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The economic contribution of public bike-share to the sustainability and efficient functioning of cities

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ABSTRACT

An expanding literature has explored the benefits of public bike-share schemes from various perspectives, including user characteristics, journey time savings, convenience, health benefits and reductions in motor vehicle use. However, rather few papers have examined bike-share schemes in economic terms. In this paper we place these benefits in an economic context of private individual benefits and public good benefits. Using data from a survey of bike-share users in Dublin, Ireland, we critically examine the relative value of these benefits and their impact on the spatial functioning of cities. We demonstrate that, for this particular scheme, the benefits associated with time savings far exceed the benefits that are commonly claimed for modal transfer. We go on to describe how, by delivering time savings and improving spatial connectivity, bike-share schemes reduce effective density and supply both conventional and wider economic benefits for the urban economy that are commensurate with investment in public transport schemes. Finally, we show how investment in the Dublin bike-share scheme has a positive benefit-cost ratio that exceeds estimates based on a more restricted appraisal.

1. Introduction

Urban administrations have sought to encourage cycling as an efficient means of movement and a sustainable form of transport (Pucher & Buehler, 2005). There are also benefits to the liveability of cities and to public health (Borjesson & Eliasson, 2012) These include the potential for cycling to reduce motor vehicle use along with the external social cost this imposes in terms of pollution, greenhouse gases, dirt, noise, and congestion (Saelensminde, 2004; Shaheen , Guzman , & Zhang, 2012).

However, various studies have revealed the challenge that policy makers face in attempting to raise the modal share of cycling (Ehrgott, Wang , Raith , & Van Houtte, 2012) due, for example, to the physical demands of lengthy journeys, safety considerations or the anxiety cyclists can feel when in close proximity to traffic (Macmillan et al., 2014; Nolund & Kunreuther, 1995; Parkin et al., 2008; Rietveld & Daniel, 2004; Saelensminde, 2004). Consequently, it is argued that an increase in urban cycling is more likely to be achieved through a comprehensive cycle infrastructure including cycle lanes, cycle parking facilities, dedicated traffic lights and traffic flow moderation (Buck and Buehler, 2012; Caulfield, 2014; Ehrgott et al., 2012; Peattie & Peattie, 2009; Ryley, 2006; Yang, Sahlqvist , Mcminn , Griffin , & Ogilvie, 2010) In particular, cycle lanes have been found to have a significant impact on the uptake of cycling (Barnes & Thompson, 2006; Hunt & Abraham, 2007; Saelensminde, 2004; Yang et al., 2010).

Public bike-share (PBS) can be a part of this infrastructure. Within the last ten years there has been a rapid increase in the number of PBS schemes around the world which are now estimated to amount to over 1000 (Metro bike, 2016). These schemes consist of strategically sited bicycle docking stations from which users can borrow a bicycle, typically for a short journey, before returning it to the same or another station. Users pay an annual subscription that allows for free use within a set time period or pay on site for a fixed period. Although PBS has been around since the mid-1990s, technological advances have enhanced its efficiency and increased its attraction to the public (Corcoran and Li, 2014; Shaheen et al., 2012). Automated bicycle stations facilitate access and security. Smartphone apps are now also being introduced to allow users to identify the location and availability of bicycles.

DeMaio (2009) argues that PBS schemes typically contribute to an average increase of 1.0-1.5% in bicycle modal share in the first year of operation. The popularity of these systems derives from their capacity to meet user needs in relation to work, non-work and leisure trips. In this context, studies have demonstrated that

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users are provided with a considerable incentive when PBS facilities are integrated with public transport (Bachand-Marleau et al., 2011; Martens, 2007; Pucher & Buehler, 2008). PBS offers much improved connectivity between destinations, including first and last mile connections between home, public transport and work places (Shaheen et al., 2012). In this respect, PBS has a distinct advantage in that the benefits extend to a population beyond that of the geographical area where the scheme is physically located.

PBS is not without its costs. For example, installing stations is costly, requiring the removal of asphalt or paving stones, underrouting of wiring and hook-ups to electrical sources (DeMaio 2009; ITDP 2013). Bike stations can also replace parking or public space (Buehler & Hamre, 2014). In all cases, there is a need for public authorities to be convinced of the virtues of this investment compared with investment in other modes of transport (Krizek, 2007). Objectivity requires that bicycle facilities are evaluated in the same manner. However, while PBS typically appeal to a smaller segment of the population than some other types of public transport, the relative scale of investment also tends to be smaller.

2. Economic benefits of public bike-share

2.1. Economic assessment

There have been economic assessments of the benefits of cycling, for example Borjesson and Eliasson (2012), Krizek (2007) and Saelensminde (2004), and of the impact on businesses adjacent to bike stations for PBS (Buehler & Hamre, 2014), but not of the wider economic benefits of PBS. A challenge to the analysis of the costs and benefits is the availability of data on use patterns and management costs. This situation is changing as on-board computers provide data on stocks and flows (Corcoran and Li, 2014; O'brien , Cheshire , & Batty, 2013), although such data is often regarded as being commercially sensitive. More specific details on use characteristics, journeys and user perceptions must be collected through surveys of users.

2.2. Private benefits

In common with other transport investments, bicycle infrastructure and PBS provides a mixture of private benefits to users and public good benefits. Demand for PBS depends on users realising private benefits. These include cost savings, savings on journey time, convenience, health and perceived utility benefits to well-being (Fishman et al., 2014; Fuller et al., 2011; Shaheen et al., 2010). By comparison, bicycle ownership involves purchase costs, maintenance costs and the risk of theft, considerations that may deter potential users. For PBS, costs are limited to subscription or rental costs and to the optional purchase of appropriate clothing and head gear. PBS is therefore an option for both existing cyclists and for people who do not own a bicycle (Martens, 2007).

A major benefit of cycling generally is the capacity to shorten journey times relative to other forms of transport where these are subject to congestion or delay (Sener et al., 2009). Borjesson and Elliasson (2012) find that people who cycle regularly place a high value on time and desire to complete a journey swiftly. In this respect, PBS has the further virtue that it allows users to circumvent the usual trade-off between the attraction of cycling for short trips and the physical demands of cycling over longer journeys. It is available on demand for short trips and can be used in conjunction with public transport or even the private car as a part of longer trips. Various studies (e.g. (Buehler & Hamre, 2014; Faghih-Imani, Eluru, El-Geneidy, Rabbat, & Haq, 2014, Fishman et al., 2014; Martin & Shaheen 2014; Rixey, 2013) have found that savings in journey time are a key motivation for use. However, the gbenefit of these time savings has not been estimated in economic terms.

2.3. Public benefits

2.3.1. Business sales

Buehler & Hamre (2014) examined the perceptions of retail business managers towards PBS and found mixed attitudes with 20% recording a negative impact on the neighbourhood, while 70% reported a positive impact. Perceptions of change in sales were found to vary by location and nature of product. These also appeared to depend on the characteristics of the cyclists. For instance 16% of cyclists reported new spending in certain locations due to the new accessibility permitted by PBS.

