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Are car-free centers detrimental to the periphery? Evidence from the pedestrianization of the Parisian riverbank

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Are car-free centers detrimental to the periphery?

Evidence from the pedestrianization of the Parisian riverbank*

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Abstract

This paper evaluates the impact of the downtown "Georges Pompidou" riverbank closure in 2016 on the Parisian ring road traffic conditions. Using high-resolution hourly data and a difference-in-difference design, I show that the closure increased the probability of congestion on ring road lanes with the same flow direction as the riverbank by 15%, translating into an additional 2 minutes spent on a 10 km trip. Train use and pollution data suggest that (i) only a small fraction of affected commuters switched to public transportation and (ii) a majority of affected residents suffered from a decrease in air quality.

Keywords: Congestion, Air Pollution, Public Transportation, Route Choice

JEL Classification: R41, R42, Q53, Q54

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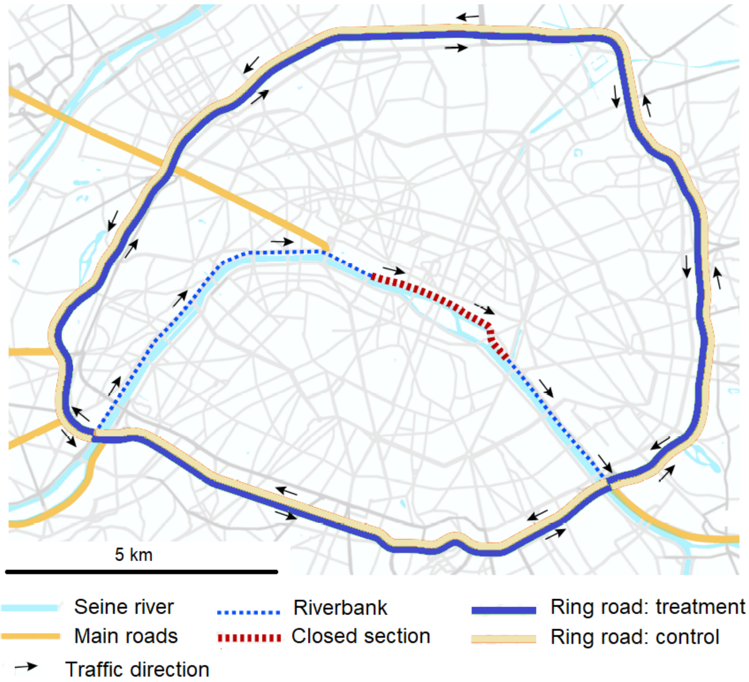
1 Introduction

Many cities in developed countries are currently rethinking the structure of their road network by reallocating urban expressways and creating car-free zones, with the hope of fostering alternative modes of urban transportation (Nieuwenhuijsen and Khreis, 2016). Unsurprisingly, these policies are not popular with most car users, while their proponents argue that they are justified by their overall positive impact on the environment and the urban quality of life. However, despite accompanying programs such as improved bus lanes, road-reduction policies have also been accused of displacing, rather than diminishing, congestion and pollution- because they do not tackle cities' deep-rooted reliance on private motorized transportation. Are high-income, high-amenity city centers becoming greener at the expense of the periphery? Evidence on this latter claim is lacking and the present paper aims to fill this gap, using the city of Paris' recent experience as a case study.

Since the early 2000s, Paris has gradually limited the use of cars within the city by implementing road-reduction policies. The most emblematic road closure decision to date was the pedestrianization of a 3.3-km segment of the expressway along the Seine's right riverbank, the "Voie Georges Pompidou" (hereafter, GP) in September 2016. The GP was the only expressway to cross the city. As shown in Figure 1, it was part of a 13-km road that crossed Paris from southwest to southeast. The closed segment was near Notre Dame cathedral, the geographical and touristic center of the city. Until 2016, this road was used by approximately 40k vehicles every day. It was partly used for travel within the city but also acted as possible substitute for the ring road for suburb-to-suburb traffic; the heavily congested southern section was especially used for this (Bouleau, 2013). As such, the riverbank was part of a road network that was of general interest to the region.

