Commuting to college: the effectiveness and efficiency of transportation demand management policies.

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Abstract

Commuting is the single largest impact a University has on the environment and represents a noticeable share of urban traffic, when the University is located within a city. There is a large amount of literature on which policies could reduce car use and improve the environmental and social sustainability of commuting to college. However, most studies focus, to the best of our knowledge, only on the effectiveness of such policies, disregarding their efficiency. This paper presents an estimate of the effectiveness and the efficiency of nine hypothetical transport policies regarding the University of Trieste, Italy, on the basis of a transport demand model estimated via revealed and stated choice data. All policies but one are effective in reducing car use, but only six of them appear to be efficient. We find that fully subsidizing bus fares would be the most effective and efficient policy. However, it is doubtful whether fully subsidizing bus fares is financially sustainable. The second best policy would be a mix of bus subsidies and parking restrictions. In case of the University of Trieste, our model suggests the adoption of a policy mix based on a relatively low hourly parking tariff (€0.3 per hour) and the use of the parking revenues to subsidize the bus users. The methodology and the results presented in this paper can be used by the college mobility managers to design better transport policies.

Keywords: university students; TDM policies; commuting; efficiency; effectiveness

1. Introduction

The efficiency and the environmental sustainability of the transport system is a critical factor in order to provide access to work, training, and social and cultural activities especially in urban areas, where more than 74% of the EU-27 population live (DG MOVE, 2013) and 85% of the European GDP is produced (EC, 2009). Education-related journeys account for 25% of the total journeys made. Universities, like other types of public and private institutions, are among the largest generators/attractors of commuters and, according to Tolley (1996), commuting is the single largest impact a University has on the environment. Commuting to college is, hence, a very interesting area on which to test the performance of mobility management policies (European Platform on Mobility Management, 2013).

In fact, in an attempt to increase their environmental sustainability, several universities implemented strategies aimed at reducing the dependence on private cars and at increasing the use of alternative transport modes. In Italy, since 1998, a law entrusted the management of the mobility of the college employees to the Mobility Manager who is required to periodically survey the employees' travel behavior in order to design policies consistent with their needs and the characteristics of the university sites (location, public transport availability, parking facilities). The implementation of this law is, however, still patchy. Some Italian universities, like Milan and Bologna, have been particularly effective in reducing the percentage of car users. Their mobility strategy is based on limiting the use of the parking facilities to faculty and staff only, granting discounts of parking tariffs to bus users, supporting carpooling programs, financing discounts for bike sharing services. Most Italian universities have granted some form of discount on the monthly or annual bus ticket to their employees and students. Almost all universities provide bike parking areas and most of them offer bike sharing services. Most universities allow employees only and not students to use their private car parking lots (Rotaris and Danielis, 2014a). The effectiveness of these policies, however, has seldom been evaluated (Barata *et al*., 2011; Browder *et al*., 2013; Delmelle *et al*., 2012; Dorsey, 2005; Brown *et al*., 2003; Zhou, 2014; Shannon *et al*., 2006; Brockman and Fox, 2011) and their efficiency has never been assessed. Consequently, Mobility Managers have little or no information on the overall performance of the transport demand management (TDM) policies that are or could be implemented in their universities.

The aim of this paper is to provide Mobility Managers with some guidelines derived from an *ex-ante* evaluation of the effectiveness and the efficiency of nine hypothetical TDM policies that could be implemented in a university setting. The analysis is based on a study of the mobility choices of the employees and the students of the University of Trieste, a medium-size city in the northeast of Italy, close to the Slovenian border. The policy suggestions derived from this case study could be useful to design TDM policies both for universities and for other institutions located in urban areas such as hospitals, courts, high schools, administrative offices, shopping centers, banks, and headquarters of large firms.

The paper is innovative both with respect to the topic - since, to the best of our knowledge, there is no literature assessing both the effectiveness and the efficiency of TDM policies designed by universities - and with respect to the methodology used, since the scenario analysis and the cost-benefit analysis performed are based on revealed and stated preference data collected *ad hoc*.

The paper is structured as follows. Section 2 presents a review of the literature on universities' transportation policies and commuting behavior. Section 3 summarizes the methodology used to collect the preference data from a sample of employees and students of the University of Trieste and the results of the scenario analysis performed for nine TDM policies. Section 4 explains the methodology and the results of the cost-benefit analysis for each policy. Section 5 compares the effectiveness and efficiency of the policies analyzed. Section 6 concludes.

2. Literature review

In spite of recent contributions to the literature on the effectiveness of universities' TDM policies (Table 1), to the best of our knowledge, there are no contributions on the efficiency of these policies.

Table 1 Recent studies on TDM policies for college mobility.

	Main focus on	Outcome	Main results / policy implications
Barata *et al.* (2011)	parking policies	effectiveness	need to reduce free on-street parking
Browder *et al.* (2013)	parking policies	effectiveness	insufficient parking space, suggested park-and-ride
Delmelle *et al.* (2012)	parking policies	effectiveness	max WTP for parking facilities $400; need to increase the yearly parking permit
Dorsey (2005)	transit and bus subsidies	effectiveness	financially beneficial to students, faculty, and universities
Brown *et al.* (2003)	transit and bus subsidies	effectiveness	56% increase in bus ridership and 20% decrease in campus visits by solo drivers
Zhou (2014)	transit and bus subsidies	effectiveness	share of transit usage among students increased by 51%
Shannon *et al.* (2006)	parking policies, transit and bus subsidies	effectiveness	subsidizing public transport services, increasing the cost of parking, and improving the quality of bus services are among the most promising policies to induce a modal change
Brockman and Fox (2011)	parking policies, active transport, car-sharing, transit and bus subsidies	effectiveness	staff members car commuting dropped from 50% in 1998 to 33% in 2007
Lavery *et al.* (2013)	demand analysis	segmentation	influence of demographic, attitudinal and spatial/land use variables, and role played by faculty staff
Miralles-Guasch *et al.* (2014)	demand analysis	segmentation	influence of demographic, attitudinal and spatial/land use variables, and role played by faculty staff
Limanond *et al.* (2011)	demand analysis	segmentation	social interdependency
Duque *et al.* (2014)	demand analysis	segmentation	more environmentally friendly attitudes of staff compared to off-campus students, inadequate policies given the attitude of the most polluting segment
Fürst (2014)	demand analysis	segmentation	six different commuter groups, need for segment specific policy mixes
Miralles-Guasch and Domene (2010)	demand analysis	segmentation	for undergraduate students public transport is the preferred means, for staff the use of public transport is higher among teaching and research members

Some authors, like Barata *et al.* (2011), focus mainly on parking policies, acknowledging that the provision of parking is one of the most troublesome transportation problems at university campuses. They find that 45% of the parking supply of the University of Coimbra (Portugal) does not involve any kind of economic regulation and that existing underpriced parking places are largely insufficient to meet current demand, so that illegal parking is widely used. According to the authors, increasing control over non-regular parking and eliminating free on-street parking would encourage modal shift from private car to public transportation. Browder *et al.* (2013) also find that the main problems of parking on campuses are related to insufficient parking spaces to accommodate growing university communities, with parking lots being located far from central gathering points of offices and classrooms, with narrow parking spaces complicating vehicle maneuvering and causing space encroachment issues and accidents. Differently from Barata *et al.* (2011), they suggest the implementation of park and ride programs, to allow students and faculty to park their vehicles at a safe designated parking lot and the provision of a shuttle service to and from campus. Delmelle *et al.* (2012) explore the spatial, temporal and gender differences in the modal choice among students commuting to the University of Idaho (USA), with the goal of uncovering incentives to increase the use of non-motorized or public transportation alternatives. They find that the maximum willingness to pay (WTP) for parking of 70% of the interviewed students is $400, while, at the time the survey, the maximum cost for a yearly permit for the lots closest to campus was $262 and the cheapest was as low as $59. Both this and other studies which suggest increasing the parking cost or replacing seasonal passes with daily passes (Shannon *et al.*, 2006; Molina-Garcia *et al.,* 2010; Whalen *et al.*, 2013), provide no estimate on the effectiveness and efficiency of the proposed policies.