2.3.2. Health benefits

The private benefits realised by individual users extend to public benefits through increased uptake of cycling and the benefits this provides to the wider population. Examples are the private and public aspects to journey time savings and the relationship between reduced private motor vehicle use and reduced external costs of congestion, pollution and CO_2 emissions (Saelensminde 2004; Shaheen et al., 2012).

Health is another area in which private and public benefits are intertwined. Cycling is a recommended means of physical exercise which provides private benefits to the individual, but also contributes to improved public health and reduced expenditure on healthcare (Boland & Murphy, 2012). Many instances of heart disease, type-2 diabetes, breast cancer and colon cancer could be avoided by maintaining a moderate level of activity for 30 min per day (Bize et al., 2007).[1] Inactivity has been estimated to cost developed countries between €150 and €300 per citizen according the World Health Organisation (WHO, 2004). Even larger benefits have been identified where improved health contributes to reduced premature mortality (Deenihan & Caulfield, 2014; Gotschi, 2011). There are also potential social benefits in terms of improved productivity at work (van Amelsvoort et al., 2006). Although it is notoriously difficult to attribute overall health benefits to any one activity, PBS provides a distinct contribution in this respect as it allows for exercise in association with work or other trips as distinct from cycling for leisure or dedicated fitness activities.

Set against these benefits are possible adverse impacts on health. Strak et al. (2010) report some adverse respiratory impacts among cyclists in the Netherlands due to exposure to particulates or soot on busy roads, although de Nazelle and Nieuwenhuijsen (2010) argue that cyclists' freedom to choose quieter routes exposes them to lower levels of pollutants than other road users. Consideration must also be given to the risk of traffic accidents. For PBS, there is the risk that some users will be less experienced or may not be using a protective helmet. However, new cycle infrastructure, including PBS, will increase cycle uptake and can heighten drivers' awareness of cyclists (Jacobsen, 2003). In a review of various health implications, de Hartog et al. (2010) find that, overall, the health benefits of physical exercise outweigh the risks from exposure to air pollution or traffic accidents.

If PBS was to result in a distinct modal shift from private vehicle use then the health benefits of greater cycling would also extend to the wider population through reduced emissions of particulates, nitrogen dioxide and sulphur dioxide. There would also be other

[1] As recommended by the Irish Heart Foundation (http://www.irishheart.ie/iopen24/physical-activity-t-7_19_73.html). Similar recommendations are made by the U.S. Dept. of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. 2008 and the Centre for Disease Control and Prevention 2010 http://www.cdc.gov/transportation

public good benefits in terms of lower emissions of greenhouse gases and reduced congestion. However, while cycle infrastructure and PBS does have the potential to reduce car use, the cross-elasticity between motor vehicle use and cycling has been shown to be low (Borjesson & Eliasson, 2012; Parkin et al., 2008). The evidence to date is that much of the transfer to PBS has been from walking or public transport rather than from private vehicle use (Bachand-Marleau et al., 2011; Fishman et al., 2013; Martin & Shaheen, 2014; Ricci, 2016). Walking, like cycling, is a valuable form of exercise and so transfers from walking would reduce the net benefits to health.

2.3.3. Time savings and wider economic benefits

Journey time has an opportunity cost in that this time can be spent doing something else, either an activity that provides greater utility to the traveller or time spent in productive activity to the benefit of both the individual or an employer. Potentially, PBS can make a significant public good contribution to the city economy by improving connectivity between journey origin and destination and by reducing journey time, especially for commuting journeys and in–work trips where time savings can be used productively as working time

In addition, time savings due to PBS provide ‘wider economic benefits’. Productivity benefits due directly to time savings provide only one perspective on the economic benefits of PBS. Public authorities invest in transportation schemes because they provide public good benefits by enabling a city to function more efficiently and competitively. To account for this effect, the concept of wider economic benefits (WEBs) has now been included in official UK guidance (UK DofT 2014) and relates closely to the discussion of “other economic impacts” included in Ireland's own Department of Transport guidelines (2009). The guidance suggests that quantified estimates of WEBs be included in the final adjusted stage of a cost benefit analysis.

WEBs are identified as comprising of four principal elements:

- Productivity gains due to workers being able to access more productive jobs.
- Enhanced labour force participation due to reduced commuting costs or time, providing people with wider geographical choice of employment.
- Reductions in imperfect competition compared with other cities due to improved competitiveness and increases in output, and
- Agglomeration benefits, i.e. gains in productivity arising from improvements in business proximity and effective density (a spatial extension of journey time savings).

Other social or public good benefits which could potentially be valued in economic terms are discussed, for example, by Ricci (2016) or Rouhani et al. (2016), include aspects such as liveability, induced demand, improved operational efficiency of public transport and tourism.

The paper proceeds as follows: Section 3 outlines the methodology, case study context and the data used in the paper. Section 4 reports the main results. The paper concludes in Section 5 by discussing the implications of the findings.

3. Methodology

3.1. Public bike-share in Dublin, Ireland

In terms of commuting, Irish government policy on sustainable transport (www.SmarterTravel.ie) has set an ambitious target of reducing motor vehicle use from 65% to 45% by 2020 largely through increased cycling and use of public transport (DTTS, 2009). PBS can make a contribution to this target as international surveys have frequently found that commuting is amongst the principal reasons given for the use of such schemes (Martin & Shaheen 2014; Shaheen et al., 2012).

In Dublin, the civic authority identified the benefits of PBS for sustainable transport, healthy lifestyles and contributing to the council's objective of maintaining and consolidating economic activity within the city core (DCC, 2011). The *dublinbikes* scheme commenced operation in 2009 with 550 bicycles, 44 stations with an average of 20 docking points. Just over one million journeys were undertaken in the first year of operation. Users pay an annual subscription (currently €20) or pay on site for a fixed period. In common with a number of other European schemes, *dublinbikes* is managed by the advertising company J.C. Decaux in exchange for valuable poster space in Dublin City. The company provided the initial investment allowing the City Council to overcome a hurdle faced by many municipal authorities, namely one of competing demands for capital expenditure.

Dublinbikes has now been expanded to 101 stations and 1500 bicycles and operates over the central area of Dublin between Docklands in the east and Kilmainham in the west. It has 55,000 annual subscribers and provided for 2.8 million journeys in 2015. The scheme was expanded in 2014 and entered into a commercial partnership with Coca-Cola, although it continues to be managed by J.C. Decaux. It is still restricted to the central city area (see Fig. 1) in contrast to schemes in some other cities, but all types of journeys are now supported by a higher density of stations including at key employment and tourism destinations. New commuting use has also been encouraged by the inclusion of new stations at public transport hubs such as the Heuston rail terminus which handles a peak flow of 3000 passengers per hour and at other key destinations such as the commercial Docklands district and St. James Hospital.

With Ireland's Department of Transport having been convinced of the success of the original scheme, the €6 million capital costs of the expansion (equivalent to €4000 per bicycle) were supported by central government funds. Capital costs include station installation, the purchase of bicycles and station equipment, and the licensing and purchase of systems, maintenance and distribution vehicles. The expansion cost compares with reported capital costs of between $3000 (€2670) for *Bixi* in Montréal and $4400 (€3916) for *Vélib* in Toulouse (NYC, 2009). Actual costs vary depending on such factors as the size of the scheme and the level of technology used.

