ARE BICYCLES GOOD FOR PARIS?
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SUMMARY

In 2001, the newly elected Paris Mayor started to implement an active pro-bicycle policy, mainly based on investments in bike paths and on the launching of a bike rental system in July 2007 (Vélibs).

This article aims at appraising such a public policy by measuring its welfare impact, expressed as the Net Present Value (NPV) of the overall changes generated over 2007-2010. Faster bikes perform more kilometres in Paris. Some people shift from cars, buses, and subway to bikes and Vélibs. Switching from a passive mode of transportation to bicycle has a positive health impact. The amounts of C02, local pollutants, noise and congestion externalities generated by each mode are also changing. By contrast, the speed of car is slightly reduced, partially because of a narrowed road capacity. Public finance is affected by the change in fiscal revenues collected whereas the bike rental system's operator (Decaux) realizes some profits. Finally, the pro-bicycle policy has an initial investment cost and a residual value.

All these changes are calculated and computed in a same monetary unit. This policy is (slightly) beneficial for society (a total NPV of +136 M€) even if the cost for public finance (-704 M€) is close to the bikers' benefit (+859 M€). Vélibers are highly subsidized by the city. This policy is also working at the expense of the cars' drivers (- 286 M€) while positive externalities are not very important (+101 M€) and Decaux's profits are moderated (+166 M€). Several sensitivity analyses are conducted to identify the key drivers of the policy's success.

I – Introduction

In 2001, the newly elected Paris Mayor, Bertrand Delanoë, started to implement an active transportation policy. Aimed at reducing the environmental damages of the motorized mobility (Parry et al., 2007, Malibach et al., 2008, CGDD, 2013), a *road diet strategy* (Prud'homme and Kopp, 2008) was the core of this new policy. The urban space dedicated to cars was reduced whereas buses and bicycles were highly promoted. Thus, the network of bicycle paths was multiplied by 1.6 over 2001-2007 (Bilan des déplacements, 2010) and bikers were authorized to use new buses' lanes since 2001.

Despite a pro-bike (and pro-bus) policy, these modes of transportation are not carrying a heavy part of the traffic. In 2007, 32% of the kilometer performed every day with Paris for origin or destination were achieved by subways; 31% by cars, 24% by express railway and trains; 7% by motorbikes, 3% by buses; 1% by taxis (Kopp, 2011). At that date, the bikes did not weight more than 0.6% of the daily traffic.

In such a context, a bicycle rental system (Vélibs) was launched mid July 2007 with great ceremony by Paris officials[1]. A Vélib is a bike which can be rented in one of the 1,400 stations located in Paris or in close suburbs. Customers can use either their credit card or a travel pass (which may be combined with buses and subways' subscriptions) to enjoy, for free during the first 30 minutes, one of the 20,000 vehicles composing the fleet. The extra time is then priced on a basis of 1 euro for the first half hour, the fare increasing with the renting duration.

In Western cities, as in Paris, bicycles reach a very low modal share. Socio-cultural and urban shape differences may explain the Dutch and Danish exceptions (Héran, 2012, Pucher and Buehler, 2008, or Martens, 2004). Despite this lack of public success, numerous academic researches have been conducted to understand if pro-bicycle public policies were desirable to achieve a *sustainable* urban mobility (see the reviews by Litman et al., 2006 and Heinen et al., 2010). Long term perspective have been used to justify public policies dedicated to increase the potential demand for bicycles, the emphasis being essentially put on biking facilities (such as dedicated lanes or parking places, see Ortuzar et al., 2000 or Hopkinson and Wardman, 1996) and transferability (Martens, 2004). Others (Cahill et al., 2008 ; Rabl et De Nazelle, 2011) have demonstrated that biking may induce large health benefits due to moving *actively,* when severe injuries can be prevented (Pucher, 2001, De Hartog et al., 2010). Lastly, the multiplication of bike sharing (or rental) programs has been observed

[1] In France, the first pro-bicycle policy dates back to 1974 with the launching of the "*Vélos jaunes*" in La-Rochelle, i.e. free bicycles parked in the city. Before the Vélibs service in Paris, the "*Vélov*" launched in Lyon in 2003 had met a great success.

worldwide (Shaheen et al., 2010) and these services are meeting, most of the time, a popular success. The growing usage of bikes appears to be followed by environmental savings (Meschik, 2012) and new business opportunities for the private sector (Gross, 2011).

Whereas the benefits of biking are generally well accounted for, it is noticeable that the associated costs are less often contrasted in a public economy perspective. In the same vein than the CBA of pro-bicycle policies in three Norwegian cities (Saelensminde, 2004), this paper aims at assessing the Paris bicycle policy. We rely on a standard costs-benefits analysis (CBA) framework and we calculate the overall welfare change generated, between 2007 and 2010, by the Paris policy. The Paris public authorities should have launched such a CBA in 2007 to assess the welfare impact of their decision. Obviously, more information is now available but the methodology is the same. The municipal intervention is here defined as the investments in bike paths realized since 2001 and the launching of the Vélib rental system in 2007. The number of kilometres performed by bicycle trough the rental system's users (*vélibers,* VB in what follows) and the *private bikers* (PB) dramatically changed during this period. By contrast, the latter category was neglected in previous French studies on that topic (Cabanne, 2010, Rabl and De Nazelle, 2011). The calculation of the magnitude of these changes are based on our own field survey collected in 2010 on 160 bikers interviewed in Paris streets.

This analysis rests on a double originality. First, because the pro-bike policy harms cars' drivers in Paris, the corresponding welfare effect must be included. Second, the Vélib service is operated by a private company (Decaux) linked to the city by a ten years public–private partnership (PPP) signed in 2007. Thus, the impact of the PPP on public finance must be encompassed by the CBA.

Following this introductive section, the second section describes the evolution of the bike usage in Paris from 2007 and 2010, just after the launching of the Vélib service. The third section is dedicated to surplus calculations. The fourth section discusses the results and concludes.