Figure 1: Map of Paris



Notes: This figure represents a sketch of Paris. The dashed line represents the riverbank used by cars to cross Paris. The thick sections with an eastward flow direction correspond to the south outer and north inner ring roads. The thick sections with a westward flow direction correspond to the south inner and north outer ring roads. The different arteries of the city are represented in yellow.

To identify the effect of the pedestrianization, I make use of one particular feature of the GP: its flow direction. Given the single flow direction of the GP, the eastward lanes of the ring road were in a position to be directly impacted by the GP closure by receiving a fraction of the displaced GP users. In contrast, the impact of the closure on the westward lanes, in the absence of alternative westward expressways within the city, may only have been indirect through a global decrease in traffic. In addition, the architecture of the ring roads (continuous steel or concrete median strip, lack of traffic lights, outward exit lanes) makes it likely that traffic flows in either direction are independent of each other. These different features allow for an evaluation of the GP closure by comparing its effect on the eastward ring road to its effect on the westward ring road, in a difference-in-difference framework.

To measure traffic, I make use of the 2013-2019 road sensor data of the Paris

City Hall. These data provide the occupancy rate (the percentage of time that vehicles occupy a given segment of the road) and the flow of vehicles, for every hour of the day and a collection of dozens of road segments that match the ring roads almost exhaustively. In my main specification, I compare, before and after September 1^{st} 2016, the occupancy rates of the ring roads with the same flow direction as the riverbank to ring roads with the opposite flow direction, controlling for segment and (over 70k) time fixed effects. I then look at different variables linked to the occupancy rate. I first compute an indicator of congestion by using the concave and quadratic relationship between traffic flow and occupancy rate. Second, relying on simple parametric assumptions, I can comment on the impact of the closure on the average speed of vehicles on the ring roads. This allows me to perform a back-of-the-envelope computation of the time lost by commuters. I identify two groups of losers: "direct losers", i.e., travelers who were using the GP prior to September 2016 and were forced to change itineraries and "indirect losers", i.e., travelers who were using the ring road prior to the closure and suffered from worsened traffic conditions. To relate these results on traffic conditions to the explicit goals of road reduction policies (improve environmental quality and trigger a modal shift), I turn to alternative data sources. I use public transportation data to evaluate the impact of the closure on the number of users of the suburban train line that links the east and the west of the Paris region and I compare the estimate to the number of commuters potentially impacted by the riverbank policy. To study the link between traffic and air quality, I use pollutant emission data and I ballpark the effect of the closure on residents' exposure to pollution by comparing population densities around the GP and ring road.

My findings are fourfold. First, I confirm that the GP closure has worsened traffic on eastward ring roads compared to westward ring roads. On average, the occupancy rate increased by 1 p.p. which corresponds to a 3.6 p.p. increase (or a 15% relative to the year prior to the shutdown) in the probability of congestion. The magnitude is always higher on the southern ring road since it represents a more direct substitute for the riverbank. The impact on the occupancy rate is always significant and positive regardless of the hour of the day or the day of the week (except Sundays); however, the impact is larger during daytime and weekdays, suggesting that the closure mostly affected commuters. Second, I show that the GP closure decreased the average speed by 1.7 km/h on the full sample and by 3.1 km/h on the south ring roads. I estimate that direct losers put up with a six-minute increase in travel time for the full trip, while indirect losers lose two minutes. Third, I identify a significant but negligible increase in the number of passengers using the suburban train, which hints at the impossibility, for most suburban commuters, to shift away from car transportation. Finally, I estimate that the number of residents who have suffered from degraded air quality is at least three times higher than the number of residents who have benefited from improved air quality. However, this comparison does not take into account the benefits accruing to other users of the car-free zone. These last two results are arguably weaker than the first two because they are based on lower-quality data but they suggest that the GP closure failed to achieve its stated goals, at least in the short run. This brings into question the political economy behind the adoption of this kind of policy, which was implemented by the Mayor of Paris but ended up hurting people (residents around the ring roads and suburban commuters) who live outside her jurisdiction.