Operating costs include maintenance, insurance, managed distribution, IT and administration. Dublin City Council estimated annual operating costs for the now expanded scheme to be around €1283 per bicycle. Daily bicycle distribution from sites of low to high demand is a key element of these costs if bicycles are not to remain idle for much of the day (DeMaio, 2009). In Dublin, the managed distribution of bicycles accounts for around 20% of total movement. At approximately €0.70 per trip, operating costs are comparable to those reported for other schemes, for example Barcelona (€0.86) (ITDP, 2013). More detail on the estimation of *dublinbike* costs can be found in Appendix B.

3.2. Survey

To examine the benefits of PBS in Dublin we undertook a face-to-face survey of *dublinbikes* users in September 2015.[2] The survey was undertaken at 17 randomly selected bike stations located within

[2] A copy of the questionnaire is available from the authors. Prior to data collection, the full questionnaire was piloted at a randomly selected *dublinbikes* station, where five surveys were administered in person. The piloting phase allowed modifications to be made to the questionnaire in an informed way.

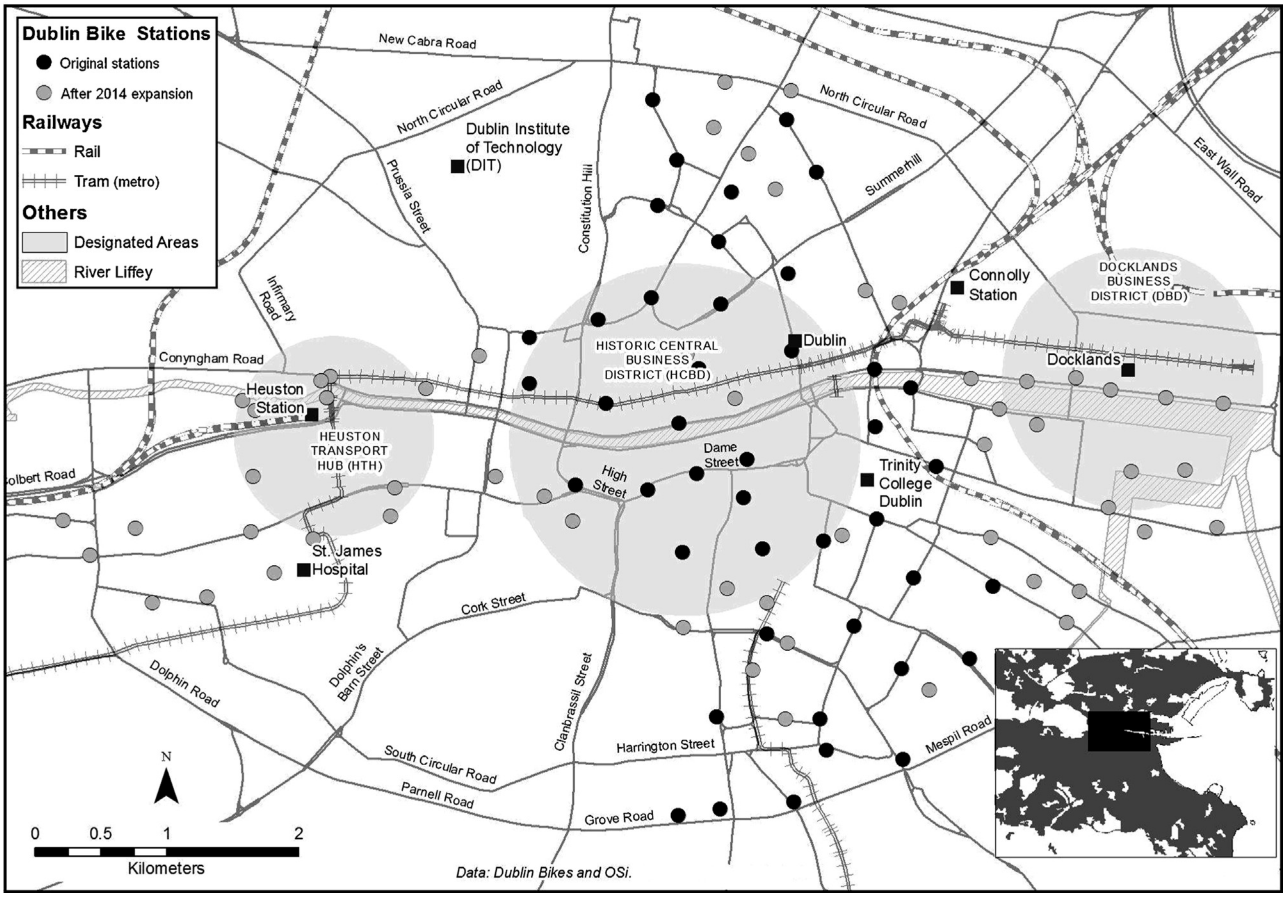

Fig. 1. *dublinbikes* stations in relation to main retail, business and administrative districts, key destinations and rail/tram lines.

four zones across the city, namely Docklands, South City Centre, the Law Courts and Heuston Station. The zones were delineated on the basis of containing one or more of the following characteristics: commercial shopping districts, high levels of commuters from outside of County Dublin, heavily trafficked areas, and areas containing stations which were installed during the *dublinbikes*' expansion in 2014.

The survey included questions on user characteristics (gender, age, education and occupation), journey characteristics (purpose, time, duration, journey stages, origin and destination), previous journey (mode, duration), reasons for using a *dublinbike* and perceived health. Two hundred and seventy users were approached of whom 104 permitted a full interview. At least 143 users were in too much of a hurry to give an interview, but were asked their reason for refusal and for what purpose they were using a *dublinbike*. Of these users, 101 were commuting. In common with other PBS surveys, males accounted for the majority of users at 75% of those approached or 72% of users interviewed. Thirteen percent of those interviewed were aged 18–24, 39% were between 25 and 34, 24% were 35–44, 18% were 45–55 and 6% were over 55 years. Eighty six percent used a *dublinbike* more than once per week. Eighty four percent of users lived in the more central suburbs of Dublin.

4. Results

4.1. Benefits due to modal shift from motor vehicles

Potentially, PBS can make a significant contribution to the city economy by improving connectivity between journey origin and destination and by reducing journey time. Indeed, in the current survey, most people reported the benefits of *dublinbikes* as being journey time, convenience or related savings (Table 1).

Most journeys at the time of the survey were short, i.e. 5% were five minutes or less and 61% were between 6 and 10 min, although 33% were between 10 and 30 min and 1% were over 30 min. *Dublinbikes* contributed to all or part of a commuting journey in 51% of cases (42% for work and 9% for college). Of the remainder, 9% were in-work journeys (e.g. for meetings), 9% were lunchtime trips, 19% were for shopping and 12% for leisure. Thirty percent of respondents, or 45% of people commuting to work or on an in-work trip, stated that they would use these time savings as additional working time.