A second area of research focuses on the subsidization of public transport. Dorsey (2005), analyzing the impact of mass transit incentive programs at the University of Utah and at the Weber State University, fully or partially subsidizing transit passes, finds that it is financially beneficial not only to students and faculty, but also to universities, seeking to cut costs on parking expenditures[1]. Brown *et al.* (2003) and, more recently, Zhou (2014) report that the implementation of a one-year, fare-free pilot study (BruinGo!) at the University of California, Los Angeles, lead to a 56% increase in bus ridership, a 20% decrease in campus visits by solo drivers, and a 51% increased share of transit usage among students.

Part of the literature analyses the effectiveness of a mix of policies instead of focusing only on one type of policy. For instance, Shannon *et al.* (2006) find that subsidizing public transport services via a U-Pass program, increasing the cost of parking, and improving the quality of bus services would be the most promising policy mix to induce a modal change at the University of Western Australia (Perth). More recently, Brockman and Fox (2011) investigated the effectiveness of a number of TDM policies implemented at the University of Bristol (UK) such as: limited parking spaces and conditions for permits, increased parking charges, improved changing facilities for walkers and cyclists, new secure cycling storage, a subsidized bicycle purchase scheme, a car-sharing scheme, a free university bus service, and discounted bus season tickets. They find that the percentage of staff members commuting by cars dropped from 50% in 1998 to 33% in 2007.

Finally, a stream of literature is devoted to analyzing the commuting behavior of university employees and students, since only if segment specific attitudes and preferences are taken into account is it possible to develop effective policy measures. Indeed, as recently reported by Lavery *et al.* (2013) and by Miralles-Guasch *et al.* (2014) the number of modes that individuals consider available/feasible for their daily commute is influenced by a combination of demographic, attitudinal and spatial/land use variables, including the role played by the staff in the social structure of the university. Social interdependency can play an important role too, especially among university students, as demonstrated by the results of a study carried out by Limanond *et al.* (2011) at the Suranaree University of Technology (North-Eastern Thailand). In this vein, Duque *et al.* (2014) stress the importance of measuring both the effectiveness and the efficiency of different TDM policies, given the specific needs and constraints of each segment of the university community analyzed. According to their results, faculty and non-professional staff members have significantly more environmentally friendly attitudes than off-campus students, but they are also more likely to contribute to a larger share of the university's carbon footprint since they drive less fuel-efficient

[1] parking personnel, parking violation ticket administration, parking lot maintenance, such as re-paving and painting, and opportunity costs related to new parking facility development

cars, more days per week, over longer distances. These findings suggest that the current 'green' transportation policies aimed at promoting more pedestrian traffic on campus, providing more local and on-campus shuttle services, and developing campus infrastructure to support more bicycle commuting, may not impact the segment of the university contributing the most to its carbon footprint. Fürst (2014) conducted a survey comprising 241 academic institutions in Germany, Austria and the German-speaking part of Switzerland with the aim of defining and addressing attitude-based user groups of alternative transport modes. He identifies six different commuter groups[2] requiring specific policies. Finally, Miralles-Guasch and Domene (2010), observing the large number of staff and students commuting by car and the inadequate parking area on campus, find that undergraduate students would prefer to use public transport but use the car because of the free parking. As for staff, they find that public transport use is higher between teaching and research staff living in Barcelona, than for administration and services staff living in peripheral municipalities which are poorly served by public transport. They conclude that the policies should focus on undergraduate students, since they are potential public transport users, via reasonable subsidies to compensate them for the shorter commute times guaranteed by the private modes, and via the reduction of the current implicit parking subsidies.

3. Transport mode choices of employees and students of the University of Trieste

With the aim of assessing the effectiveness and the efficiency of different policies and policy mixes, in 2010 we interviewed a sample of students and employees of the University of Trieste (Rotaris and Danielis, 2014b). We collected both revealed and stated preference data. The first part of the interview focused on the characteristics of the actual commuting trip: destination, transport mode, transport cost, time needed to find a parking place, commuting frequency, arrival time, and in-vehicle travel time. The second part, as depicted in Table 2, required each respondent to examine ten hypothetical choice scenarios (including the *status quo*) and to choose the preferred transport alternative. The alternatives, commuting by car and commuting by bus, were characterized by different time (walking time, in-vehicle time, parking time) and costs (parking fare and bus ticket) components. The time components were described as percentage changes (±25%, ±15%; ±0%) of the values reported by each respondent. The cost components ranged for the hourly parking price from €0 to €1.50, for the annual parking permit from €40 to €90, for the one-way bus ticket from €1 to €1.5, and for the monthly bus ticket from €27 to €36.

[2] eco-travelers; see-saw-travelers; pragmatic users who are environmentally open-minded; pragmatics travelers who dislike public transport; prestige-orientated travelers; car-oriented travelers

Table 2 Example of stated preference scenarios.

Which of the following transport possibilities would you choose?					
	Current transport mode	Car and hourly parking fee	Car and annual parking fee	Bus and one-way ticket	Bus and monthly ticket
Cost	28 € (annual permit)	1.6€	60€	1€	30€
Time from home to car/bus stop	5'	4'	6'	9'	3'
In-vehicle travel time	14'	10'	8'	20'	12'
Parking searching time	10'	5'	12'		
Time from car/bus stop to university	2'	5'	10'	5'	7'

Source: Rotaris and Danielis, 2014b, p. 130.

We took also into account that the buildings of the University of Trieste are spread across the city in seven main locations characterized by different accessibility and parking facilities. Three of these sites are in the city center, two in the suburban area and two in the peripheral area of Trieste. In 2010 almost 21,300 persons commuted to the University of Trieste, 13% were faculty and administrative staff. Our analysis focused only on the persons residing in Trieste, and who could actually travel either by car or by bus, excluding those commuting by train.

We collected 372 interviews. Almost half the respondents (47%) stated they commuted by car and the majority reported they commuted to the university more than 4 times a week. The average travel time of those using the car, 23 minutes, is slightly shorter to the travel time of those using the bus, 24 minutes. Indeed, car users face shorter in-vehicle time, but have additional parking searching time that almost compensates for the longer in-vehicle time of bus users. The data collected allowed us to estimate a random parameter model describing the mode choice of the sample. Our estimates revealed that the preferences for all the time and cost components are highly heterogeneous and that they differ according to status (student versus staff) and car availability. Based on the estimated transport demand model, a scenario analysis of nine TDM policies was performed.