This paper relates to several strands of literature. Road reduction is part of a wide array of congestion policies implemented in cities, which have been studied in numerous works. Downs (1962) coined the *law of peak-hour expressway congestion* which states that *on urban commuter expressways, peak-hour traffic congestion rises to meet maximum capacity*, thus proving that road expansions fail to reduce congestion in urban areas. Duranton and Turner (2011) recently confirmed this relationship by estimating a close-to-unit vehicle-km-traveled elasticity to lane kilometers of roads for different types of roads. Given this paradox, a general consensus in the literature has emerged, whereby road pricing is the only efficient and reasonable solution (Duranton and Turner, 2011; Liu and McDonald, 1999; Santos et al., 2008; Tirachini and Hensher, 2012; Winston and Langer, 2006). Nevertheless, many cities have used road space rationing instead of road pricing by restricting the days or hours in which car users can drive on congested roads (de Grange and Troncoso, 2011; Gallego et al., 2013; Kornhauser and Fehlig, 2003). Other cities, including Paris, have opted for quantity-rationing by gradually reducing their road capacity. For example, Seoul transformed its main highway into an urban boulevard (Kang and Cervero, 2009) while New York has used *High Occupancy Toll* (HOT) lanes (Poole Jr and Orski, 2000). In the case of Paris, the choice of road reduction rather than road pricing takes on a political dimension due to the low levels of consent to taxation among French car users[1].

Many studies have tried to evaluate behavioral responses to traffic policies. Gibson and Carnovale (2015) show that drivers substitute itineraries for unpriced roads or times whenever an urban toll is implemented. Closely related to this analysis are Gallego et al. (2013) and Davis (2008), who find evidence on substitution behaviors to circumvent traffic policies. To the best of my knowledge, this paper is the first to study the causal effect of road reduction, instead of road expansion or road pricing, on traffic displacement in the outskirts of a city.

The impact of traffic, and in particular traffic congestion, on air quality has long been a source of concern (Shefer, 1994). Yet, despite the large body of work in urban studies and transportation economics devoted to the quantification of the negative consequences of urban road traffic on health through pollutant emissions, causal assessments are rather scarce (Currie and Walker, 2011)[2]. A common finding of many studies is that congestion policies may only have a positive impact on air quality if they do not increase congestion on untargeted roads (Bhalla et al., 2014). For example, Davis (2008) shows that banning some drivers from using their cars in Mexico City failed to decrease the use of car, thus providing no evidence that the restrictions have improved air quality. My results on road substitution behavior suggest that the decrease in car use was minimal, and similarly provide no evidence of an increase in air quality.

Last, this paper relates to the literature on public transportation and pollu-

[1]When President E. Macron made the decision to impose a gasoline tax, it backfired on him and the *Gilets Jaunes* were quick to react and cause turmoil in the country (Boyer et al., 2020).

[2]In the case of Paris, there has been some pollution quantification; but with no causal assessment (Prud'homme et al., 2011).

tion. Several studies focus on the improvement of public transportation in terms of price or quantity and its impact on urban pollution. Chen and Whalley (2012), for example, study the opening of a new urban rail transit in Taipei and show that it is responsible for a significant decrease in the concentration of carbon monoxide. Parry and Small (2009) estimate welfare effects of fare adjustments in rail and bus transit and document meaningful gains in extending fare subsidies through the ease of car traffic congestion, especially during peak hours. Other studies look at public transport disruptions to quantify the impact on congestion and pollutant emissions. Anderson (2014) uses the strike of transit workers in Los Angeles in 2003 to show that transit riders are likely to be commuters who use congested roads and thus that transit largely contributes to reducing traffic congestion. This finding is in line with that of Bauernschuster et al. (2017) who show that public transit strikes in Germany caused an increase of 14% in pollution due to traffic volumes and longer travel times. In the context of suburb-to-suburb commute in the Paris metropolitan area, my results offer suggestive evidence public transportation network may not always easily substitute to car use.

The remainder of the paper is organized as follows. Section 2 presents background information on the Paris region in terms of commuting patterns and describes the different datasets. In section 3, I lay down the empirical strategy. Section 4 describes the main results and discusses various robustness checks and heterogeneity analyses. Section 5 presents further evidence on the impact of the GP closure on congestion and provides an approximation of time loss. Section 6 discusses whether the policy has reached its intended goals and section 7 concludes. Additional material is presented in the Online Appendix.