All but three users could describe how they might otherwise have travelled. The responses demonstrate that rather than simply replacing a single mode of transport, PBS can lead to a change in the combination of transport modes used given that more than one mode may be used for a single journey. Of those respondents who did switch, Table 2 reveals that most (88%) did so from walking trips (77% of total switches), although some walking was typically still required. Switches from bus and tram totalled 16%. For many short trips, a *dublinbike* was used for the last (or first) leg of a commuting journey by public transport. Only two respondents transferred from private car, of whom just one was the driver. Rather, all previous use of taxis by the respondents was replaced by use of a *dublinbike*.

Similar results have been reported for Dublin by Murphy and Usher (2011). The very low transfer from private vehicles may be rather specific to Dublin because the scheme is still restricted to the central area of the city despite the expansion to some

Table 1
Perceived benefits reported by respondents of using a *dublinbike*.

journey time savings	waiting time savings	convenience	no need to park	exercise	cost savings	enjoyment
93.3%	25.0%	64.4%	15.4%	26.9%	37.5%	3.4%

Note. Multiple choice question.

Table 2
Modal transfer – trips replaced.

Users reporting transfers	Walk	Bus	Tram	Light rail	Cardriver	Car passenger	Taxi
number	28	9	7	2	1	1	6
percent	88.5%	9.6%	6.7%	1.9%	1.0%	1.0%	5.8%

inner suburbs.[3] Nevertheless, this result resembles the evidence described above for various international schemes in revealing that most transfers occur from walking rather than from private vehicles. They also demonstrate a shift from public transport which corresponds to the evidence from other locations. For example, Martin and Shaheen (2014) and Shaheen et al. (2012) found that PBS led to a fall in public transport use in dense central urban locations due to the faster, cheaper connectivity it can provide.[4]

Benefits from reductions in emissions (including CO_2) and congestion are often claimed for PBS. However, in the Dublin survey most of these reductions arise from reduced taxi use rather than from transfers from private car journeys, most of which originate from outside the central area (see also Gormley (2013)). When this proportion of private vehicle and taxi journeys replaced is applied to the current total of 2.8 million *dublinbike* journeys per year, the benefits of reduced emissions are estimated to be just 70.26 t per year based on average emissions of 123 g CO_2/km and journey lengths of between 2 and 4 km (see Appendix A). This equates to a saving of just €5340 per year on the basis of CO_2 abatement costs provided by the European Conference of Ministers of Transport (ECMT), equivalent to savings of €76 per tonne of CO_2. Savings in non-CO_2 emission costs (mostly NO_x, SO_2 and VOCs) are estimated at 8.26 g/km equivalent to €96,350 per year, and particulates (PM_{10} and $PM_{2.5}$) at 0.0027 g/km and 0.0025 g/km respectively at €53 per year and €487 per year. Fuller details of these calculations and the indices used are given in Appendices 1 and 3. As an increasing number of Dublin taxi drivers now use hybrid vehicles both figures represent a maximum as fuel consumption for many taxis will now be less than that for regular private vehicles.

In principle, private benefits would also arise from savings on vehicle operating costs (VOC) and can be estimated based on the COBA function.[5] These include savings on fuel and non-fuel costs, i.e. oil, tyres, maintenance and depreciation. However, as most vehicle transfers occurred from taxis this reduction would only apply if these taxis were unable to find another fare. For private cars only the saving would amount to €27,000 per year. The savings in public transport and taxi fares are much higher. Taking the average bus and tram fares for trips in the central city, the savings based on the respective transfer to *dublinbikes* would amount to just over €600,000 per year (see Appendix C). Savings on taxi use would be more substantial at €1.62 million per year given an average fare of €10. However, rather than an absolute economic benefit, these savings represent a transfer in that there would be a corresponding decrease in the revenue of bus operators and taxi companies.

4.2. Reductions in accidents

The average annual number of all vehicle-related accidents of fatal, serious, and slight severity to drivers, pedestrians and cyclists recorded by DCC (2010) for the period 1998–2007 can be valued at €17.44 million based on the Irish Department of Transport (2009) estimates of collision costs.[6] *Dublinbikes* accounts for only a small proportion of total journeys by all modes. Keeping all other factors unchanged and assuming that the accident rate amongst taxis is equal to that of other vehicles,[7] a 6.8% transfer from motor vehicles indicates savings through reduced collisions of a maximum of €30,240 per year, of which fatalities account for €27,890.

On the other hand, the potential cost of fatalities amongst *dublinbikes* users has to be taken into account. As over two million journeys are now undertaken each year, this rate of use would imply one fatality every 25 years on the basis of the figures recorded for cyclists in London by the UK Department of Transport.[8] A Value of Statistical Life (VSL) approach could imply an annual cost of €80,560 based on the estimated cost of a road fatality at €1.32 million plus €694,000 due to lost productivity (Goodbody, 2005).[9] On this basis the social cost of *dublinbikes* would exceed the benefits of the reduced recorded collisions by €52,670 per year. However, noting the arguments presented above by de Hartog et al. (2010), it is equally possible that increased cycling could lead to a proportional reduction in cycle accidents due to the effect of "safety in numbers" (Jacobsen, 2003; Macmillan et al., 2014). On the other hand, only 4% of people approached for the *dublinbikes* survey were wearing a helmet and this risk is exacerbated where less experienced cyclists take to using a *dublinbike*.

4.3. Benefits to health

Potentially, there are significant benefits to health as a consequence of *dublinbikes*. In Ireland, 29% of adults engage in a low level of physical activity (Morgan et al., 2008) and 22% are classed as inactive (Fahey et al., 2004). Of course, *dublinbikes* can only make a small contribution to reducing overall inactivity, although as remarked earlier, PBS does provide a distinct motivation for exercise given that 60% of survey respondents were using a *dublinbike* for a com-

[3] There are plans to extend *dublinbikes*, for example to the campus of the Dublin City Univesity in the north central city but disputes over responsibility for capital investment have delayed this transition to date.

[4] These authors also reported a corresponding increase in public transport use in suburban areas.

[5] COBA is a computer program originally developed by the UK Department of Transport for estimating the value of road improvements.

[6] Serious injury collision is defined by DCC as "no death, but a person or persons seriously injured." Minor injury is defined as involving no death or serious injury.

[7] A study by Schaller Consulting (www.schallerconsulting.com) in New York reported that taxis were involved in one third as many crashes as other vehicles, but that injury rates amongst passengers and cyclists are higher, the latter frequently due to the opening of doors (http://wirednewyork.com/forum/archive/index.php/t-9163.html)

[8] Briefing Paper for Stop Killing Cyclists Meeting with Transport for London's CEO and the London Mayor's Cycling Commissioner

[9] As this estimate is based on individuals' response to risk it could be argued to represent a private rather than a public good benefit. Ideally, the costs should also take into account reduced accidents due to transfers from other modes of movement.

muting or in-work journey. Twenty-seven per cent of respondents also mentioned "exercise" as one of the benefits of the scheme.