3.1 Effectiveness of hypothetical TDM policies

The first group of policies we analyzed focuses on increasing the cost of travelling by car since, as reported by Meyer (1999) and discussed in the literature[3], they are the most effective ones. They include:

- Policy C1: raising the cost of the annual parking permit. Currently it is available at some university sites to staff only at €40. The aim is to reduce the implicit subsidy of the parking costs granted to

3 Indeed, parking restriction and pricing are two of the most powerful TDM policies and are frequently used to discourage car use in central business districts (Wilson 1995), less so in university campuses, at least in Italy. According to Marsden (2006) when transport alternatives are available, changes to parking supply or price produce substantial modal shift. Bond and Steiner (2006) demonstrate that parking pricing encourages commuters to use alternative modes and also that this policy enables the raising of substantial funds. On this topic, Shoup (1999) concluded that at least a portion of the costs of construction and maintenance of parking areas should be recovered by universities via the found raised charging parking spaces.

some employees on a discriminatory basis (only 7% of the sample are allowed to use these facilities) which, in a private garage in Trieste, would be at least equal to €1,100 per year;

- Policy C2: setting the hourly parking tariff to €0.6, the minimum tariff charged in Trieste. Currently most of the parking areas around the university sites are free of charge and are used by 45% of the sample;
- Policy C3: reducing the number of parking spaces on campus, hence increasing the time needed to find a parking space from the current level of 5 minutes to 15 minutes;
- Policy C4: shifting the parking facilities outside the campus or further away from the university sites, hence increasing the time needed to reach the university from the parking areas from the current level of 3 minutes to 10 minutes.

The second group of policies deals with the bus users' costs[4]:

- Policy B1: fully subsidizing the one-way ticket which currently costs €1.1 with a bus share in our sample equal to 18%;
- Policy B2: increasing the one-way ticket from the current level of €1.1, covering 30% of the variable cost of providing the bus service, to €2.2.

The third group consists of 3 policy mixes:

- Policy mix M1: aimed at reducing the implicit subsidies granted to car users, that is increasing both the monetary cost and the travel time of car users. This policy mix consists of: 1) eliminating the annual parking permit; 2) setting the hourly parking tariff at €0.6; and 3) reducing the number of parking spaces, so that the time needed to find a parking space on campus becomes 20 minutes;
- Policy mix M2: aimed at reducing the subsidies currently granted both to car users and to bus users, with the aim of increasing the revenue cost ratio of the bus company from the current 30% to 50%. More specifically, this policy mix consists of: 1) eliminating the annual parking permit; 2) setting the hourly parking tariff at €1.6; 3) reducing and relocating the parking areas, so that both the time needed to find a parking space and the time needed to reach the university from the parking space become equal to 15 minutes; 4) increasing the one-way bus ticket to €1.65 and the monthly bus ticket to €42 (allowing the bus company to cover about 50% of the variable costs);
- Policy mix M3: aimed at increasing the travel costs of the car users, earmarking the parking revenues to further subsidize the bus users[5]. This policy mix consists of: 1) eliminating the annual parking permit; 2) setting the hourly parking tariff at €0.3 and the one-way ticket at €0.8.

4 A survey conducted in the late 90s by Miller (2001) found that 35 major American universities offered some form of unlimited access transit, that is the University pre-pays the transit provider to carry students, faculty and staff without charging them a fare and then distributes the transit passes to the students and employees who are willing to use the bus. Financing for unlimited access often comes from a combination of student fees, university funds (parking revenue, general funds) and government aid. The user cost and the university subsidy for unlimited access vary across universities. Given the large number of transit passes bought by the university, the fares are substantially discounted. Bond and Steiner (2006) report ridership increases due to fare-free transit between 30% and 50%. Senft (2005) reported that since the universal transit pass was introduced at the University of British Columbia in 2003, a fifty percent increase in transit ridership and a twenty percent decrease in single occupant vehicle traffic were registered.

5 According to a research performed by Schuitema and Steg (2008), in fact, "transport pricing is more acceptable if revenues are allocated to the transport system. When revenues are allocated to benefit users of alternative transportation (for example public transport), car users … expect to benefit more than when revenues are invested in general public funds."

The scenario analysis performed (Rotaris and Danielis, 2014b) shows that the most effective policies in terms of modal shift would be fully subsidizing the one-way ticket (Policy B1), which reduces car users by 58%, followed by further subsidizing bus users, earmarking the parking charges to this aim (Policy mix M3), which decreases car users by 34%, and by setting parking pricing and restrictions (Policy mix M1), which diminishes car users by 29%, as illustrated in Table 3. Increasing the one-way ticket (Policy B2), with the aim of reducing the subsidy currently paid by local authorities to the service operator, a policy actually debated in Italy in order to reduce the public expenses, would hugely impact the modal share in favor of car use.

Table 3 Impact on modal share of each TDM policy.

	Number of commuters switching from car to bus	% variation of car users	% variation of students using the car	% variation of faculty using the car	% variation of staff using the car
C1 annual parking permit €160	5	-3	0	-7	-3
C2 hourly parking tariff €0.6	23	-12	-19	-7	-5
C3 parking searching time 15'	3	-2	-1	-2	-2
C4 time form car to univ. 10'	27	-14	-18	-12	-10
B1 free one-way ticket	111	-58	-71	-55	-41
B2 one-way ticket €2.2	-75*	+39	+68	+19	12
M1 Mix1 Parking pricing and restrictions	55	-29	-25	-36	-30
M2 Mix2 Cutting both bus and parking subsidies	48	-25	-16	-36	-32
M3 Mix3 Subsidizing bus with parking charges	65	-34	-35	-38	-30

Note: * commuters switching from bus to car

The ability of these policies to induce a modal shift varies according to the type of user considered: students, faculty and administrative staff (see Rotaris and Danielis, 2014b, for more details). In fact, the most effective policy is fully subsidizing the one-way ticket no matter who the user type considered is. Policy mixes M1 and M2 are almost equally effective if the university employees are the target of the policy, but much less effective when the students are targeted. On the contrary, setting an hourly parking tariff at €0.6 would be much more effective for students than for employees[6].