2 Context and data

2.1 Commuting in Ile-de-France and the riverbank shutdown of 2016

In the Ile-de-France region, job concentration follows a decreasing gradient, with Paris City as its core (see Figure O.B.1), consistent with the monocentric model (Chapelle et al., 2020)[3]. Most individuals commute to the center of the region either by car or by public transportation, depending on access to train stations. Municipalities located in the east or west of Ile-de-France have the highest share of car commuters (Figure O.B.2a) and car use is particularly dominant for suburb-to-suburb journeys (Figure O.B.2b).

The urge to transform the city into a greener one was at the heart of the 2014 municipality campaigns, won by Anne Hidalgo[4]. Her campaign mainly focused on environmental and urban strategies that reversed previous schemes based on increasing road capacities[5]. Her program was threefold: offer a greater role to nature within Paris proper; promote the creation of public housing; and improve the efficiency of urban logistics. This included reducing the number of cars in the city by pedestrianizing some roads and creating new bus and cycling lanes.

The GP riverbank was the object of her most contested reform. While in the 2000s the progressive pedestrianization of the riverbank had already taken place. Banning cars from this road was initially implemented every Sunday and during bank holidays; then, an entire month during the summer dedicated to "Paris Plage" (Paris-by-the-beach), A. Hidalgo formally established it on September 1^{st}, 2016. This policy was justified with the urge to decrease vehicle circulation by provoking a modal shift, thus reduce pollution in the city when around 40,000

[3]However, the gradient is reversed within Paris: densities are higher on the outskirts of the city, particularly around the ring roads.

[4]Anne Hidalgo has been the Mayor of Paris since 2014. She has been a member of the Socialist Party since 1994. Her political view is mainly centered around environmental policies. To fight air pollution, she introduced in 2016 a scheme called "*Paris Respire*", literally "Paris Breathes" by banning some cars from certain areas in Paris on the first Sunday of every month.

[5]For example, the riverbanks along the Seine river (dashed line of Figure 1) were first open to vehicle circulation in the 1970s with the aim of reducing travel time. This expressway was inaugurated in December 1967 by the Prime Minister Georges Pompidou. Originally, the project was meant to gather different sections in order to create a continuous fast track across the city.

vehicles were circulating on this expressway every day. After the Paris Plage event of summer 2016, the GP riverbank from the Tuileries to the Henry IV tunnel was never reopened although the shutdown was not yet official. This project was first implemented in autumn 2016, but went through many protests and disputes before it legitimately took place[6]. Despite the struggles she had to face during her first term, Mayor A. Hidalgo was re-elected in 2020.

2.2 Data description

This study makes use of several databases:

Comptage routier -Données trafic issues des capteurs permanents. This is the main dataset for the study. The City Hall (Mairie de Paris) monitors the traffic situation on the main roads of Paris by implementing electromagnetic loops endowed with sensors in its pavements[7]. Roads are composed of sections and designed to deduce the traffic situation on an axis. The sensors can detect two main types of data:

- Occupancy rate: This corresponds to the time vehicles stay on a loop as a percentage of an hour. For example, an occupancy rate of 25% indicates that cars were present in the loop for 15 minutes.
- Flow: This counts the number of cars that pass by a point in an hour. The same flow can correspond to either a saturated or a fluid traffic situation, depending on the corresponding occupancy rate level.

Each road is decomposed into arcs. On some arcs, both flow and occupancy rates are provided and on others only the occupancy rate is given. The unit observation is an arc of a road. For each observation, I have hourly data of the occupancy rate and flow from 01/01/2013 00:00:00 to 31/08/2019 23:00:00. Furthermore, by assuming an average length of vehicles, I can compute the average speed on each road section. Unfortunately, these data are only available

[6]See Online Appendix O.A for further details.
[7]https://opendata.paris.fr/pages/home/

for Paris' main roads. Therefore, I can only look at the traffic impact on roads in intramural Paris. I also lack socioeconomic data regarding road users and cannot track vehicles due to the aggregated shape of the data. I also use other datasets to ballpark aggregate consequences of the GP closure such as exposure to pollution or modal shift.