Sixty per cent of respondents were using a *dublinbike* five or more time per week and in 84% of cases more than once per day. It is understandable therefore that only 5% of respondents thought themselves to be unfit while 42% considered their fitness to be "average". However, 60% of respondents also reported that they previously cycled less than once per week. If we were to assume that just 5% of subscribers (2750) would have previously belonged to the "low physical activity" category, this would imply annual benefits of €950,000 per year based only on productivity gains estimated at 4.7 days per year (van Amelsvoort et al., 2006) applied to the average national wage of €36,000 and the proportion of the Dublin City population in work (51%).[10] Assuming that half of these respondents were previously in the lower activity class of "inactive", the public healthcare savings for this subset, based on the WHO estimates quoted earlier, would amount to between €206,000 and €412,000 per year.

In addition, there are private benefits due to the reduction in mortality risk associated with better health. As demonstrated by Deenihan and Caulfield (2014), these can be estimated using the Health Economic Assessment Tool (www.heatwlkingcycling.org) which is based on estimates of VSL. Noting that 60% of cyclists surveyed were infrequent cyclists before, the recorded increase in cycling of 20 min per week by the 55,000 subscribers would provide reduced mortality benefits of €939,000 per year.[11] Account could also be taken of private welfare and expenditure gains associated with users' sense of personal fitness.

Evidently, these health estimates involve various assumptions. They must also be treated as tentative given the difficulty of attributing health benefits to any one activity. Indeed, 88% of respondents previously walked part of the route for which they now use a *dublinbike*. Furthermore, the capacity of the scheme to attract new cyclists from a core inactive cohort of the population is likely to diminish over time. Consequently, the estimates of health benefits are best treated as an upper bound.

4.4. Time savings

While savings in journey time are a key motivation for use of PBS, to date the benefit of these time savings has not been estimated in economic terms. Based on the evidence of the *dublinbikes* survey, savings in journey time are found to be far more significant than the reduction in external costs due to transfers from motor vehicles.

Time savings typically result from a transfer from one mode to another, but also occur within modes, particularly in terms of shorter walking time. Fig. 2 reveals that most time savings arose from transfers from walking compared with the duration of previous trips. Significant savings also occurred relative to the time spent travelling by public transport or taxi. The one car driver in the sample reported no time savings and, indeed, depending on traffic conditions, travel time by PBS could be either shorter or longer than by private car. A transfer from this mode could also be determined by factors such as the relative weight people place on the time spent finding parking, wait time (e.g. at traffic lights) and convenience (see Table 1). Overall, average time savings amounted to 34% of previous journey time.

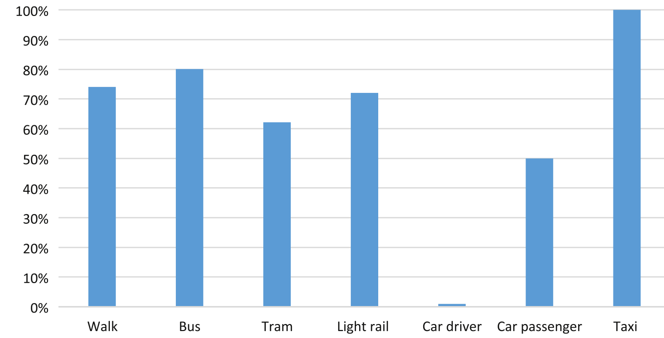

Fig. 2. Total reported time savings as a proportion of former journey duration within mode.

Table 3
Purpose of journey and value of time (per hour market prices).

	in work	commuting for work	non-commuting
value per hour (2002)	€26.50	€8.10	€7.30
value per hour (2015)	€31.74	€9.70	€8.74

Source: Department of Transport (2009).

Ireland's Department of Transport (2009) provides indices of value of time for in-work, commuting and non-commuting journeys (Table 3) (DKM, 1994; Goodbody, 2004). These estimates were prescribed at national level and took account of opportunity costs relating to work productivity. Although average values were prepared, estimation can involve various means included stated preference and can vary by quality of transport, comfort, inconvenience and wait time. Other national value of time indices are similar to those used in Ireland, but may include a more distinct value for leisure time.[12]

No figure is provided for commuting to college so we have allocated a value equivalent to non-commuting time. The indices are provided at 2002 prices and, for the purposes of the analysis here, have been increased to take account of real GDP growth since this time.

Savings on in-work time can be treated as a public good benefit and attract the highest value because of the opportunity cost of lost output. Commuting trips are valued at a rate less than in-work trips, but represent a major share of the benefits given the ability of PBS to supply improved connectivity with workplaces. In direct terms, savings on commuting time represent a public benefit only in as far as this extra time is spent in work. By comparison, leisure time savings are exclusively a private rather than a public benefit, but are nonetheless a contribution to economic welfare that could potentially be valued in terms of willingness to pay to reduce travel time (Ovaskainen et al., 2012). For the individuals themselves, based on stated preference values elicited by Borjesson and Eliasson (2012), the benefits of PBS could, in principle, be higher given the relative disutility of the longer wait times experienced for the alternatives of walking (e.g. at road crossings), public transport (e.g. bus stops), or driving (e.g. traffic congestion).

The user survey provided data on reasons for journey as well as estimates of previous journey time. Altogether, 23% of former journeys were less than 15 min, 33% were between 15 and 30 min and 44% were more than 30 min. Commuting trips to work are typically longer than other journeys such that the respective shares of all journeys formerly taking less than 15 and 15–30 min were 29% and 27% respectively, but represented 61% of journeys taking more

[10] van Amelsvoort et al. (2006) found that workers in the Netherlands who are physically active report significantly less sick leave than inactive workers (14.8 days versus 19.5 days per year). Hendrikson, Simons, Garre, and Hildebrant (2010) report that (of these) people who cycle have one less sick day per year.

[11] HEAT calculation includes a base of 5 min cycling per week for an age group of predominantly 20–44 over 5 years and the earlier VSL figure of €1.32 rather than the default figure of €2.59m.

[12] The figures are comparable to international estimates, e.g. for the Netherlands of €21 for work time, €6.40 for commuting and €3.20 for leisure (van Essen et al. 2004).

than 30 min. In work-trips are short and accounted for 25% of former journeys of 15 min or less and 8.8% of journeys of 15–30 min, but no journeys of more than 30 min.

On average, *dublinbikes* accounted for a 7 min trip. For journeys that would previously have taken 15 min, 16–30 min and more than 30 min, journey time savings average respectively at 5, 13 and 15 min. For the same categories, these figures represent respectively 7, 13, 19 min less time spent walking; 0, 7, 13 min less time by bus; 0, 8, 8 min less time by tram and an equal ten minutes less by taxi.

Asked directly, respondents' own estimate of time savings averaged 11.4 min. Given that commuters in particular can be expected to be aware of when to leave for work, we proceed with this figure as a lower bound and multiply it by the 2.8 million journeys currently undertaken.[13] On this basis, the value of journey time savings is estimated at €6.06 million according to the stated purpose of the trip (Table 4). However, when asked how they would spend the extra time, 29.5% of respondents said that it would allow more work time. In this case, the value of the time savings would be higher at €10.4 million (see Appendix A). When compared with estimates of the benefits arising from other sources (Table 5), either estimate represents a significant saving.