II– Evolution of bike usage in Paris

1 - Bike users profile

Our field survey was collected in October 2010 over six sites in Paris city[2]. 160 bikers were interviewed. The statistics are consistent with other surveys on the bike mobility in Paris (Bilan des déplacements, 2010, OMNIL, 2012). The bikers are mostly men (54%), especially the VB (57%). PB are slightly richer

[2] Place de la République, Saint Lazare, Odéon, Belleville, Volontaires, Quai de la Rapée.

than VB (2,500 €/month and 2,400 €/month respectively), probably because they are older (40 versus 35 years old). As a consequence, PB are more likely to own a car (48% and 41%). Executives (40%) and students (20%) are the more important groups among VB[3]. Bikes are not only used for shopping (10%) and leisure (19%), but also for commuting (44%). Vélibs are more prone to be used for that purpose (49%) than private bikes (37%). Most of respondents use their vehicles intensively: 87% more than once a week. Occasional bikers are naturally more found across VB (11% and 4% for PB).

Table 1 – Who are the bikers?

	All sample	Vélibers	Private bikers
Individual characteristics			
Age	37	35	40
Male	54%	57%	52%
Monthly Income (€)	2,487	2,407	2,573
Executive	36%	40%	32%
Student	17%	20%	13%
Car or Motorbike Ownership	44%	41%	48%
Trip Motivation			
School	10%	11%	9%
Commuting	44%	49%	37%
Leisure	19%	19%	20%
Shopping	10%	7%	12%
Others	17%	14%	22%
Bike usage frequency			
Daily	59%	61%	58%
Several times a week	28%	23%	33%
Weekly	5%	5%	5%
Occasionally	8%	11%	4%
Trip description			
Paris-suburbs	9%	7%	11%
Door-to-door duration (min)	29	25	32
Bike usage (min)	23	20	26
% of bike usage>30 min.	19%	15%	23%
Distance (km)	4.1	3.7	4.4
Door-to-door speed (km/h)	8.5	8.7	8.3
On-vehicle speed (km/h)	10.7	11.2	10.2

Source: field survey in Paris.
Notes: The survey was based on "face-to-face" interviews either at crossing lights or when bikers were parking their vehicles. 50% of the sample was asked during the peak hours and 50% are VB. The interview duration was approximately 5 minutes, with 25 questions.

The average door-to-door duration of the trip is declared to be 29 minutes. Trips of PB are longer (32 minutes) than those of VB (25 minutes). We find similar results for the time spent on the bikes: 26 minutes for PB and 20

[3] We do not enjoy any information on places of residence of interviewees. However, 78% of VB (having an annual pass) live in Paris city (Bilan des déplacements, 2010).

minutes for VB4. This is consistent with the pricing scheme of Vélibs that over-prices journeys above 30 minutes. Only 9% of trips connect Paris and its suburbs (7% for VB and 11% for PB). Knowing the average length of a trip within the sample (4.1 km)5, speed indicators can be calculated: 10.8 km/h considering the on-bike travel time and 8.5 km/h with the door-to-door duration. We observe that VB travel closer and faster (3.7 km and 11.2 km/h on the bike) than PB (4.4 km and 10.2 km/h respectively).

2 - Changes in the bicycle market

Many bikers declared that they were not using this mode before the launching of the Vélib service in July 2007 (46%, see Table 2). This is especially true among VB (71%). The group of VB who used to be former PB is significant (29%). Among the 25 million (M) trips performed by Vélibs in 2010, 17.8 M were *new trips*.

Table 2 – Bikes trips evolution

	Vélib	Private bike	Total
2010 trips (M)[a]	25.0	48.5	73.5
Share[1] of each bike type (%)[a]	34%	66%	100%
Share of *new bikers*[b] (%)	71%	33%	46%[2]
New bikes trips (M)	17.8	16.0	33.8
Average length *new* trips (km)[b]	3.8	4.6	-
New km (M)	67.5	73.6	141.1
Share of *old* bikers (%)[b]	29%	67%	54%
Old bikes trips (M)	7.3	32.5	39.7
Average length *old* trip (km)[b]	2.5	3.5	-
Old km in 2007 (M)	18.1	113.7	131.8

Sources : [a] Bilan des déplacements 2010 ; [b] Our sample.
Note: [1]The "new" bikers are those who were not performing the trip by bike before the launching of Vélib [2] In our sample VB and PB are accounting for 50% when in reality their respective share is 34% and 66%. Therefore we calculate a weighted average: 0.34*0.71+0.66*0.33=0.46.

Symmetrically, 33% of PB declared they were not using this mode before July 2007. This corresponds to 16 M trips newly performed in Paris with private vehicles. On the whole, the rise of bike usage in Paris is equal to 33.8 M trips. Bicycles usage has increased from 39.7 M trips performed before the launching of the Vélib service to 73.5 M in 2010 (+ 85%)[6].

[4] The average access time is 6 minutes, with a shorter duration for the VB (5 minutes).
[5] Distances were calculated thanks to *Mappy,* a trip-calculator website. Importantly, *Mappy* takes into account the road network when proposing distance figures.
[6] This 85% growth is around twice the one reported by official statistics: +40% over 2006-2010 according to Bilan des déplacements (2010). However, municipal statistics do not take into account the densification of the bike paths network which has been quite real over the period (see *infra*). Assuming that bikers are distributed uniformly on the physical network, the 85% figure is plausible. This result will be tested in the last section.

Because our calculations are based on kilometres measures, we look at the average length of trips performed by *old* bikers. It amounts to 3.5 km and 2.5 km for PB and VB respectively. In 2007, 131.8 M km have been performed by bikes (=3.5*32.5+2.5*7.2). The average length of *new trips* is 4.6 km and 3.8 km for VB and PB respectively. In 2010, the bike mobility in Paris is equal to 272.9 M km (=131.8+4.6*16.0+3.8*17.8). This result implies an increase of 141.1 M km over 2007-2010. Because *new bikers* perform longer trips than *old bikers*, the number of km driven in Paris has more than doubled. As a consequence, the share of kilometres performed every day by bikes, having Paris for origin and/or destination, amounts to 1.2% in 2010[7].

3 - Modal origins

The field survey displays the distribution of modal origins of bikers. The majority of *new bikers* are former subway's users (51%), followed by ex-buses' users (18%) and by individuals who declared they were not performing the trip before the launching of the Vélib service (13%). Walking is the fourth previous mode (10%). Most of ex-walkers are now using Vélibs (13%, only 3% are PB). Considering the kilometric modal repartition proposed by Kopp (2011), switches from subways, buses and cars represent 1%, 3% and 0.1% respectively of the total distances realized with these modes in 2010.