Population Census of 2015 -Logements, individus, activité, mobilités scolaires et professionnelles, migrations résidentielles en 2015. For each individual, information about home location, workplace, mode of transportation, age, and status are available from censuses conducted by the National Institute of Statistics and Economic Studies (INSEE). This allows me to conclude the percentage of people commuting by car and public transportation. This census does not include all inhabitants in every municipality but a representative sample of the population. Therefore, I couple it with the population data of 2015 that gives the number of people in each municipality[8].

Population Census of 2016 -Base infra communale (IRIS). Municipalities of at least 10k inhabitants are categorized into IRIS[9]. Each residential IRIS is composed of a population that falls between 1,800 and 5,000. It is constructed in a way that is homogeneous in terms of the environment. I use these data to compare the size of the population near the riverbank to that near the south ring road.

Pollution levels -Airparif. Airparif is a nonprofit organization, linked to the Ministry of Environment, that monitors air quality in the Ile-de-France region. Different stations across the region register emission levels of various pollutants (NO_2, PM_{10}, $PM_{2,5}$ and O_3). I am interested in the station near the Boulevard

[8] Unfortunately, it does not give the total population of each *arrondissement* of Paris. I therefore use the census of 2014 *"Populations légales des arrondissements municipaux en vigueur au 1er janvier 2017 - date de référence statistique: 1er janvier 2014"* which provides the number of residents in each *arrondissement*.

[9] IRIS stands for *aggregated units for statistical information* in English. It is similar to a census tract.

Périphérique, located on ring roads, which registers hourly emission levels of NO2, PM10 and PM2,5 for the years 2013 to 2018.

Public transport traffic per entry -"Trafic annuel entrant par station du réseau ferré". The RATP[10] (Autonomous Parisian Transportation Administration) provides data on the annual number of people entering each RATP station. I have data on the two RERs (regional express networks), which are the trains serving Paris and its surrounding suburbs, belonging to the RATP[11] as well as all the metro lines of Paris.

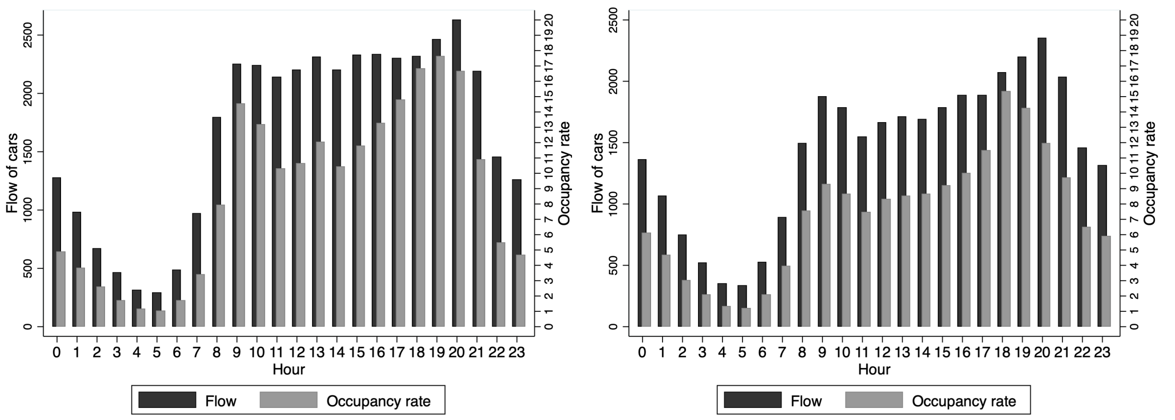
2.3 The Georges Pompidou riverbank

The *Georges Pompidou* riverbank is 13 kilometers long and crosses Paris from the southwest to the southeast (see Figure 1) with a unique flow direction (west-east). Figure 2a provides some descriptive statistics of the riverbank traffic in 2015, a year before the pedestrianization of its center. The descriptive statistics of the pedestrianized segment (figure 2b) suggest that this part of the riverbank is less congested or occupied than the average (lower flow and occupancy rate). In fact, the occupancy rate never exceeds 15%, which highlights the fluidity of the traffic in this segment. Furthermore, there is no obvious variability between peak hours and non peak hours. Instead, the flow of cars is always high from 8 AM to 9 PM. However, roads appear to be slightly more occupied during evening hours from 5 PM to 8 PM. This could imply that most commuters live in the east and work in the west.