4.5. Estimates of wider economic benefits (WEBS) for dublinbikes

The analysis so far shows that, in economic terms, journey time savings are by far the largest conventional benefit of bike-share in Dublin. However, user and productivity benefits due to time savings provide only one perspective on the total economic benefits. Additional benefits could also arise from WEBs as listed below. For *dublinbikes* the data suggests that most of these benefits are due to agglomeration effects.

a) Productivity gains

Of the individual WEBs introduced earlier, productivity gains arise from the removal of capacity constraints on workers' access to the city. This enhanced accessibility can allow businesses to relocate to the locations where Gross Value Added (GVA) per worker is higher. However, as there is likely to be an upper limit to the proportion of employees prepared to cycle, business relocation is unlikely to be a significant consequence of *dublinbikes*.[14]

b) Labour force participation

Dublinbikes has the potential to improve labour force participation by providing workers with enhanced connectivity to commute to more suitable or better paying jobs. For instance, the availability of bike stations at the main railway stations would allow workers to access employment on the other side of the city centre that might previously have involved a tedious bus journey or long walk.

UK Department of Transport guidelines recommend that the value of increased labour force participation is estimated on the basis of the predicted change in employment multiplied by the differential in local GDP. In this respect, the Irish government is projecting 66,000 new jobs for the capital by 2020 where the differential with national GVA is €9200.[15] Unfortunately, we cannot predict how many of these new jobs will be accessed with a *dublinbike*. In our survey, no respondent reported that the availability of *dublinbikes* had permitted them to take a new job, although the sample may have been too small to locate such individuals. However, one third of respondents did report that the scheme had allowed them to reach parts of the city that were previously less accessible. As an illustration, the London Crossrail underground project estimated the benefit of increased labour force participation to be 21% of the value of savings in total commuting travel time. Although the mode of transport is different, the same benefit of accessibility would apply to the commuting proportion of *dublinbike* users. The differential in UK and London GVA is also similar. Given the average reported journey time savings for commuters of 14 min, a figure of 21% applied to the proportion of commuting journeys (42%) would imply savings of €560,000 per year.[16]

c) Reductions in imperfect competition

The UK Department of Transport guidelines also suggest that benefits due to reductions in imperfect competition are valued on the basis of the improvement in business price/cost margins or approximately 10% of in-work time savings. On this basis, transfers to *dublinkikes* would be valued at €131,000 per year. The OECD/ITF (2008) does, however, caution that it can be difficult to estimate the impact accurately with small transportation schemes and this advice would certainly apply to PBS given that these support only certain types of in-work trips.

d) Agglomeration benefits

Of the various sources of WEBs, the most realisable and significant economic gains are represented by agglomeration. Agglomeration is the driving force behind the success of cities and tends to be the most prominent benefit of public transport investment (Graham, 2007a). Agglomeration benefits arise from companies being located close to one another with the opportunity this provides for sharing in innovation, networking or complementary activities. These benefits derive from spatial improvements in *effective density*, i.e. a measure of employment weighted by the physical and journey time proximity of firms, workers and markets, by which time savings provide a further stimulus to productivity.

To estimate agglomeration benefits, information is needed on existing economic output as a measure of the relative benefit of concentrated economic activity. Average income in Ireland is estimated at €35,815 per annum (CSO, 2013) and GVA at €75,831 (CSO, 2010) per person. Average national GVA per worker in the financial, public and retail sectors is €85,392 (CSO, 2012b). A stronger agglomeration effect can be expected towards the centre of the city, but the official data provides no geographical breakdown below the level of County Dublin.[17] However, studies of the relationship between employment density and labour productivity in international cities indicate agglomeration elasticities of 0.02–0.04 for retail and manufacturing, 0.12 for services and more than 0.2 for financial services (Graham, 2007b; Rosenthal & Strange, 2004; Venables & Rice, 2004). As services are more prominent in the central city followed by retail, it seems reasonable to use an elasticity of 0.06 for the *dublinbikes* area and a GVA of €85,000 applied to a total workforce of 215,000.[18]

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[13] It is also arguable that this figure could include some underestimate of time previously spent waiting at bus/metro stops or finding a cab.

[14] Inevitably cycling will not appeal to everyone. Fishman et al. (2014) note that a distinct proportion of non-users express disinterest in cycling or bikeshare.

[15] https://www.djei.ie/en/News-And-Events/Department-News/2016/January/25012015.html

[16] Various researchers have reported a firm relationship between public transportation and job creation (e.g. Sanchez, 1998). However, Kanemoto (2013) describes the Crossrail assumptions as being optimistic.

[17] GVA per worker would be €257,233 if only the financial, insurance and real estate category were to be selected (as could apply to a central financial district).

[18] Employment figure provided by NTA (2015) Draft Transport Strategy for the Greater Dublin Area 2016–2030 (based on 2011 Census data).

Table 4
Total value of time savings (per annum).

	Commuting to work	Commuting to college	In-work trips/in work	Amenity trips
Minutes saved	14	12	10	10
Proportion of total journeys	42%	9%	9%	40%
Value of savings	€2.66 m	€440,500	€1.33 m	€1.63 m
Value of users' alternative use of time savings.	€1.14 m	€440,500	€7.53 m	€1.29 m

Table 5
Projected annual benefits due to *dublinbikes*.

Time savings	Emissions	Vehicle operating costs	Cost savings (pub transp fares)	Cost savings (taxi fares)	Health (exercise)	Accidents
€6.06 m–€10.40 m	€102,230	€27,000	€600,000	€1.62m	€2.10 m–€2.30 m	−€52,670 ±€27,890

Table 6
Projected minimum annual benefits of *dublinbikes* including WEBs.

dublinbikes 2015	Time savings	**Wider Economic Benefits**	Other benefits (emissions, VOC)[a]	Prospective health benefits[b]
	€6.06 m	€6.79 m	€129,230	€2.10 m

[a] Public transport fare savings of €2.22 m represent a transfer from other operators rather than a benefit.
[b] Potentially deduct €52,670 due to annualised cost of fatal accidents.

Table 7a
Sensitivity analysis applied to estimates of benefits and costs including WEBs.

Parameters	Sensitivity value	NPV	Benefit-cost ratio
Estimated value inc health and WEBs	–	€196 m	12.32:1
Include fatalities	every 25 yrs.	€196 m	12.29:1
Value of time	Respondents use	€308 m	18.57:1
	time – Dutch indices (van Essen 04) at present prices xii	€172 m	11.04:1
Discount rate	2.5%	€242 m	14.74:1
	10%	€134 m	9.03:1
Labour force participation & reduction in imperfect competition	Excluded	€179 m	10.37:1

Table 7b
Sensitivity analysis applied to estimate of agglomeration, benefits and costs.