Why did individuals switch in favour of the bikes? As illustrated in Table 4, the main driving force behind the modal changes is the search of more comfort (for 29% of the respondents). This makes sense due the large share of *new bikers* who previously used the Paris subway, highly congested during peak periods (Prud'homme et al., 2012, Haywood and Koning, 2012). Bikes are also reported to provide time gains (22%), especially for former buses users (35%). This is consistent with the low speed of buses despite the dedicated lanes they benefit.

[7] Kopp (2011) provides a matrix of distances travelled in and/or from/to Paris thanks to motorized modes of transportation for 2000 and 2007. The matrix does not include bikes. Adding our results, we find a total of 21,600 M km travelled in 2007. Assuming that the mobility was kept constant over 2007-2010, we find a 1.2% figure for the modal share of bikes in 2010 and 0.6% in 2007.

Table 3 – Modal origins of "new" bikers

	All	Vélibers	Private bikers
Walking			
Modal origin (%)	10%	13%	3%
New km (M)	14.1		
Subway			
Modal origin (%)	51%	53%	44%
New km (M)	72.0		
Bus			
Modal origin (%)	18%	16%	22%
New km (M)	25.4		
Cars			
Modal origin (%)	5%	2%	12%
New km (M)	7.1		
Others [1]			
Modal origin (%)	3%	5%	0%
New km (M)	4.1		
New trips [2]			
Modal origin (%)	13%	10%	19%
New km (M)	18.4		
Total			
Modal origin (%)	100%	100%	100%
New km (M)	141.1		

Source: author's calculation from the field survey.
Notes: [1] Motorbikes, streetcars, regional trains; [2] These trips were not performed before the launching of Vélib.

New bikers think that they enjoy health gains (20%), probably due to an increased practice of sport. Moreover, the individual modal choice is not only motivated by personal reasons. The environment is an important concern for *new bikers* (18% of individuals quoting this factor). The low importance of monetary costs and of car congestion (2% and 5% respectively) is consistent with the stable level of the public transportation fares in the Paris area and with the small share of former cars' user. Whereas jobs and housing changes could be expected to be a factor justifying the *new trip demand*, it was quoted by only 7% of the concerned individuals.

Table 4 – Factors influencing the modal shift

	Total	VB[1]	PB[1]	Subway	Bus	New[2]	VB/PB[3]
Environment	18%	17%	17%	18%	20%	14%	12%
Comfort	29%	30%	24%	32%	15%	29%	29%
Monetary cost	2%	2%	4%	0%	5%	7%	8%
Car congestion	5%	3%	9%	0%	0%	14%	0%
Bike's Time gains	22%	27%	13%	5%	35%	14%	25%
Health gains	20%	20%	20%	24%	25%	14%	13%
House/job Change	4%	0%	13%	4%	0%	7%	4%

Source: Author's calculation from the field survey.
Note: [1] VB: Vélibers and PB: private bikers. [2]Individuals who declared not to perform this trip before Velib's launching. [3] Individuals who switched from private bikes to Vélibs.

4- Evolution of the physical network

For the purpose of the analysis, it may be useful to look at the changes of the supply of physical infrastructures accommodating the bike usage. As made clear in Table 5, the bike paths network passed from 399 km in 2007 to 648 km in 2010 (+60%). Whilst overpassing the network growth observed over 2001-2007 (from 256 km to 399 km respectively), the recent extension should be discussed. Thus the efforts made over 2007-2010 have mainly focused on the opening of routes in opposite direction from the car traffic (+64 km per year). By contrast, the investments engaged over 2001-2007 concerned the *hard* and protected dedicated lanes (+11 km per year). We can hypothesize the objective was here to provide the future bikers with a safer and more attractive paths network, once launched the Vélib rental service.

Table 5 – Structure of the bike paths network in Paris

	2001 (km)	**2007** (km)	**Δ/year** (km)	**2010** (km)	**Δ/year** (km)	**2010 costs** (€/km)
Dedicated lanes	91	158	11.2	172	4.7	200,000 €/km
Bike lanes	41	46	0.8	55	3.0	10,000 €/km
Buses lanes opened to bikes	107	140	6.2	171	10.3	5,000 €/km
Opposite direction roads	0	21	3.5	213	64.0	5,000 €/km
Others	17	34	2.8	37	1.0	5,000 €/km
Total	256	399	22.2	648	83.0	

Sources: Authors' estimates from Bilan des déplacements (2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010) and Héran (2012).

The physical infrastructures necessary to biking also include the parking places in Paris. Table 6 illustrates that the bikers were proposed 30,200 additional parking places over 2006-2010: 20,000 places for the Vélib rental service and 10,200 for private bikes. Similarly to what happened for the network of bike paths, the space available for cars served as adjustment variable. Thus cars' drivers in Paris have lost around 11,500 outdoor parking places over 2006-2010.

Table 6 – Outdoor parking places in Paris

	2006	2010	2006-2010
Cars			
Total	165,300	153,810	-11,490
Paying	159,300	151,890	-7,410
Free	6,000	1,920	-4,080
Private two-wheels			
Total	34,000	55,500	+21,500
Motorbikes	8,800	19,100	+10,300
Bikes	6,000	16,200	+10,200
Mixed	19,200	20,200	+1,000
Vélibs	0	20,000	+20,000

Source: Author's calculation from Bilan des déplacements (2006 and 2010)

III – Surplus calculations

The pro-bicycle policy has an initial investment cost whose residual value is disputable (see *infra*). Bikes, at a higher speed, perform more kilometres in 2010 than in 2007. Some people shift from cars, buses, and subway to bikes. The amounts of C02, local pollutants, noise and congestion externalities generated by each mode are consequently changing. Individuals also expect benefits when they shift to a more *active* mode of transportation as biking. Symmetrically, the speed of car in Paris has been slightly reduced. A part of the slowing process is imputable to the narrowing of the streets necessary to create bikes' lanes and parking places, another is not. Public finance is also affected by the change in fiscal revenues collected and Decaux realizes additional profits. All these variations must be calculated and computed in a same monetary unit.