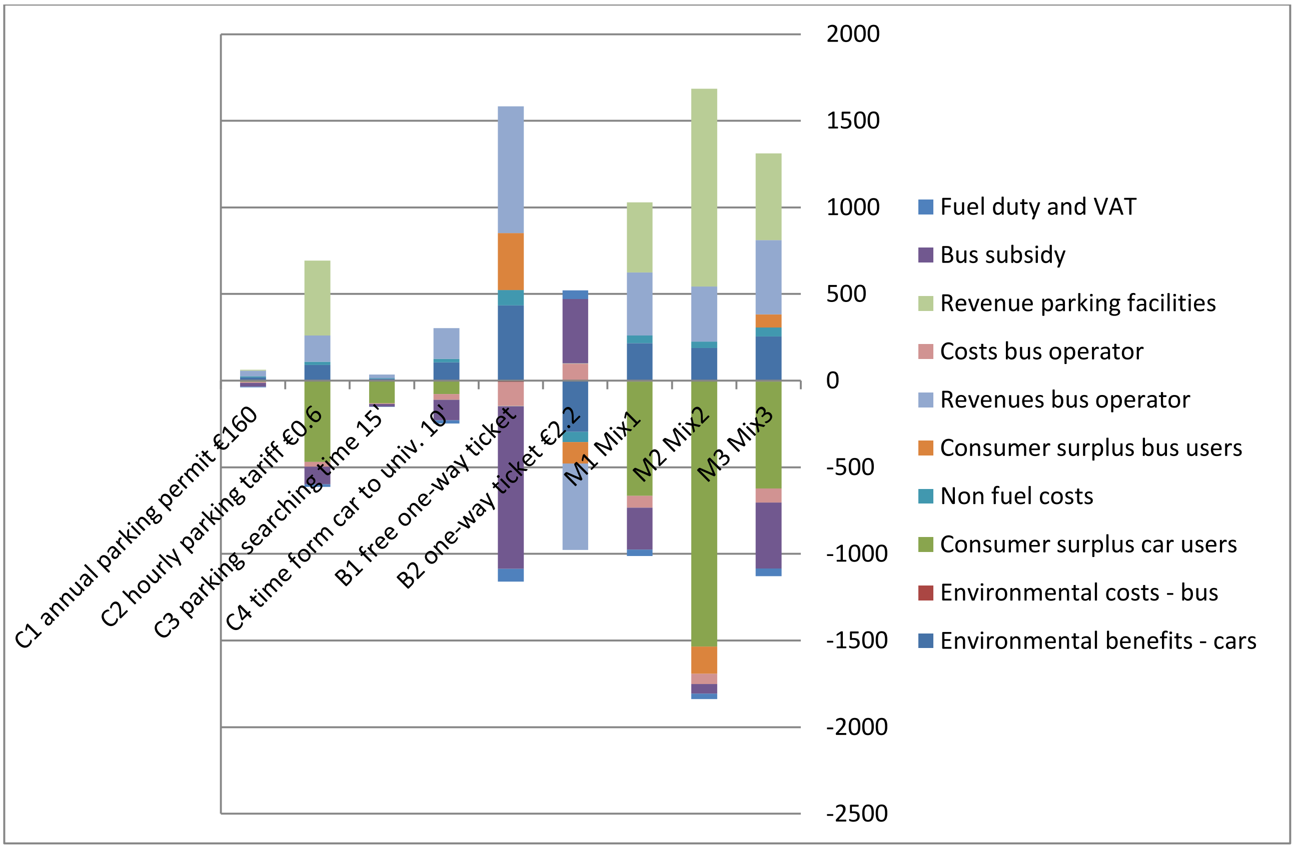
4. Cost-benefit analysis of nine hypothetical TDM policies

The results of the previous analysis demonstrate that the most effective policies in reducing car use are the full subsidization of public transport (Policy B1) and the increase of the generalized transport cost of car users with a joint reduction of the bus fares (Policy mix M3). It needs to be tested whether this conclusion is confirmed when the social costs and benefits of the policies are taken into account. To this aim a cost-benefit analysis has been performed, the results of which are summarized in Figure 1. A detailed description of the results, of the data used and of the methodology applied is presented in Appendix A1 and A2.

[6] The policy effectiveness will substantially depends also on the specific university site considered, since in Trieste there are seven location sites characterized by very different public transport service levels (number of bus lines, bus stops and frequency of bus services) and parking facilities (number of parking spaces and level of parking tariff).

The cost-benefit analysis shows that the most effective policies (Policy B1 and Policy mix M3) are also the most efficient ones, providing a net social annual benefit of €154,450 (Policy B1) and €67,147 (Policy mix M3), respectively. Figure 1 presents their main cost and benefit components. It is interesting to note that while Policy B1 does not impact car users' surplus and produces a large positive impact on bus users, the opposite is true for Policy mix M3, whose main positive effects are the additional revenues accruing to the bus company and to the parking facility operator, whereas the largest negative impact is on the car users' surplus. The implications in terms of policy acceptability are important and should be carefully taken into account for their successful implementation.

Figure 1 Cost and benefit components of each policy type



Three policies - increasing the one-way ticket (Policy B2), policy mix M2 and increasing the parking searching time (Policy C3) - are inefficient, since their implementation would reduce the net annual benefit by €165,993, €55,677 and €42,119, respectively.

A sensitivity analysis and a risk analysis have also been performed. They indicate that the monetary value of car congestion and the average distance travelled are the parameters that affect the net benefits the most and that none of the policies, except Policy mix M1, present switching signs of the net benefit variable, thus confirming the robustness of the results obtained. For a detailed presentation of the sensitivity and risk analysis refer to Appendix A3.

5. Efficiency and effectiveness of the TDM policies

The nine hypothetical policies are plotted in Figure 2, their efficiency, measured in terms of daily net social benefit, is depicted in the vertical axis, while their effectiveness, measured as the percentage change of car use, is depicted in the horizontal axis. Consequently, the most desirable policies are the ones in the upper-left quadrant of the diagram while the least desirable are the ones in the lower-right quadrant.

It can be seen that all policies but one (Policy B2) are effective in reducing car use, but only six of them are efficient (Policies B1, M3, M1, M2, C4, C2, C1 and C3) while three are inefficient. Interestingly, effectiveness and efficiency are quite well but not perfectly correlated.

Examining each policy more in detail, the following can be noted.

Policy B2 - “increasing the one-way bus ticket to €2.2”, aimed at reducing the subsidy paid by the local authority - is the most inefficient (-€455) and the least effective policy (75 additional car users). The subsidy savings are, in fact, more than compensated by the substantial environmental impact caused by the modal shift (-€289) and by the noticeable reduction of both the bus users surplus and the revenues of the bus operator. The impact of this policy would be highly negative both in terms of modal shift and in terms of net social costs.