	Sensitivity value	Agglomeration	NPV	Benefit-cost ratio
Agglomeration elasticity	0.08 0.12	€8.36 m€12.55 m	€219 m€265 m	13.61:1 16.20:1
Proportion of all in-work journeys by *dublinbike*	2.5% 1%	€6.78 m €6.96	€192 m€197 m	12.11:1 12.43:1

A calculation of agglomeration benefits first requires an estimate of effective density taking into account the number of commuting and other work-related trips. There are currently around 370,000 outward and return peak hour journeys each day into Central Dublin by car, train, bus and light rail.[19] We do not have enough data to estimate the generalised cost of users' travel from different locations, but the average survey commuting time of 41 min corresponds closely to the average of 39 min into central Dublin reported by the CSO (2009). PBS are often used by commuters for the last leg of their journey, although these average commuting times also include commutes by people who both live and work in central Dublin and who account for around one quarter of the central population of 219,000 and 20% of commuters in the survey. Based on the survey data, total current annual commuting time savings in 2015 due to *dublinbikes* are estimated at 16.5 million minutes for people in paid employment and are equivalent to 0.39% of the total return commuting time of all workers. These time savings are worth €2.66 million (see Table 4). There is no available figure for the number of in-work trips by the city's working population, but taking into account the practicality of making work trips by bicycle we assume the proportion of such trips by *dublinbikes* is just 5%.

Given the proportion of the respective journey time savings for all journeys into central Dublin, *dublinbikes* would therefore be increasing effective density by 0.0057. This figure is multiplied by the 0.06 estimate of agglomeration elasticity density and then by an estimated GVA of €18 billion for the total workforce in the area serviced by *dublinbikes*. Altogether this suggests that in 2015 the scheme was providing agglomeration benefits in addition to direct time saving benefits worth at least €6.10 million per year or €6.79 million per year once all relevant WEBs are accounted for. Table 6 illustrates the contribution of the benefits due to WEBs and the lower level of direct time savings from Table 5 along with other benefits. The table demonstrates that the benefits of time savings and WEBs exceed the other benefits, although these too are of a high level.

Relative to other transport investments, it can be argued that *dublinbikes* is more cost effective in achieving agglomeration and other wider benefits given its location within the central city area and its unique capacity to fill a significant gap in connectivity. These benefits contribute to economic growth and competitive-

[19] As estimated on the basis of counts by Transport for Ireland in 2014 of 191,583 daily vehicle journeys, of which 98,207 were by public transport, 64,169 by private car, 19,711 by foot, 10,349 by bicycle, 2775 by taxi and 1372 by motorcycle. Excluding goods vehicles.

ness, returns from which can be collected by municipal authorities as tax revenue or through central business district commercial rates.

4.6. Cost benefit analysis

The original capital and running costs of *dublinbikes* are estimated to have been €33 million discounted over 15 years and including the provision of stations, systems and bicycles (www.irishcycle.com/dublinbikes). The scheme was expanded in 2014 at an initial capital cost of €6 million. Operating costs for the expanded scheme are estimated at €2.18 million per year. Replacement bicycles are assumed to be required every five years at a cost of €1000 each. Bike stations have been constructed on pavements and in public spaces, but in some cases parking spaces have been removed for which we have estimated the lost revenue at €250,000 per year (Appendix B).

The cost benefit analysis is assumed to operate over the 15 years of the investment. Total journeys are assumed to grow by 5% each year along with income from subscriptions and charges beginning at around €1.38 million per year.[20] New bicycles are added every five years in line with this rate of growth which also applies to operating costs. The principal benefits include time savings, WEBs and productivity benefits due to improved health. Fare savings are not included as these are a transfer from bus/taxi companies to cyclists. Purely private benefits due to personal health (fitness) are excluded as they are internalised within the decision to cycle and so are captured by the aggregate level of cycling uptake (Borjesson & Elliasson 2012).

On this basis, over the period of the investment, benefits and costs discounted at 5% represent a sizable benefit-cost ratio (BCR) of 6.4:1 on the basis of conventional benefits at the lower estimate of time saving benefits or 8.0:1 with the inclusion of the lower estimate of health benefits. These figures increase to 10.7:1 and 12.3:1 respectively if WEBs are included. The BCRs indicate a significant benefit from the scheme and are much higher than estimates based on more restricted criteria, for example for PBS in London (TfL, 2014) and Washington DC (MWCOG, 2010).

Arguably, health benefits cannot be attributed to a single scheme, but even excluding these figures the benefits of *dublinbikes* greatly exceed the capital and operating costs. Tables 7a and 7b provide a further sensitivity analysis of these estimates to include potential fatality costs or to exclude the estimates of more tenuous estimates for labour force participation and imperfect competition. It also examines alternative values of time, agglomeration elasticity, discount rate, and the proportion of all in-work journeys undertaken by *dublinbike*. Of these parameters, changing the reference values of time to those used in the Netherlands, the discount rate and agglomeration elasticity are amongst the most critical factors that alter the NPV and BCR.

5. Conclusions

PBS have increased rapidly in number across the world and a growing number of articles have discussed the benefits of such schemes, including user characteristics, journey characteristics and the direct benefits to users themselves. However, rather few studies have investigated their benefits, in particular the economic benefits. In this paper we have critically examined the relative benefits of PBS and shown how PBS can supply significant economic returns for the urban economy.

There has been much discussion of PBS as a means to widen the choice of urban transport and to provide a sustainable alternative. In most cases, we find that the level of modal shift from cars to bicycles has been slight. Rather, most transfers have been from public transport, walking or taxis. Taking the example of Dublin, we find that the contribution to health from more physical exercise is significant, but difficult to quantify and to attribute to cycling. Rather, the more important benefit is realised by allowing cities to function more efficiently. This is achieved firstly by reducing journey time, an outcome that is both a private benefit to users and a public good benefit. We show how journey time savings, allied with improved connectivity, make a considerable contribution to the urban economy. This takes the form of 'wider economic benefits' in particular in terms of agglomeration. The fundamental source of these benefits is the gain to productivity that arises from the positive relationship between journey time, urban compactness, employment and economic activity.

Much of the journey time saving is achieved by improving connectivity including between public transport termini and place of work. This improved connectivity and accessibility in turn supplies significant agglomeration benefits. In the case of *dublinbikes*, journey time benefits are estimated as being at least €6.06 million per year while the total wider economic benefits amount to €6.79 million per year. Together journey time savings and wider economic benefits account for between 85% and 96% of total benefits depending on how time and health are treated. The more conservative estimates still account for a BCA of 12.3:1.

A caveat of the current study is that the estimates of the WEBs are dependent on accurate estimates of time savings. It is quite plausible that these estimates will vary over time, due to changes in use and other transport infrastructure investments. However, it is quite straightforward to adjust for the effect of lower or higher estimates of trips and time-savings or, indeed, changes in other assumptions such as the composition of transport modes. On the other hand, a subsequent further expansion of the scheme into areas where other traffic moves more smoothly may not result in the same increase in use such that there is more of a convergence between benefits and costs. As regards the scheme as it is now, it is clear that bike-share has a positive benefit-cost ratio and that it can be highly competitive in relation to major public transport investments even before consideration of the low investment outlay and the additional private benefits to health and urban liveability.

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Appendix A.

Tables A1 and A2

[20] This includes subscription and trip costs. In the survey, 15% of journeys exceeded the 30 min of free time by an average of 20 min priced at €1 per 30 min.

Table A1
Principal calculations.