The Net Present Value (NPV) of the *total welfare change* (ΔW_{NPV}) induced by the pro-bicycle policy is given by the sum of several discounted flows of costs and benefits (Boardman et al., 2006):

$$\Delta W_{NPV} = \Delta SC + \Delta SP + \Delta CE + (1+\alpha) * \Delta G \qquad (1)$$

The following items are the NPV in 2007 of:

ΔSC is the variations of the consumer surplus (bikers and car drivers);

ΔSP is the variation of the producer surplus (Decaux);

ΔCE, is the variation of the external costs generated by other modes;

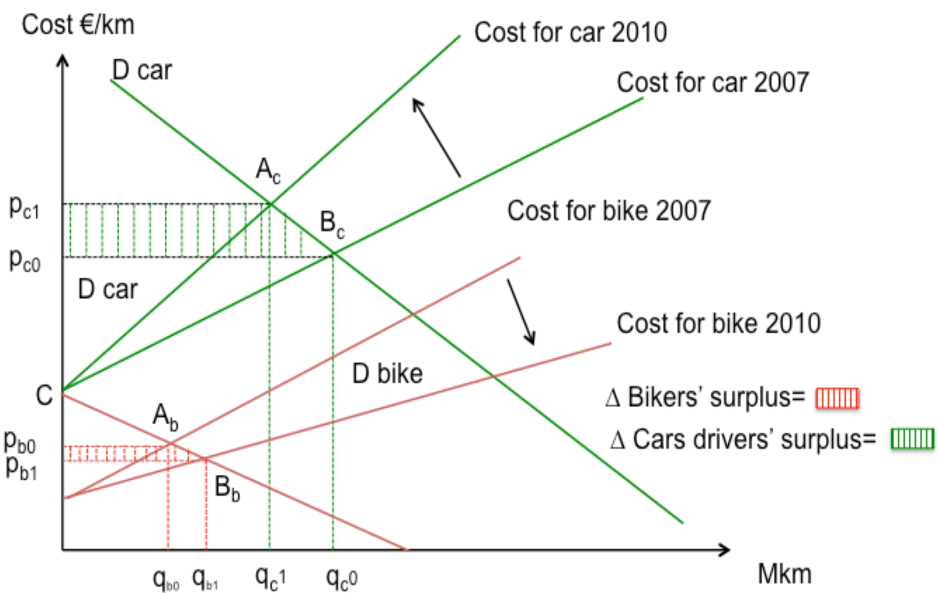
$(1+\alpha) * \Delta G$ is the welfare impact of the change in public finance. It is equal the variation of the public finance (ΔG) multiplied by the marginal cost of public fund multiplier $(1+\alpha)$;

Discounting is based on the official rate of 4.5% (Quinet, 2013) and the calculations take into consideration Velib's launching period and contract's end in July (reducing the length of the first and last year to a half year period). If ΔW_{NPV} is positive, the Paris pro-bicycle policy is desirable. This means that the costs generated by the policy are lower than the induced benefits.

1 - Consumer surplus

Figure 1 illustrates the changes that occurred on the bicycle market from 2007 to 2010. D is a decreasing demand line for bicycles trips. Horizontally, the number of trips is measured in millions of trips*kilometres (Mkm). Vertically, the *full cost* of a trip is measured in euro/km. The private cost of biking includes: (i) the monetized travel time, (ii) some out-of-pocket payments, (iii) negative health effects of accidents and (iv) some health benefits due to an *active* mobility. The difference between the *full cost* and the *willingness to pay* demand curve defines the individual surplus.

Figure 1: Bikers and car driver's surplus



In 2010, the equilibrium on the bike usage's market is in point B_b, with q_{b1} describing the number of Mkm performed in Paris, both by VB and PB, and p_{b1} the corresponding *full cost*. q_{b1} is higher than q_{b0} describing the increase of the trips driven in Paris due to the fall of *full cost* of biking from p_{b0} to p_{b1}. The municipal policy succeeds in attracting *new bikers* because it lowers the relative *full cost* of biking below those of alternative transportation modes[8].

Before the launching of the Vélib service, in 2007, the economic surplus of the bikers was described by the area $p_{b0}A_bC$. In 2010, it becomes[9] $p_{b1}B_bC$. Two areas compose the variation between 2007 and 2010 ($p_{b1}B_bA_bp_{b0}$): the rectangular part is the surplus increase for the individuals who were already using bikes in 2007 and the triangular part measures the surplus for the *new bikers*.

Somehow symmetrically, the car's speed decreased during the same period, weighting the *full cost* of car trips and triggering a decrease of the drivers' surplus by the area $p_{c1}A_cB_cp_{c0}$. This negative evolution is, to some extent, due to the road-space narrowing necessary to the extension of the bike paths network and to the reduced number of parking places available for cars in Paris (that increases the cruising time). Other evolutions in Paris city may also play whilst not being imputable to the pro-bicycle policy.

Biking monetary costs

Before the launching of the Vélib service, monetary costs of private biking in Paris were composed by the buying of vehicles and equipment (special clothes, cask), expenditures (and the time) necessary to their maintenance, the consumption of additional calories compared to *passive* mobility (cars or subways by instance). Papon (2002) provides a comprehensive survey of these values in the French case: a total of 0.112 €/km in 2000, including 0.012 €/km for the buying and the amortization of the bike, 0.028 €/km for equipment, 0.024 €/km for the maintenance, 0.024 €/km for the time spent on that maintenance and 0.024 €/km for the food. After applying an inflation rate of 2%, monetary costs of private biking are equal to 0.137 €/km in 2010.

It is much more complicated to calculate the monetary costs supported by the rental system's users[10]. Assuming that *regular* VB (using the service at least once a week, 89% of VB, see Table 1) buy an annual or weekly travel pass, that their trips never overpass the 30 minutes' threshold and that they account for

[8] A major issue when conducting a CBA is the chosen *counterfactual*: What would have been the evolution of the bike mobility in Paris without the policy studied here? Because municipal statistics highlight a constancy of bike usage over 2005-2006 (Bilan des déplacements, 2010), we assume that the whole change in bike usage can be imputed to the pro-bicycle policy.

[9] For sake of simplicity C is common for both demand curves.

[10] It was difficult to find reliable financial information on the Vélib rental system. The main sources used here are the "*New York Times*", "*Les Echos*", "*Le Figaro*" and "*Slate*", respected (paper or on-line) journals. We also rely on a presentation given by a Paris municipal agent during a conference on PPPs organized by the OECD. See references.

89% of the km driven in Paris with Vélibs (76.2 M)[11], we divide revenues arising from annual and weekly subscriptions (5.4 M€ in 2010[12], i.e. 39% of revenues generated by the Vélib service estimated at 14 M€ at that date) by the number of km performed by the *regular* VB: a 0.071 €/km figure is found. Adding equipment and fooding expenditures, the average monetary cost for *regular* VB is 0.134 €/km, close below the corresponding cost for PB. Concerning *occasional* VB (who spend 8.6 M€ [13] in 2010 and drive 9.4 Mkm), the monetary cost is 0.978 €/km, quite expansive.