[10] *Régie autonome des transports parisiens* is a state-owned public transport operator and maintainer.

[11] Paris' train network is owned by RATP or SNCF. Metros are RATP's property while RER are divided. Only RER-A and RER-B belong to the RATP, except the stations inside Paris that belong to SNCF.

Figure 2: Descriptive statistics of the riverbank - 2015



(a) 13 km riverbank **(b)** 3.3 km closed in 2016

Notes: Data come from the open data source of the city hall. The sample in Figure 2a is composed of the 33 road sections that compose the GP riverbank inside the city. The sample in Figure 2b is composed of 7 road sections that represent the part of the GP riverbank to be pedestrianized.

In 2015, the average daily flow on the entire riverbank was 40,000 vehicles representing half of the daily flow of the south outer ring road. The 3.3 kilometers to be pedestrianized have a daily flow of around 35,000 cars. Although the shutdown was implemented on September 1^{st} 2016, the pedestrianized area was already closed as of mid-July and throughout August for the *Paris Plage* event; hence, no traffic can be recorded during this period. To obtain a sense of the impact of the closure on circulation, I plot the hourly mean of traffic flow of the riverbank when omitting the 3.3 km to be pedestrianized on a 3-month window, before and after the shutdown (Figure O.B.3). The non-pedestrianized stretch of the riverbank presents a lower flow average after the shutdown, which corroborates the idea that ex-riverbank users abandoned the whole riverbank itinerary once its center was shut down. Indeed, former riverbank commuters could have either decided to change their means of transportation or to change itineraries. Had they decided to change routes, a direct substitute would be the ring roads outside Paris. The trip west-to-east can be replaced by the south outer ring road or the north inner ring road, depending on the location of each commuter. However, adding extra vehicles to these roads is very likely to generate traffic jams given the initial high use of ring roads[12].

2.4 The ring roads

Three main bypasses encircle the French capital (Figure O.B.4) and allow travelers to circumvent Paris. The first one is the *Boulevard Périphérique*, which separates the municipality of Paris, over which the Mayor has jurisdiction, from the rest of the metropolitan area. The second circle represents the A86 highway, sometimes called the *Super Périphérique*. It forms a complete circle at a variable distance between 8 and 16 kilometers from the center of Paris in which suburb-to-suburb transit represents 87% of private vehicle commutes (Bouleau, 2013). The third bypass is called *La Francilienne*, which is an incomplete set of highways and express roads circling the Ile-de-France region; it is 160 kilometers long and a distance of approximately 30 kilometers from the center of Paris.

In this paper, I evaluate the impact of the GP closure on the first bypass: The *Boulevard Périphérique*. These ring roads are among the most commonly used urban roads of Europe. They are 35 kilometers long, which represents 20 times the length of the Champs-Elysées, and accounts for 2.5% of Paris' total linear roadway. Moreover, they take up to 40% of Paris' road traffic (Apur, 2016). Suburb-to-suburb transit represents almost 40% of the traffic on these roads, compared to 55% for Paris-Suburb journeys (Bouleau, 2013).

3 Empirical Strategy

3.1 *Boulevard Périphérique*: treatment and control groups

By using a difference-in-difference strategy, I evaluate the impact of a car-free downtown zone on the traffic conditions of the first ring road around the city. More precisely, I compare, before and after September 1^{st} 2016, ring roads with the same flow direction as the riverbank (treatment group) with ring roads with

[12] In Table O.B.1, I provide descriptive statistics of the ring roads traffic before and after the riverbank shutdown. During daytime, we can deduce saturated traffic conditions even in the pre-shutdown period.

an opposite flow direction (control group). I choose to look at the impact of the riverbank shutdown on the *Boulevard Périphérique* for different reasons. The first is the lack of data concerning any road outside of Paris. Second, the ring roads around Paris are the closest to the riverbank and hence a more direct substitute. As previously argued, the road along the Seine River was part of an itinerary for western-based commuters to access the eastern suburbs and vice versa. Since its pedestrianization, this group of car users had to adjust their travel plans. One option is the use of ring roads as a substitute. This analysis would therefore be useful to discuss the displacement effect of such a policy and its evolution over time. Third, to evaluate the impact of this policy on Paris' traffic situation, I use a difference-in-difference research design. To do so, I need a proper control group; I choose the ring roads since the outer and inner roads are quite comparable: they are almost the only akin roads that are completely independent of each other in the urban area.

