benefits that come from the scheme. In the case of changes in traffic accidents due to the scheme being developed, costs resulting from an increase in slight injuries to cyclists were subtracted from the benefits that come from the fall in the number of car accidents (reduction in slight and serious injuries and deaths).

Once the most relevant impacts had been valued, a net result was computed for each year by subtracting the costs from the benefits. These results give a sense of the major benefits that come from the bicycle promotion policies in the city of Seville.

The net annual figures were aggregated through current net value (CNV) and internal rate of return (IRR). The CNV was calculated using a 5% discount rate following the recommendations of the European Commission (2002). This discount is extremely conservative if we take into account the fact that the Euribor has remained at less than 1% for many years.

The aggregated results were 557,120,897 € (Euros of 2006) CNV and 130.54% IRR. These two results both give great support to the execution of the scheme.

Given the logical uncertainty that surrounds some aspects of the process to evaluate the scheme, a sensitivity analysis was carried out of some key parameters to measure their robustness. To be specific, the sensitivity analysis considered 7 parameters: the percentage over estimated journeys (p1), the per kilometer cost of car use and maintenance (p2), the percentage of journeys switched to the bicycle from private motorized vehicles (car or motorcycle) (p3), the value of the time saved by switching from car or bus to bicycle (p4), the per tonne value of each of the pollutants considered (p5), the considered value of statistical life (p6), and the reduction in mortality risk due to the health benefits of the bicycle (p7).

For the first of these parameters, the possibility of an evolution of up to 10% fewer estimated journeys was considered from 2014 on. For all other parameters, a 20% range of variation above and below the initial value was considered for the estimated variables.

The results of this sensitivity analysis allow it to be concluded that the values obtained for both CNV and IRR are quite robust, as in all cases a very positive evaluation of the scheme is obtained, despite the variations in the parameters considered. Considering

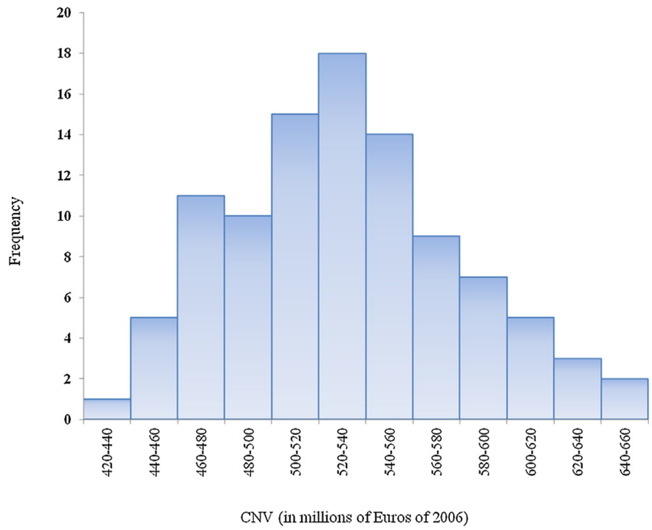

Fig. 3. Scheme CNV histogram.
Source: Prepared by authors.

the variation in each of these parameters with all other parameters remaining constant, CNV ranges from 489,152,348 to 627,391,578 (Euros of 2006) with −12.20% and +12.61 percentage variations on the initial CNV. With respect to the IRR, the range is between 116.38% and 143.84% for the different variations considered for the parameters. Even considering the best and worst scenarios for the values of these parameters all together, i.e., with all the parameters varying as one toward the maximum and minimum values considered, CNV ranges from 331,089,534 to 765,384,998 (Euros of 2006). With respect to the IRR, the range is between 84.87% and 169.42% for the different variations considered for the parameters.

The analysis also enables the parameters that have the greatest impact on the results to be identified. Thus, the parameters that affect the results to the greatest extent are, above all, p1 (the percentage of variation of estimated journeys), and p6 (the statistical life value used) and p7 (the reduction in mortality risk due to the bicycle's health benefits). Although the other previously commented parameters, such as the value considered as a substitution percentage from private motorized vehicles (car or motorcycle) to bicycle (p3) or the valuations of time savings by car and public transport (p4), may affect the obtained results, the results obtained from the sensitivity analysis show that their effects are more limited.