According to our data and assumptions, PB, *regular* and *occasional* VB represent 69%, 28% and 3% of q_{b1} respectively. Therefore, the average monetary component of p_{b1} is 0.165 €/km (=0.69*0.137+0.28*0.134+0.03*0.977). Paradoxically, the out-of-pocket payments have increased by 18% compared to the past situation. This is mainly due to *occasional* VB who support an important monetary cost because of more than 30 minutes, and over-priced, trips.

Biking travel time costs

According to Orfeuil et al. (2006) the door-to-door speed of bike trips in Paris streets was 6.5 km/h in 2005. The door-to-door speed has increased to 8.5 km/h in 2010 (see Table 1). Still below cars' and subways' performances for long journeys, the door-to-door bike speed is nowadays attractive for short travels in Paris. This could explain the major increase of bike's usage found here.

The 31% growth of bicycle speed, over 2005-2010, seems consistent with major investments in bike paths realized by the Paris municipality (see Table 5). Thanks to an extended physical network bikers are not obliged to decelerate when the motorized traffic flow slows down. In addition, most of new paths greatly ease the crossing of streets. The additional parking places may also have reduced the cruising time. Finally, bikers were authorized to use many roads in

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[11] Assuming that *regular* VB do not pay any extra fee is generous. Within our sample, 10% of *regular* VB spend more than 30 minutes on the bike. However, municipal statistics highlight that the average duration of VB having an annual pass is 16 minutes (Bilan des déplacements, 2010). Within our dataset, we also observe that *regular* and *occasional* VB travel approximately the same distance: 3.8 km and 3.4 km per trip respectively. According to duration figures (19 minutes for *regular* VB and 23 minutes for *occasional* users), the on-bike speed serves as adjustment variable: 11.9 km/h and 8.9 km/h. This appears consistent with a sort of *practice-performance* relationship. To reinforce this result, the average duration of *occasional* VB is 37 minutes according to Bilan des déplacements (2010).

[12] 5.4 M € = 0.21 M weekly passes * 5 €/pass + 0.15 M annual passes * 29 €/pass. Data from Bilan des déplacements (2010).

[13] Around 2.14 M daily passes have been sold in 2010, at 1 €/pass. Therefore, revenues from extra fares (trips over 30 minutes) are equal to 6.5 M €.

the opposite direction of cars since 2009, which may strongly shorten distances across Paris.

Assuming that the door-to-door speed grew linearly between 2005 and 2010, the performance of bikes was 7.2 km/h in 2007. Using the official value of travel time savings of 10.7 €/h for 2010, (Quinet, 2013), we deduce travel time costs equal to 1.484 €/km in 2007 and to 1.257 €/km in 2010 (-15%). As often pointed out in transportation economics, the time component of the *full cost* of traveling is predominant compared to monetary expenditures (approximately 10 times).

Biking accident costs

Accident costs are a component of the full cost of bike trips. Bikers are aware of the risks they take by using that mode, 67% of bikers judging this mode of transportation as dangerous in Paris (especially because of the presence of cars around them). Table 7 describes the evolution of bikes' accidents in Paris according to their gravity (killed, severe and light injuries). Because many accidents in 2007 occurred between July and December, once the Vélib service had been already launched, we consider the periods 2003-2006 and 2007-2010. The number of accidents has clearly increased between dates. Whereas 2.3 bikers were yearly killed over 2003-2006, fatal accidents in Paris amounted to 5.3 per year over 2007-2010. Concerning severe and light injuries, they increased from 27.3 and 431 per year to 37.5 and 578 respectively.

Table 7 – Evolution of bikes' accidents in Paris

	2003	2004	2005	2006	Mean	2007	2008	2009	2010	Mean
Killed	1	3	3	3	2.3	5	5	5	6	5.3
Severe injuries	15	21	32	41	27.3	40	38	40	32	37.5
Light injuries	450	382	423	643	431	649	592	552	520	578

Note: authors' calculations from Bilan des déplacements (2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010)

In 2010, the *statistical value of lives* lost is 3.00 M€, 0.45 M€ for severe injuries and 0.06 M€ for light injuries (Quinet, 2013). The accidents' kilometric cost, i.e. the economic value of accidents divided by the number of km driven by bikes, is 0.346 €/km before the introduction of the rental system and of 0.247 €/km after. Conversely to the common belief, the expected cost of having an accident by bike has decreased between 2007 and 2010 (-40%). This is due to the huge increase of the km performed by bike in Paris. Moreover, bikers may anticipate that traffic conditions have improved thanks to the numerous paths they now enjoy.

Biking health benefits

These welfare changes should also consider the health benefits arisen from moving more *actively*. Thus biking instead of using a motorized mode significantly reduces risks of cardiovascular diseases. As made clear in Table 4, *new bikers* also declared they had switched in order to improve their health capital. Even if a growing exposure to local pollutants in Paris streets may increase morbidity (because of a deeper breath due to physical activities), a recent research conducted for the Ile-de-France region has shown that the net health effect of biking was highly positive, by a one-to-nine ratio (Praznoczy, 2012).

Studying the Paris case with the *statistical life method*, Rabl and De Nazelle (2011) propose a health benefit of 0.565 €/km for travellers who used to be car drivers, subway or bus passengers, and who are now biking. The individuals concerned by health benefits represent 90% of the *new* km (127 Mkm, including the individuals who were not travelling before July 2007). In fact, Rabl and De Nazelle (2011) explain that health gains are higher for *new walkers* (1.037 €/km). As a consequence, we deduce a loss of 0.472 €/km for the 10% of *new bikers* (14.1 Mkm) who used to walk in Paris before the launching of the Vélib service. Recognizing that 48% of km performed in 2010 are not concerned by these changes, because they are realized by *old bikers*, the average health gain is + 0.238 €/km over 2007-2010.