Reduced CO2	(2.8 m trips × 6.8% (i.e. 190,400 switch from vehicles) × (0.000123 t/kg × 3 km) = −70.26 × €76/t = €5340 pa
Reduced Non-CO2	190,400 × (8.26e−6 t/kg × 3 km) = 4.178 t × €23,061/t = €96,348 pa
Reduced PM10	190,400 x (2.7e−9 t/kg × 3 km) × 0.001542 t × $30,000/t = €53 pa
Reduced PM2.5	190,400 × (2.5e−9 t/kg × 3 km) × 0.001428 × $300,000 = €487 pa
Reduced sick-leave	(4.7/250) *(5% × 2750) × 51% = €950,000 pa
Reduced accidents	(((190,400/139 m (0.00137) × €2.036m) = €29,890 + (0.00137 × 233,526) = €320 + (0.00137 × €21,382)) = €29 = €3132
Time savings	((14 min/60 min) × €9.70) × (42% × 2.8 m)) + ((12/60) × €8.74) × (9% × 2.8 m)) + ((10/60) × €8.74) × (40% × 2.8 m)) + ((10/60) × €31.74) × (9% × 2.8 m)) = 6,066,618
User's alternative use of time savings	commuting: ((43% × 1.17) × €2.26) + leisure: ((79% × 1.12) × €1.46) + transfer to working time: (((57% × 1.17 m) × €7.40) + ((21%*1.12 m) × €5.29) + €1.33 m
Effective density	Value of commuting and in-work time savings (€4 m)/value of calculated number of all annual commuting and in-work journeys (€719 m).
Agglomeration	Effective density (0.06) × (GVA €85,000 × workforce 215,100)

Table A2
Assumptions.

Assumption	estimate	rationale
Agglomeration elasticity	0.06	On basis literature review which suggests 002-0.04 for retail, 0.12 for services & 0.2 for financial.
Proportion of all work journeys by *dublinbike*	5%	Made on a further assumption that 10% of the workforce make regular in-work journeys.
Subscribers previously "low physical activity"	5%	Compared with 29% for general population (DB users assumed to be relatively fit.
Social cost of emissions	Appendix c	Estimated on basis of avoided cost of climate change and health costs.

Appendix B.

Dublinbike costs

In addition to direct capital and operating costs, there is the opportunity cost of lost advertising revenue and the loss of revenue where car parking spaces are replaced with bike stations. In 2010, JC Decaux was allowed 72 advertising spaces worth around €3.6 million per year (Murphy & Usher, 2011) in exchange for investing in and operating the scheme. In addition, there is the cost of lost parking revenue due to the space taken by bike stations. As of 2015, there are 101 stations located mostly within three parking tariff zones. This infrastructure is estimated to have resulted in the loss of 300 individual car parking spaces which generate revenue of €1.60 (10% of stations @ 10 h 5 days per week), €2.40 (30% @ 12 h 6 days per week) or €2.90 per hour (60% @ 12 h 6 days per week). On the evidence that these spaces are occupied for an average of 30% of the time, this implies an annual loss of income of €833,000. We estimate the actual loss at €250,000 (30% of this amount) given that drivers have an opportunity to locate new public paid on-street spaces most of the time.

Appendix C.

Vehicle related costs

Emission reductions

The estimates are based on average emissions for urban car use as reported by Ireland's Department of Transport (DoT) (2009). Although current average emissions have been falling (http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm) we retain the urban CO_2 emissions figure of 123 g/km given in the guidelines for central city traffic given the stop and start nature of movement. The Department's index for the social cost of vehicle emissions for CO_2 and non-CO_2 is based on cost estimates provided by the European Conference of Ministers of Transport (ECMT, 1998), (Rouhani et al., 2016) and are set out in Table A3 below. These take into account the economic implications of climate change in the case of CO_2 and of health in the case of non-CO_2 emissions, with the former estimated on the basis of avoidance costs. While for CO_2 these allocate a low value relative to other types of emission, the figure of €76 per tonne is at the higher end of abatement cost estimates. The guideline's estimate of emissions in urban areas are based on the COPERT III model. In addition, particulates have been found to have a significant impact on health (Rouhani & Neiemeier, 2014) and are higher for diesel vehicles. Using a variety of sources, (Rouhani et al., 2016) estimate these social costs at US$30,000 for PM10 and US$300,000 for PM2.5.

Table A3
Benefit of reduced emissions.

	g/km	cost per tonne	Benefit of reduced emissions
CO_2	123	€76	€5339
non-CO_2	8.262	€21,400	€96,350[a]
PM10	0.00268	€30,000[b]	€53
PM2.5	0.0025	€300,000[b]	€487

[a] Based on inflation adjusted values for NOx & non-methane volatile organics of 0.01099, SOx 0.00102 and CO2 0.000061.
[b] Based on emissions of 0.0044 for PM10 and 0.0041 for PM2.5 (EPA (US), 2008).

Estimates of private Vehicle Operating Costs

Estimates of VOC are based on the COBA function used by Ireland's Department of Transport (2009) based on a fuel price index commencing in 2002. Private savings in fuel and non-fuel costs assume average vehicle speeds in central Dublin of 15 km/h (CSO, 2007, 2012a) and a share of petrol to diesel 65:35 (Cames & Helmers, 2013). Given that only a 1% transfer occurred from private vehicles and 5.8% from taxis, fuel savings due to the scheme would amount to €60,775 at 2002 prices (around €73,202 at current fuel prices). Non-fuel costs are estimated at €98,932 per year (around €118,496 in current prices).

Public transport revenue

The public bus service is supported by state subvention amounting to €69 million in 2012 (Dublin BUS, 2012). According to the *dublinbikes* survey, 9.6% of sampled users would otherwise have travelled by bus. Only 2% of bus fare transactions now involve cash (Deloitte, 2009), but a *dublinbike* will often be selected for reasons of convenience by people who possess pre-paid cards for which the city centre fare is €0.60 and a three-stage fare is €1.50. This switch will therefore have benefitted users, but cost the bus company €282,240 per year taking an average of the two fares. In addition, 8.6% transferred from other forms of public transport, with most transfers (6.7%) occurring from the tram service for which the fares are €1.90 and €1.49 for the central and inner zone. On the same basis as for bus, this switch will have resulted in a loss of revenue of €318,920 per year. In other cities, PBS has been found to be complementary to public transport. Shaheen et al. (2012) find that some users in North America have substituted vehicle use with a combination of public transport and PBS.

Appendix D.

Accident costs

Dublin City Council estimated the annual average number of fatal, serious and slight vehicle-related accidents at 2.67, 40.33 and 121.12 for which the Department of Transport (*ibid*) guidelines suggest respective human costs of €2.02m, €226,757 and €17,486, and material costs €2791, €6769 and €3896. Given an estimated 139 m annual journeys by all modes within the area covered by *dublinbikes*, the maximum respective costs are €27,890, €320 and €29 per year given the 190,400 km vehicle savings due to *dublinbikes*. We do not know the average distance of journeys in central Dublin and these are likely to be longer than those replaced on which basis the total of €30,240 per year amounts to a maximum. This benefit can, however, be compared with the much higher cost of fatalities potentially arising from the use of *dublinbikes*.

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