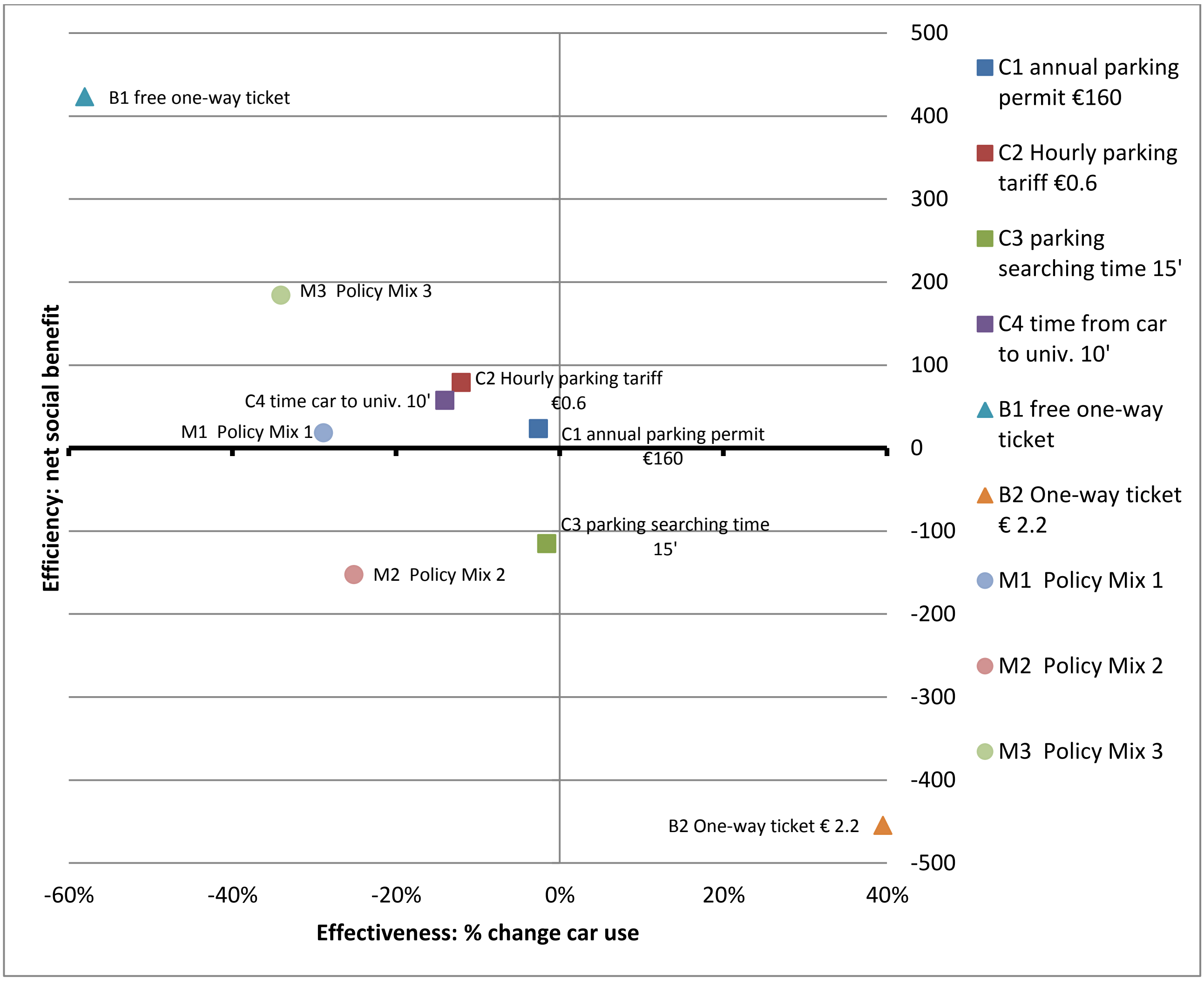
Policy C1, “increasing the annual parking permit to €160”, and Policy C3, “increasing the parking searching time of employees by 5 minutes and of students by 10 minutes”, are both ineffective. Policy C1 provides a positive although moderate net benefit (€23), due to the positive environmental impact and the revenue increase accruing to both the car park operator and the public transport company that more than offset the loss of the car users’ surplus. Policy C3 is also inefficient (-€115), since the decrease of the car user surplus far outweighs the environmental benefits and the increase in net revenues of the public service operator.

Policy C2, “increasing the hourly parking tariff to € 0.6”, and Policy C4, “increasing the searching parking time to 15 minutes” via the relocation of the parking facilities further away from the university sites, are definitely more effective than the previous ones, reducing the number of car users by 23 and 27 units, respectively. For both policies the difference between the social benefits and costs is positive and the net social benefits are comparable, although the decrease of the car users’ surplus is considerably higher with Policy C2 (-€448) than with Policy C4 (-€53) and is almost compensated by the significant revenues of the car park operator (€432). It should also be noticed that in order to simplify the analysis the costs needed to relocate the parking facilities have not been taken into account, a cost component that would further reduce the already small efficiency gains estimated for Policy C4.

The full subsidization of the bus ticket (Policy B1) is the most preferable policy both in terms of effectiveness, reducing the number of car users by 58%, and in terms of efficiency, generating a positive net social benefit of €423. This result is mainly due to the substantial environmental benefits allowed by the reduction of car users, as well as the increase of the bus users’ surplus. The higher costs of the public subsidy, however, more than offsetting the additional revenues of the public service operator, would jeopardize the financial sustainability of this policy.

Finally, the three Policy mixes have been analyzed. They are very similar in terms of effectiveness, allowing a modal shift ranging from 25% to 34%, but they are very different in terms of efficiency. Policy mixes M1 and M2, in fact, are particularly unfavorable for car users and Policy mix M2 also for bus users. The consumers' surplus decreases and the additional subsidies needed are not offset by the environmental benefits and by the increased revenues of both the public transport and the car park operators. Policy mix M3, instead, allows the compensation of the costs of the subsidies for the bus company with the revenues gained by the car park operator, ensuring the financial sustainability of the policy. Moreover, the decrease of the car users' surplus is more than compensated by the increase of the bus users' surplus and the environmental benefits.

Figure 3 Efficiency versus effectiveness of the policies analyzed.



Finally, it needs to be stressed that, although Policy B1 is the best policy, , depicted in the upper left corner of Figure 3, both in terms of effectiveness and efficiency, it would require a financial support that is not compatible with the current lack of resources faced by the local authorities. The second best policy is, then, Policy mix M3.

6. Conclusions

Universities are large generators/attractors of commuters, generating substantial impacts on congestion levels, parking availability and environmental quality, especially when they are located in urban areas.

Specific TDM policies should then be designed in order to satisfy the commuters' needs but also to improve the economic and environmental sustainability of the transport system.

Italian universities are increasingly implementing policies aimed at reducing car use and at increasing public transport, bike- and car-sharing and carpooling. The effectiveness of these policies has been, however, seldom assessed, not only in Italy but in other countries as well, and, to the best of our knowledge, no study exists on their efficiency.

This paper, making use of a commuting demand model we estimated for the University of Trieste (Rotaris and Danielis, 2014b), has analyzed both the effectiveness and the efficiency of nine hypothetical policies that could be implemented by the university Mobility Manager. Overall, it can be seen that all policies but one (Policy B2) are effective in reducing car use, but only six of them are efficient (Policies B1, M3, M1, M2, C4, C2, C1 and C3) while 3 are inefficient.

We find that fully subsidizing bus fares (Policy B1) would be the most effective and efficient policy, since it would reduce the number of car users by 58% and generate a positive net social benefit of €423. The effectiveness of the policy is neither new, nor surprising, since it has been already stated in many previous studies (Boyd *et al.*, 2003; Brown *et al.*, 2003; Dorsey, 2005; Bond and Steiner, 2006; Akar *et al.*, 2012; Barla *et al.*, 2012; Zhou, 2012 and 2014; Whalen *et al.*, 2013).

However, it is doubtful whether fully subsidizing bus fares is financially sustainable. Our evidence in Italy is that the scarcity of public funds, competing among alternative social uses, does not realistically allow a higher level of bus subsidization. According to our results, at least the fare discounts currently offered to employees and students by the Italian universities should be maintained. We also find that increasing the cost of the bus ticket[7] would be highly detrimental both in terms of modal shift and in terms of efficiency.

The second best policy - a mix of bus subsidies and parking restrictions (Policy mix M3) - should then be implemented. In case of the University of Trieste, our model suggests the adoption of a policy mix based on a relatively low hourly parking tariff (€0.3 per hour) and using the parking revenues to subsidize the bus users. This suggestion is in line with Aoun *et al.* (2013) who states that unlimited access transit in combination with strong parking policies are key factors to offset parking demand and congestion issues around campuses.

Contrary to previous evidence (Meyer, 1999; Toor and Havlick, 2004; Shoup,2005; Marsden, 2006; Barata et al., 2011; Brockman and Fox, 2011; Barla *et al.* 2012; Delmelle *et al.*, 2012), we find that increasing only the monetary parking cost (Policy C2) would produce a modest modal shift, since it would reduce the number of car users by only 12%. We also find that reducing the number of parking spaces (Policy C3), and consequently increasing the searching parking time, would only marginally affect the percentage of people using the car, while substantially decreasing the net social benefit.