Figure 1 represents the outer and inner ring roads of Paris. Roads with an eastward flow direction are considered the treatment group because they have the same flow direction as the GP riverbank. Hence, the treatment group is composed of the south outer ring road and the north inner ring road. The control group is composed of the south inner and north outer ring roads.

I consider a balanced panel of road sections that compose the ring roads around the city. The sample includes all the arcs that compose the outer and inner ring roads. Both roads display several entrances and exits, so the traffic is not completely correlated between the different arcs of roads[13]. The sample provides the hourly occupancy rate and flow on every arc for the period September 2013-September 2019, 3 years before and 3 years after the closure of the GP riverbank. However, August is omitted from the analysis due to construction works on some roads that mostly happen during this holiday and could affect the traffic in one direction of the ring road differently than the other. The treatment group includes the 26 arcs that compose the south outer ring road from the entrance to

[13]For example, the south outer ring road has 6 entries and 9 exits and the south inner 4 entries and 9 exists on 10 km of road.

the exit of the riverbank, as well as the 58 arcs composing the north inner ring road. These roads have the same flow direction as the GP riverbank. The control group is composed of the 24 arcs of the south inner ring road and the 58 that compose the north outer ring road. The final sample used is composed of 144 arcs since 12 arcs have been omitted from the outer ring road and 10 arcs from the inner ring road due to missing information on flow and occupancy rate.

I decompose the time variable in hours, days, weeks, months, and years in order to have different time levels. The sample is composed of 6,636,283 observations. I split the ring roads into four sections: south outer, south inner, north outer, and north inner. The treated (control) roads register an hourly flow of approximately 4,000 (4,300) vehicles (Table 1).

Table 1: Descriptive Statistics - Occupancy rate and hourly flow

	South outer (N=1,019,037)		**North inner** (N=2,339,886)		**South inner** (N=967,597)		**North outer** (N=2,293,403)		**Control** (N=3,261,000)		**Treatment** (N=3,358,923)	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Flow per hour	3,605	1,841	4,245	1,987	3,672	1,857	4,568	2,110	4,300	2,079	4,060	1,967
Occupancy rate	18.63	14.807	14.638	12.054	16.08	11.659	13.203	9.881	14.056	10.523	15.849	13.081

Notes: The data are composed of observations from 09/2013 to 08/2019. August is removed from each year. The treatment group represents the south outer and north inner ring roads. The control group is the south inner and north outer ring roads.

By averaging over a day, we obtain a daily flow of more than 200,000 vehicles on the ring roads. Given that the average daily flow on the riverbank in 2015 was approximately 40,000 vehicles, the riverbank traffic represented 40% of the treatment group traffic. Unsurprisingly, traffic is highest during the daytime (8 AM to 9 PM) and on weekdays (Figures O.B.5 and O.B.6).

3.2 Specifications

I first estimate the following specification over the period September 2013 - August 2019 :

$$Y_{it} = \alpha + \lambda_t + \psi_i + \gamma \mathbb{1}_{treated_i=1} \mathbb{1}_{post=1} + \epsilon_{it} \quad (1)$$

where i represents the arc, a segment of a road, and t represents the time by the hour. Y_{it} denotes the outcome considered on arc i at date t. The indicator variable $\mathbb{1}_{treated_i=1}$ equals 1 if arc i belongs to an eastward ring road (treatment group) and 0 if it belongs to a westward ring road (control group). The indicator variable $\mathbb{1}_{post=1}$ equals 1 if the reform has been adopted (after September 1, 2016) and 0 otherwise. ψ_i and λ_t are arcs and time fixed effects, respectively. Standard errors are clustered at the arc level. Here, the causal inference we are interested in is captured by the coefficient γ. We expect this coefficient to be significant and have a positive sign on the occupancy rate if the policy displaces traffic on the periphery.