Variation of the bikers' consumer surplus

Adding the different components, the *full cost* of biking was 1.967 €/km in 2007 and 1.430 €/km in 2010. As a consequence, its variation between dates is equal to 0.536 euro/km. Recalling that q_{b0} amounts to 131.8 M km and q_{b1} to 272.9 M km, we find the annual variation of the bikers' surplus: +108.5 M€ (=0.536*131.8+0.536*141.1*0.5). Benefits of *old bikers* are of 70.6 M€, those of *new bikers* reach 37.9 M€. We can also calculate that VB enjoy only 26% of the total welfare gains[14] (28.1 M€). In order to calculate the NPV of bikers' gains over 2007-2017, we use the conventional discount rate of 4.5%. Considering that bike users do not support any initial investment, the NPV of welfare changes over ten years is +858.9 M€.

Car's consumer surplus variation

Between 2007 and 2010 the *full cost* of using a car in Paris has increased. The average sped and the number of km performed by car decreased respectively from 15.7 km/h to 15.2 km/h and from 5,110 Mkm to 4,884 Mkm (Bilan de déplacements, 2010, Kopp, 2011). Assuming that monetary expenditures of cars

[14] We deduce from Table 2 that VB account for 48% and 14% of *new* and *old* km respectively.

were hold constant over 2007-2010, (P_{c1}-P_{c0}) is equal to 0.029 €/km (using the time value of 10.7 €/h). Therefore, the variation of drivers' surplus amounts to 144.3 M € per year: -140.5 M € for the individuals still driving a car in Paris and -3.8 M € for those who stopped.

This welfare loss cannot be entirely inferred to the creation of bike paths in Paris and to the reduced number of parking places for cars. First, the car mobility would have probably dropped in trend. In addition, some civil works in North-East Paris related to the extension of the streetcar network have worsened traffic conditions in these areas. Other urban renewal programs disturbed traffic conditions too. However, the supply of dedicated lanes for buses did not grow over 2007-2010 (Bilan de déplacements, 2010). More generally, the increased usage of non-motorized two-wheels in Paris has forced other street's users (and mainly cars' drivrs) to *internaliz*e their presence. This has surely led to the deceleration of cars' speeds because it implies more vigilance from drivers, especially since 2009 with bikers facing cars in several streets of Paris city.

To be on the safe side, we assume in the benchmark case that 25% of the cars' speed and traffic decreases are due to streets reshaping in favour of bikes. Annual losses linked to the pro-bicycle policy consequently amount to -36.1 M€. The NPV of the car consumer's surplus variation from 2007 and 2010 is equal to - 285.5 M€, using the discount rate of 4.5%.

2 – Producer surplus

The Vélib rental service is operated by Decaux, a private company operating in sectors of street infrastructures and advertising. Decaux payed the total cost of the infrastructures (110 M€, including Vélibs' infrastructures for 90 M€ and new billboards for 20 M€) on which an opportunity cost of capital (5%) must be applied (Boardman et al., 2006). The firm runs the system and transfers all the fare revenues to the city (estimated at 14 M€ for 2010). Decaux's profits are mainly generated by the usage of 1,628 billboards on Paris' walls (a market value of 60 M€ in 2007) for which one annual fee is paid to the municipality (3.5 M€).

This PPP has been renegotiated in 2008 at Decaux's demand. Thus the municipality of Paris agreed to bear the burden of the extension of the Velib's network in the close suburb (8 M€ per year). In addition, the new contract stipulates that the municipality pays 400 euros per damaged bike (4,000 per year). The total cost beared by the citizen for keeping constant the Vélib fleet is estimated at 1.6 M€ per year. Under these new contractual conditions[15], Decaux officials stated in 2009 that the breakeven point was met.

Importantly, we assume that the residual value of the investments will equal zero in 2017 due to the magnitude of bikes' destructions and to the quick outdating of the monitoring system. Moreover, Decaux is unlikely to dismantle the infrastructures in Paris to relocate them somewhere else. In most of PPPs, the public entity generally gets for free the infrastructures at the end of the contract ("built, operate and transfer"). This assumption allows us to determine the last unknown, i.e. Vélibs' operational costs.

We consider that the breakeven point stated by Decaux officials in 2009 corresponds to obtaining an Internal Rate of Return (IRR) of 12%. This threshold may be seen as the minimal profitability asked by the private company for being involved with the transaction (Bonnafous, 2010). Starting from IRR's definition and using available data, we find an operational cost equal to 1,124 €/bike, i.e. 22.5 M€ per year. This figure appears consistent with operational costs of bike sharing services reported for other French cities (GART, 2009).

Table 8 – Decaux's benefit M€

Initial cost for infrastructure and building the billboards	-110
Opportunity cost of the invested capital (5%)	-5.5
Running cost[1]	-22.5 per year
Access fees for billboard	-3.5 per year
Advertising Turnover	+60 per year
City subsidy for bikes maintenance	+1.6 per year
Benefit	+35.6 per year
NPV in 2007 of Decaux's profits (2007-2017)	+166.4

Note: [1] The unitary operational cost (Cop) is found by starting from the IRR's definition and by considering an IRR equal to 12% : $C_{op} = \frac{(Adv+Comp-Fee)-\frac{(I_0+Kop)}{T}\times(1+IRR)^T}{n}$, where (Adv) is the advertising revenues, (Comp) the compensations transferred by Paris city, (Fee) the access fee, (Kop) the opportunity cost of the capital invested, (T) the length of the contract and (n) the fleet size.

We have the whole data necessary to calculate Decaux surplus' variation: +35.6 M€ per year. Because we stand here from the social planner's perspective, we also use the discount rate of 4.5%. Accounting for the initial investments, the NPV of Decaux' profits realized thanks to the Vélib contract is +166.4 M€.

[15] Also, some penalties linked to the quality of the service provided by Decaux were cancelled and incentive's premiums on the marginal revenues were added (if the latter would overpass 15 M€, which was not the case in 2010).

3 - Public finance change

The PPP signed with Decaux to make the rental service available has an impact on local public finance, conversely to the announcements made by Paris officials. Summing the 14.0 M€ income generated by the Vélibs service plus the 3.5 M€ of access fees for billboards minus the cost of broken bikes (-1.6 M€), the cost of under-pricing these billboards to Decaux (-60 M€) and the cost of extending the Velib's network to suburbs (-8.0 M€ plus 0.4 M€ for the capital opportunity cost), we find an annual loss of -52.5 M€ for the municipal finance.

In the same vein, the urban space used by the bikes' network is not anymore available for tolled parking space. As illustrated in Table 6, around 11,500 parking spaces disappeared in Paris between 2006 and 2010. Assuming that 50% of the evolution is imputable to bikes, the rest being re-allocated to motorized two-wheels, a 1.20 euro per hour fare leads to a 20.7 M€ loss of revenue for the municipality (considering that places are occupied 10 hours per day and 300 days a year).