Our research demonstrates the importance of performing accurate effectiveness and efficiency analysis when designing and implementing new TDM policies, since their outcome, especially in terms of efficiency, could be very different from what might be expected. In our case study Policy mix M2, whose effectiveness was quite high in terms of modal shift, turned out to produce highly inefficient outcomes.

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[7] According to ISFORT (2014,a p. 13) between 2002 and 2012 the bus ticket increased by 51% (the inflation rate within the same time horizon was 24%).

The focus of the paper is on the effectiveness and the efficiency of different TDM policies. Obviously, their acceptability should also be carefully evaluated, as suggested by Schade and Schlag (2003). For instance, Policy mix M3 generates environmental benefits (€249) and increases the bus users' surplus (€75) at the expense of a substantial decrease of the car users' surplus (-€566). Therefore, car drivers might oppose its implementation. Our next research effort will focus on measuring the impact that these policies have on students and staff at different university sites, since it might depend on the attitude that different segments of the university community have towards alternative transport modes and on the parking conditions and public transport availability at the various university sites.

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Appendix:

A1 Cost benefit analysis results

Table A1 Cost-benefit analysis by policy type

	C1 annual parking permit €160	C2 hourly parking tariff €0.6	C3 parking searching time 15'	C4 time form car to univ. 10'	B1 free one-way ticket	B2 one-way ticket €2.2	M1 Mix1	M2 Mix2	M3 Mix3
Commuters switching from car to bus	5	23	3	27	111	-75*	55	48	65
Environmental benefits - cars	20	90	12	105	434	-295	216	188	255
Environmental costs - bus	0	-2	0	-2	-9	6	-5	-4	-5
Consumer surplus car users	-7	-466	-131	-75	0	0	-660	-1530	-618
Vehicle operating costs – non fuel	4	18	2	22	89	-60	44	38	52
Consumer surplus bus users	0	0	0	0	329	-123	0	-157	75
Revenues bus operator	33	152	20	177	732	-498	364	317	430
Costs bus operator	-6	-28	-4	-33	-136	93	-68	-59	-80
Revenues parking facilities	6	432	0	0	-2	1	405	1141	501
Bus subsidy	-22	-101	-14	-118	-939	371	-243	-55	-382
Fuel duty and VAT	-3	-15	-2	-18	-74	51	-37	-32	-44
Net daily benefit	23	79	-115	57	423	-455	18	-153	184
Net annual benefit	8,494	28,845	-42,119	20,924	154,450	-165,993	6,589	-55,677	67,147

Note: * commuters switching from bus to car

A2 Details of cost benefit analysis calculations

Environmental benefits and costs

The estimation of the environmental benefits and costs of the modal shift induced by each policy is based on the monetary value of the external costs by cost category (air pollution, climate change, noise, congestion, accidents) and transport mode (car, bus) published by CE Delft, Infras, Fraunhofer ISI (2011) and reported in Table A2.

Table A2 External costs by cost category and transport mode

	Car (€)	Bus (€)
Air pollution 1000 vkm	9.6	63.2
Climate change 1000 vkm	17.3	9.1
Noise 1000 vkm	0.5	2.5
Congestion 1000 vkm[8]	330	*660*
Accidents 1000 pkm(car)/ vkm(bus)	33.6	12.3

Since the data of the length of the daily travel by each respondent was not collected during the interview, an average commuting distance of 5 km is assumed, in line with the data reported by ISPRA (2013, p.401) for the cities located in the northeast of Italy. To transform the parameters from vehicle-km to passenger-km, it is assumed that car users travel alone (transformation coefficient equal to 1) and that each bus can carry an average of 90 individuals (coefficient of transformation equal to 0.01). For each transport mode

[8] As there is no specific data for the bus, we assumed a value that is twice the value reported for cars.

and policy, the number of individuals changing transport mode is then multiplied by the average distance travelled and by the external cost coefficient (estimated in passenger-km).

For all the policies analyzed, except Policy B2 “increasing the one-way ticket to €2.2”, the environmental benefits of reducing the number of car users is considerably higher than the environmental costs of the additional bus users and the net environmental benefits represent a very high percentage of the total net benefits (refer also to Figure 1). Policy B1 “full subsidization of the one-way ticket” presents the greatest net environmental benefit (€424) due to the large modal shift.

Consumer surplus of car and bus users and vehicle operating costs.
The increase (or decrease) of the generalized cost of transport caused by each policy is specifically estimated for each commuter type: car users and bus users. The monetary value of the travel time components affected by the policies, that is the time needed to find a parking space and the time required to reach the place of destination from the parking area, are based on the parameters of a choice model estimated using the revealed and stated preferences collected from the sample (Rotaris and Danielis, 2014b, p. 134). The model used is a random parameter logit model, where the density probability function of the two travel time components and of the hourly parking costs are assumed to be triangularly distributed.

Since the parameters of both the time and cost components of the generalized travel cost are not fixed, in order to derive the monetary value of time a Monte Carlo simulation is used. From the probability density function of each parameter 100,000 values are drawn, for each draw the ratio of the value of the time parameter and the cost parameter is calculated. Finally, the average of the 100,000 ratios obtained is estimated. The results are reported in Table A3.

Table A3 Value of parking searching time and of the time needed to go from the car to the university by commuter type.

	Value of parking searching time (per hour)	Value of time needed from car to university (per hour)
Students	€ 1.9	€ 10.2
Employees	€ 7.0	€ 0.4

The variation of the consumers’ welfare (car or bus users) is estimated applying the rule-of-half, that is multiplying the increase (or decrease) of the generalized cost of each transport mode by the sum of the number of commuters using the transport mode before and after the policy implementation, divided by two. The analysis is performed for each transport mode and for each policy affecting the amount of time needed to find a parking space and the time needed to reach the university from the parking facility (Policy C3, Policy C4, Policy mix M1, Policy mix M2).

The larger the number of car drivers switching to the bus, the larger the cost savings from non-fuel operating costs, partially compensating the surplus loss of the car users. The vehicle operating costs due to engine and tire wear are calculated multiplying €0.08, the estimated operating cost per km (Maffii *et al.*, 2011, p.106), by the number of commuters changing transport mode and by the average distance travelled.

According to our results the most demanding policy for the car users is Policy mix M2 (-€1.491), followed by Policy mix M1 and Policy mix M3, since they are substantially based on increasing the parking costs. Policy C3 “increasing the parking searching time” and Policy C4 “increasing the time required to reach the university from the parking area”, have a considerably smaller impacts.

Bus users are much less affected than car users by all the policies analyzed, except for the Policy B1 “full subsidization of one-way ticket” that would increase the bus users’ daily welfare level by €329.

Revenues and costs of the public transport sector.
To simplify the analysis it is assumed that the revenues of the public transport sector are equal to the additional number of users multiplied by € 3.3, a value comprising both the ticket paid by the customers and the subsidy paid by the local authorities to fully cover the variable costs of the bus operator.

The average operating cost per passenger is € 1.23 and is obtained multiplying €0.96, that is the value of the average operating costs per passenger estimated in 2002, by 1.28, that is the rate the operating costs increase estimated from 2002 to 2012 (Asstra, Hermes and Isfort, 2012, p.21 and p. 78).