In addition, the probability distribution of the results was also examined in terms of CNV. In this case, using the above parameters, a uniform distribution was considered for parameter p1, ranging between 90% and 100% of the initial value. A triangular distribution was found for the remaining values, with a mean value that is the initial value considered, and the bottom values corresponding to valuations of ±20%. The histogram shown in Fig. 3 is obtained with 100 values extracted for the 7 considered parameters. This shows that CNV distribution is always within a clearly positive range of values. It also shows the likelihood of achieving certain CNV values. For example, on 58% of occasions a CNV value of over 520 million Euros (Euros of 2006) can be expected, rising to a value of over 560 million Euros (Euros of 2006) on 26% percent of occasions.

5. Conclusions

Promoting bicycle use is turning into one of the main policies used in cities as a measure to achieve so-called sustainable transport. More and more cities are making large investments and also giving over more and more urban land to this sustainable mode of transport. This justifies the need to conduct studies that analyze the economic rationality of such actions.

The present article's findings would appear to support this type of action. The CBA that was conducted to evaluate the investments in the construction of a full bicycle lane network in the city of Seville provides very positive results. To be specific, a CNV value of 557 million Euros and an IRR of over 130% are obtained. The analysis does not provide any results that call the investment into question in any scenario. Furthermore, this value could have been even higher if other impacts had been included that are all positive, but which were omitted because they were considered of lesser importance for the case study or because they were difficult to quantify. Among these we can mention the improved sensation of convenience and safety felt by cyclists with the construction of the bicycle lanes, the reduction in noise levels and traffic congestion, and the scheme's terminal value. Finally, some other clear indirect benefits have not been included in the analysis, such as the improvement to Seville's image both nationally and internationally. Some examples of this are the positive references that this policy has received in internationally prestigious media, such as CNN[4] and The Guardian.[5]

Most studies on bicycle promotion have traditionally highlighted the environmental and health benefits of bicycle use compared to motorized vehicles. However, the CNV has shown that time savings in journeys achieved by switching to the bicycle can also have a very important effect in monetary terms. This may be explained this article's use of surveys to estimate the changes in citizens' journey times instead of using some form of extrapolation from another study, as both the unitary monetary values used to evaluate the changes in monetary terms, and the methodology used to quantify the environmental and health impacts monetarily are in keeping with the academic literature.

Finally, the responses to the surveys conducted also show the existence of differences in the behavior of private cyclists and users of the public bicycle hire system. The two groups would appear to display different behaviors in their changes in mode of transport with respect to the bicycle. Thus the relative size of the two groups in different cities would affect the results of the evaluation of similar policies.

In other respects, a cost-benefit analysis such as that conducted in this article contributes in the first instance by responding to the social demand for greater economic rationality to be introduced into the planning of transport infrastructure in Spain. This is a sector that has experienced a veritable bubble with too many examples of few or negative social returns since the end of the last century (see Albalate et al., 2015). Second, it also serves as a pedagogic instrument to raise awareness of the potential economic benefits of urban policies based on aggressive urban land use to promote bicycle use in cities with no tradition of cycling. This education should contribute to mitigating the degree of conflict associated with a land policy that breaks with the traditional status quo. It can in fact be concluded that, in the case of Seville, the policy's socio-economic success and its widespread perception has more than likely been the balm that has healed the conflict to the point of rendering it negligible (although it is still bubbling under the surface in certain areas, such as the still imperfect coexistence of cyclists and pedestrians). Finally, this article offers elements that can be used as a basis for similar transformations to Seville's, with minimal conflict, in other cities, such as the two nearest, Huelva and Cadiz.

[4] http://edition.cnn.com/2015/02/19/travel/seville-cycling-cnngo/o http://edition.cnn.com/2014/08/17/travel/best-cycling-cities/.

[5] http://www.theguardian.com/cities/2015/jan/28/seville-cycling-capital-southern-europe-bike-lanes.

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