Importantly, we assume that Paris deciders saw the 2001-2007 expenditures in bike paths as initial investments. Using costs data from Table 5, the investments realized over 2001-2007 are equal to 13.9 M€ (with an initial capital opportunity cost of 0.7 M€), i.e. 2.3 M€ per year. Over 2007-2010, the investments in bike paths are equal to 4.1 M€, i.e.1.3 M€ per year (and a capital opportunity cost of 0.1 M€). As a consequence, the annual financial effort decreased by 39%.

Considering that the physical network will not deteriorate over ten years, the residual value of the initial investments is equal to 9.4 M€ in 2017 (with the discount rate of 4.5%). Considering that the current investments will be sustained over the next 10 years (14 M€ invested until 2017), the residual value will reach 9.0 M€. As for Decaux, we do not consider any residual value for the investments in Vélibs' infrastructures realized by the municipality in close suburbs.

Table 9– Public finance (M€)

Access fees for billboard	+3.5
Lost advertising revenue	-60.0
Network extension cost	-8.4
Lost Parking space income	-20.7
Contribution to bikes maintenance	-1.6
Annual Cost of dedicated lanes	-1.4
Annual Variation of Public Finance[1]	-89.5
Initial Investment in dedicated lanes	-14.6
Residual Values of 2001-2007 investments	+9.4
Residual Values of 2007-2017 investments	+9.0
NPV in 2007 of PF variation (2007-2017)	-704.4

Sources: author's calculations
Note: [1]: the variation includes the marginal opportunity cost of public fund fixed at 20%.

Using these data, the annual variation of public finance induced by the pro-bikes policy is equal to -89.5 M€ (-708.2 M€ over ten years using the 4.5% discount rate). This result includes the marginal opportunity cost of public funds officially fixed at 20% in France (Quinet, 2013). Adding the initial investments and the residual values of bike paths, the NPV of public finance variation over 2007-2017 is -704.4 M€.

The analysis is not extended to the financial consequences for the central government or for the public transport operator. First, the taxes from *new bikers'* fooding and equipment are probably compensated by the reduced taxes' from cars' gases. Moreover, we believe that most of the *new bikers* are still using the public transport network on a regular basis and still buy a travel pass. Finally, savings on public transport (operational and environmental) costs would exist only if the supply of subways and buses was finely tuned to the reduced number of passengers. Given the insignificance of the modal changes with respect to the total usage of these networks (see *supra*), these adjustments were unlikely to occur.

4 – Externalities

We have assumed that the pro-bicycle policy is responsible for 25% of the traffic decrease in car trips observed over 2007-2010 (66.5 M km). Such a change is theoretically accompanied by less emission of CO2, noise and local pollutants. In order to value these environmental externalities, we rely on a recent report proposed by the French Ministry of Ecology (CGDD, 2013). The marginal cost of CO2 emissions in dense urban areas reaches 0.005 €/km, 0.006 €/km for noise and 0.012 €/km for local pollutants. As made clear in Table 10, the environmental savings amount to 1.5 M€.

Using Table 3, we can also hypothesize that 50% of the modal shift from buses and subways leads to decongestion benefits during peaks, holding constant public transport supply. Using the 0.23 €/km parameter proposed by Haywood and Koning (2012) for public transport decongestion benefits, the gains of 11.2 M€ largely out-weight the environmental savings.

Table 10 – Externalities (M€)

Subway decongestion benefit	+8.3
Bus de crowding benefit	+2.9
CO2 car saving	+0.3
Car local pollutants	+0.8
Car noise	+0.4
Total annual externalities welfare impact	+12.8
NPV_{2007} from 2007-1017	+100.8

Sources: CGDD (2013) for cars' external costs, Haywood and Koning (2012) for public transport decongestion benefits.

The total savings on externalities are +12.7 M€ per year. Using the discount rate of 4.5%, the NPV of these gains over 2007-2017 is +100.8 M€.

IV – Results and discussion

1 – A modest green light

Summing all the previous results according equation (1) gives the NPV of the total welfare change during 2007-2017. The total welfare change is slightly positive (+ 136.2 M€ over ten years). As a consequence, the CBA conducted here gives a retrospective modest green light to the Paris pro-bicycle policy.

Table 11 – Total welfare change (M€)

NPV of Bikers Consumer's surplus	+858.9
NPV of Cars Consumer's surplus	- 285.5
NPV of Producer surplus[1]	+166.4
NPV of Externalities	+100.8
NPV of Public finance[1]	-704.4
Total	+ 136.2

Note: Author's calculation from previous sections; [1]:The NPV of producer surplus and of public finance include the initial investments, net of the residual values.

The public intervention is globally beneficial for Paris society even if the cost for local public finance (-704.4 M€) is close to the bikers' benefits (+858.9 M€). Importantly, we have seen that the usage of bikes in Paris has more than doubled over 2007-2010. Whereas Decaux runs the Vélib rental system and realizes some profits (+166.4 M€), the global economy of its implementation suggests that the bikers, and mostly the VB, are highly subsidized by the municipality. In fact, VB account for only 26% of bikers' gains whereas 88% of the annual public spending is dedicated to the bike rental service[16]. The policy is

[16] Assuming that 66% of losses due to un-tolled parking space for cars are linked to the Vélib service (20,000 places on a total of 30,000, see Table 6), we can deduce an annual

also working at the expense of the cars' drivers (- 285.5 M€) while positive externalities are not that important (+100.8 M€), especially the environmental savings.

2 – Sensitivity analyses

Our analysis is relying on many assumptions. Some are pretty solid, others could be discussed. In order to check how the verdict of our assessment survives to changes in the assumptions, we run several sensitivity analyses.

The first tests concern the changes occurring on the bicycle market. Thus we consider a 40% growth of bike trips performed in Paris over 2007-2010 (instead of +85%, see footnote 6) and a 9% growth of the door-to-door bike speed (instead of 18%). As illustrated in Table 1, bikes are also used for commuting, when individuals have a higher time opportunity cost. Weighting the value of travel timing savings with respect to the share of commuters within our sample (44%) and the corresponding time value (12.6 €/hour, see Quinet, 2013), we find an average of 11.5 €/hour (a growth of 8% compared to the benchmark). Because they are sometimes subject to debates (Cahill et al., 2008), one scenario ignores health gains for *new bikers*.