The policies improving the economic performance of the public transport sector the most are Policy B1 “fully subsidizing the one-way ticket”, which increases the net revenues of the public transport operator by €596, and Policy mix M3, moderately increasing in the cost of parking in order to finance a partial reduction of the cost of the ticket, which increases the net revenues of the public transport operator by €350. Policy B2, “increasing of the bus ticket to €2.2”, would be extremely negative for the economic sustainability of the public transport sector, since it would reduce the net revenues of the operator by €405 due to the large modal shift.

Car park revenues.
The revenues of the car park operator are calculated multiplying the tariff foreseen by each policy by the number of users of the infrastructure, assuming a daily average parking time equal to 5 hours. All policies, except those increasing the travel time of car users (Policy C3 and Policy C4) or increasing the subsidy of the bus ticket (Policy B2), have a noticeable increase of the park revenues, ranging from €1,141 (Policy mix M2) to €405 (Policy mix M1). Even a minimal increase of the hourly parking cost, for example € 0.3 per hour as in the case of Policy mix M3, would generate substantial daily revenues (€501). Since the parking areas already exist, no additional costs have been added to the analysis.

Public transport subsidy.
To simplify the analysis, the subsidies paid per passenger by the local authorities are assumed to be €2.2, which is twice the value of the ticket paid by the passengers (ISFORT, 2014b, p.10). The subsidy increase is therefore calculated multiplying the additional number of bus users generated by each policy by the value of the subsidy granted per passenger. When the policies foresee a change of the ticket cost (as in Policy B1, B2, C2 and C3), the value of the subsidy per passenger has been varied accordingly, so that the sum of the fare plus the subsidy is equal to €3.3, which is the estimated variable cost of the bus operator per passenger. Consequently, the subsidy change caused by the policies depends both from the variation of the number of passengers and from the different contribution of the local authority to the variable cost of the public transport operator.

All the policies analyzed require an increase of the subsidies paid by the local authorities, the only exception being Policy B2 that increases by 100% the bus fare paid by the passengers. The most expensive policy for the public body, beside Policy B1 “full subsidization of the one-way ticket” (-€939), is Policy mix M3 (-€382), not only because it induces a significant modal shift, but also because it increases the subsidy per passenger by 14%.

Fuel duty and VAT.

It is assumed that the value of fuel duty and VAT per km is equal to € 0.067 (Maffii *et al.*, 2011, p.106). The reduction of the taxes collected by the government is estimated multiplying this parameter by the average distance traveled and by the number of commuters using the bus instead of the car.

These costs are marginal if compared to the net social benefits of most of the policies analyzed, but increase the larger the modal shift induced by each policy, as in Policy B1 or Policy M3, whose forgone duties and taxes are equal to €74 and €44, respectively. Indeed, taking into account both the additional resources needed for the bus subsidization and the reduction of the fuel duty and VAT, it turns out that the public body should invest considerable additional resources to finance all the policies analyzed, except for Policy B2.

A3 Sensitivity and risk analysis of the daily net benefit.

A sensitivity analysis of the net social benefit of each policy has been performed with respect to each uncertain parameter used for the cost-benefit analysis. The parameters' value ranged from +20% to -20% of the value currently used. In Table A4 the absolute value of the ratio of the difference of the net benefit estimated at the extremes of the parameter range over the value of the net benefit estimated at the current value is reported. The monetary value of car congestion and the average distance travelled are the parameters most affecting the net benefit of almost all the policies considered.

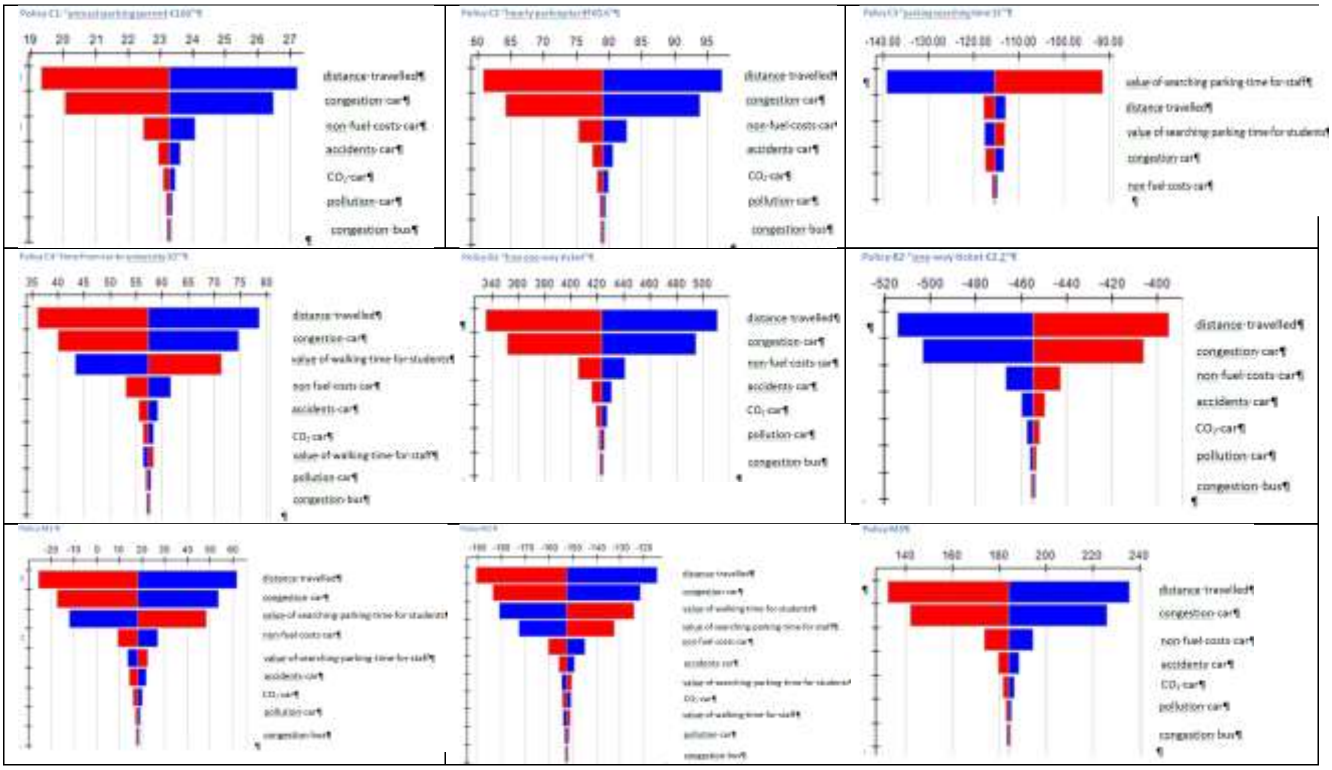
Table A4 Net-benefit percentage change by policy type and uncertain parameter.

Uncertain parameters	**C1 annual parking permit €160**	**C2 hourly parking tariff €0.6**	**C3 parking searching time 15'**	**C4 time form car to univ. 10'**	**B1 free one-way ticket**	**B2 one-way ticket €2.2**	**M1 Mix1**	**M2 Mix2**	**M3 Mix3**
pollution car	1%	1%	0%	2%	1%	1%	12%	1%	1%
CO_2 car	1%	2%	0%	3%	2%	1%	21%	2%	2%
noise car	0%	0%	0%	0%	0%	0%	1%	0%	0%
congestion car	28%	38%	3%	61%	34%	21%	394%	41%	46%
accidents car	3%	4%	0%	6%	4%	2%	41%	4%	5%
pollution bus	0%	0%	0%	0%	0%	0%	1%	0%	0%
CO2 bus	0%	0%	0%	0%	0%	0%	0%	0%	0%
noise bus	0%	0%	0%	0%	0%	0%	0%	0%	0%
congestion bus	1%	1%	0%	1%	1%	0%	9%	1%	1%
accidents bus	0%	0%	0%	0%	0%	0%	0%	0%	0%
distance travelled	34%	46%	4%	74%	41%	26%	484%	50%	56%
searching parking time students	0%	0%	4%	0%	0%	0%	48%	3%	0%
searching parking time staff	0%	0%	41%	0%	0%	0%	334%	26%	0%
time park-univ students	0%	0%	0%	49%	0%	0%	0%	37%	0%
time park-univ staff	0%	0%	0%	3%	0%	0%	0%	2%	0%
non fuel car operating	7%	9%	1%	15%	8%	5%	98%	10%	11%
Min daily net-benefit	**19**	**61**	**-139**	**36**	**335**	**-514**	**-26**	**-191**	**132**
Max daily net-benefit	**27**	**97**	**-91**	**79**	**511**	**-395**	**62**	**-115**	**235**

None of the policies result in the net social benefit variable switching sign over the parameters range analyzed, except for Policy mix M1, whose positive, although small, net benefit turns to a negative value if the parameter of the monetary value of car congestion and the average distance travelled are much lower than the values actually used and if the searching parking time for staff is much higher than the value actually used.

In Figure A1 the tornado charts illustrate how the net social benefit of each policy changes as each uncertain parameter changes over a range of -/+20%. The blue corresponds to a positive variation of the uncertain parameter, while the red corresponds to a negative variation of the uncertain parameter.

Figure A1 Sensitivity analysis by policy type and by uncertain parameter.



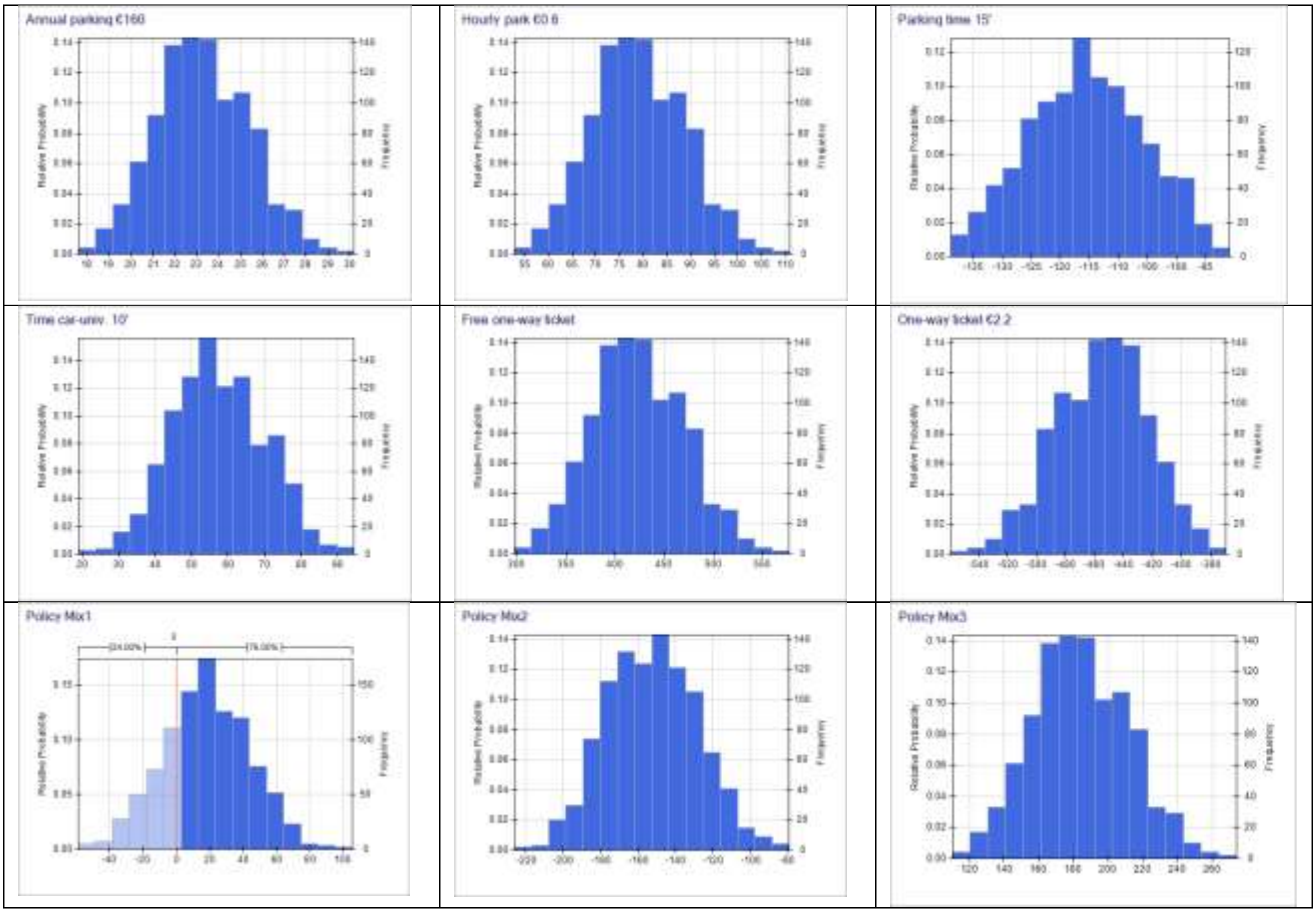
The robustness of the net-benefit results has been evaluated also via a risk analysis. A Monte Carlo simulation with 1,000 trials has been performed for each policy assuming that the density probability function of each uncertain parameter is triangularly distributed with the minimum, maximum and mean values reported in Table 8.

Table A5 Minimum, maximum and mean values of the triangular density function of the uncertain parameters.

Uncertain parameters	Minimum	Maximum	Mean
pollution car	7.7	11.5	9.6
CO_2 car	13.8	20.8	17.3
noise car	0.4	0.6	0.5
congestion car	264	396	330
accidents car	7.7	11.5	9.6
pollution bus	50.6	75.8	63.2
CO_2 bus	7.3	10.9	9.1
noise bus	2.0	3.0	2.5
congestion bus	528	792	660
accidents bus	9.8	14.8	12.3
searching parking time students	1.5	2.2	1.9
searching parking time staff	5.6	8.3	7.0
time park-univ students	8.1	12.2	10.2
time park-univ staff	0.3	0.5	0.4
non fuel car operating cost	0.064	0.096	0.08
distance travelled	8	12	10

The diagrams of Figure A2 represent in the horizontal axis the range of the net-benefit values estimated via the Monte Carlo simulation for each policy and in the vertical axis the relative probability.

Figure A2 Risk analysis of the net-benefit of each policy.



It should be noted that the sign of the net-benefit value does not change for any of the policies analyzed except for Policy mix M1, whose probability of producing a positive result is 76%. The risk analysis confirms the robustness of our results.