The second set of tests relates to the share of cars drivers' losses imputable to the pro-bicycle policy: 0% and 50% respectively, instead of 25% in the benchmark case. Then we observe the evolution of Decaux' profits assuming one IRR equal to 8%, as opposed to 12% currently. The producer surplus will also change with respect to the market value of the advertising billboards in Paris streets[17], 40 M€ or 80 M€, as will do the local public finance. Finally, we make vary the fare of cars' parking places: 3.6 €/hour (as in most expansive and central city's areas) or 0.65 €/day (as paid by Paris inhabitants).

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spending of 79.4 M€ for VB (including the marginal opportunity cost of public funds). This should be compared to a total of 89.5 M€ per year.

[17] The operational costs of Vélibs are here fixed at 1,124 €/bike.

Table 12 – Sensitivity analyses *(*M€)

	Bikers	*Car*	*Decaux*	*Paris city*	*Externalities*	*Total*
Benchmark	*859*	*-286*	*166*	*-704*	*101*	*136*
ΔTrips = +40%	494	-286	166	-704	67	-263
Δ Speed = +9%	671	-286	166	-704	101	-47
ΔTime value = +8%	888	-309	166	-704	101	141
Zero health benefits	477	-286	166	-704	101	-246
Cars' losses = 0%	859	0	166	-704	90	411
Cars' losses = 50%	859	-571	166	-704	113	-137
IRR = 8%	859	-285	80	-704	101	50
Advertising = 40	859	-285	8	-515	101	168
Advertising = 80	859	-285	325	-894	101	105
Parking = 3.6 €/hour	859	-285	166	-1097	101	-257
Parking = 0.65 €/day	859	-285	166	-519	101	322

Source: Author's calculations.

As illustrated in Table 12, the analysis is very sensitive to the changes in paramaters or assumptions. In 5 cases (on 11), the total welfare impact of the pro-bicycle policy becomes negative and the final balance improves only in 4 cases (compared to the benchmark).

Worst results are linked to the variation of consumers' surplus, especially when we consider a lower growth of the bike usage in Paris over 2007-2010 or when health benefits for *new* bikers are ignored. From the former scenario, we notice the predominance of public transportation decongestion benefits within externalities. Also, the increased environmental savings are numerrically small compared to the additional time losses when assuming that the pro-bicycle policy is responsible for 50% of cars' deceleration and reduced usage. Finally, these tests stress the importance of the marginal opportunity cost of public funds in a CBA framework. The 20% premium applied on public finance explains why transfers from Paris city to Decaux, due to the increased (decreased) market value of the advertising billboards, results in a more (less) than proportional total welfare change. Moreover, it allows to understand the strong deterioration of public finance when the opportunity cost of outdoor parking places is increased.

3 - Discussion

When conducting a CBA, a major issue generally relates to the welfare changes potentially induced by the policy and not integrated to the assessment. Are some costs and benefits of the municipal policy ignored here? Among the latter: the surplus' variation of bike dwellers (who may increase their selling due to the expenditures of *new bikers*), the additional profits of indoor parking's operators (who may benefit from increased market rents), the growing attractiveness of Paris city, both for the inhabitants and for the touristic sector... Among the former: the environmental damages due to the trucks necessary to the re-allocation of the Velibs' fleet across stations, the transaction costs supported by Decaux and the Paris municipality during the contracting (and the renegotiation) of the PPP. An accurate analysis of these effects would require future research, out of the scope of this article. In addition, we believe that most of the changes are merely distributive[18] and don't affect the efficiency.

A second shortcoming in the analysis may be linked to the residual value of the initial investments in Vélib's infrastructures and billboards which we assumed to be nil in 2017. In the case these spending would have positive residual values, they would also reinforce the policy's social desirability. From a contractual perspective, however, interesting lessons could be drawn from the identity of the residual property rights' owner. In fact, it has been shown that the owner is more likely to renegotiate the PPP at its advantages, especially if the assets engaged into the transaction are specific ones (Williamson, 1976). Said differently, either the infrastructures will belong to Paris city in 2017 and the municipality can easily fire Decaux in order to choose a "cheaper" operator. Or the private company will own the residual property rights and it can probably obtain larger a better renegotiation.

Conclusion

Even if the group of benefiters is numerically small, the pro-bicycle policy was not rejected by Parisians. Around 200,000 persons[19] use a bike on a regular basis that contributes to 1.2% of the daily km performed in Paris. Nonetheless the pro-bicycle policy seems to be popular among Parisians and the Mayor Betrand Delanoë was easily re-elected in 2008. Some tentative explanations may be raised.

First, around 40% of the bikers own a car. They use the bike as a complementary mode of transportation and they balance the negative impact of the policy on their commuters' self by the improvement of their bikers' (or walkers') self.

[18] For example, see Bureau and Glachant (2010) on "the green neighborhoods" in Paris city. Using the hedonic price methodology, they show that land prices have increased more quickly in places where the cars' speed was decreased (due to street reshaping) and where investments in parks and walking areas were realized, i.e. almost the same places where the usage of bikes was promoted. This is a "good deal" for land owners but a "bad deal" for people who rent their flats (the majority of Paris inhabitants), because meaning higher rents.

[19] We assume that individuals biking "*daily*", "*several times a week*", "*weekly*" and "*occasionally*" perform 9 trips/week, 3 trips/week, 1 trip/week and 0.3 trip/week respectively. Considering the weights in Table 1, a representative biker in Paris realizes 7.1 trips/week. Knowing that 73.5 M trips were performed by bikes in Paris in 2010, we find around 200,000 bikers.

Second, most of the drivers in Paris are not living in the central city but in the suburbs. They use their car to commute to Paris because a suburb-Paris-suburb car trip is still much faster than a public transportation or bike trip. The Paris' pro-bicycle policy is a burden for them but they don't vote to elect the Paris mayor.

Third, voters are usually sensitive to avoided costs (those beared by Decaux to run and to launch the system) and not very concerned by the city's increasing public debt (due to income losses on advertising and cars' parking places).

The pro-bike policy is mainly dedicated to the richer population of Paris benefiting of the dense subway network and using a bike for complementary trips. Such a policy is less favourable to lower income population living in suburbs and obliged to palliate the lack of public transportation by an intensive use of the car.

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