I then estimate the following leads-and-lags regression to evaluate the impact of the policy several years after its implementation and test for the presence of pre-trends.

$$Y_{it} = \alpha + \lambda_t + \psi_i + \sum_{k=-3}^{+2} \beta_k \mathbb{1}_{treated_i=1} \mathbb{1}_{T(t)=k} + \epsilon_{it} \tag{2}$$

where $T(t)$ represents the relative year compared to the year the GP riverbank was pedestrianized of time t[14]. β_k represents the incremental impact of the policy on year k, compared to the reference year. All coefficient are normalized relative to year -1 (from September 2015 to end of July 2016).

3.3 Identification strategy

In the absence of treatment, the identification assumption claims that the difference between the treatment and control groups is constant over time. Here, it implies that absent from the September 2016 reform, the occupancy rates in the treatment and control groups would have evolved similarly. I portray below the three main threats to the identification strategy and provide support for the common-trend assumption.

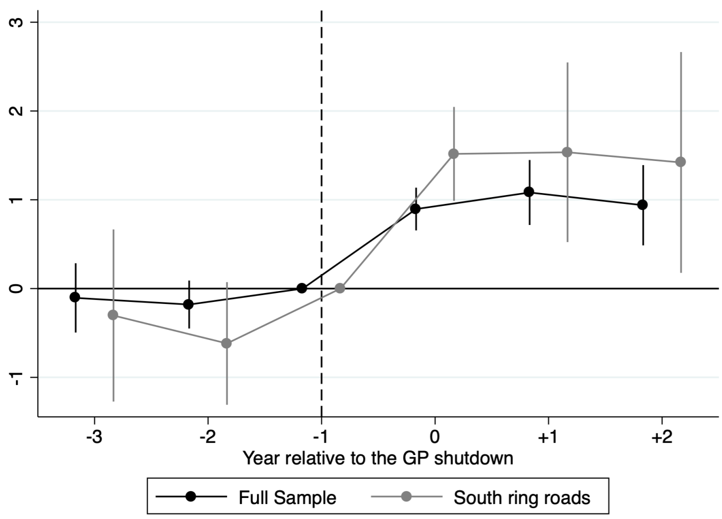
The main concern is the credibility of the control group. First, one could

[14] A year includes the period from the 1^{st} of September to the 31^{st} of July of the following year, since August is omitted.

wonder whether the effects on the treated roads would spill over onto the non-treated roads. However, the control group has an opposite flow direction to the riverbank. Therefore, commuters are unlikely to substitute the riverbank itinerary with a road that has an opposite flow direction and individuals commuting from the west to the east would still keep the same path on their way back home. Second, if commuters choose public transportation over their cars then treated and control roads would experience less traffic. This would overestimate the effect; however, as will be shown in Section 6, the modal switch effect is very small compared to the number of people affected by the policy.

The second worry boils down to anticipation effects: since the GP closure was announced in December 2015, commuters might have deviated from this itinerary before its official shutdown. Figure O.B.7 provides evidence of a potential anticipatory effect showing that individuals googled this event at the end of 2015. This is shown in Figure O.B.8, where the difference in occupancy rates of the treated and untreated units begins to differ slightly before September 2016. However, Figure 3 shows no significant difference between the treatment and control prior to 2016.

Figure 3: Impact on occupancy rates



Notes: This graph plots the estimates and 95% confidence intervals from equation (2). The black line represents the estimates on the full sample, when all treated and control lanes are included. The gray line represents the estimates of the analysis performed on the south ring road.

Finally, A. Hidalgo's first mandate was crammed with urban modifications to promote alternatives to car. One of these was *Plan vélo 2015-2020*, which aimed for biking to represent 15% of the modal share of Paris and its nearby suburbs, versus 3% in 2014. If not taken into consideration, it could be responsible for part of the average treatment effect observed; however, there is no reason to think that additional cycling and/or bus lanes would affect the eastward lanes differently than the westward lanes. Other transportation programs such as new tramway lines were also implemented in recent years. To ensure that I disentangle the effect of the GP pedestrianization from these other programs, I perform a placebo test. I take a subsample including all the observations before the event from January 1^{st}, 2013 to August 31^{st}, 2016. I then perform a difference-in-difference with 31 phantom events (every 30 days starting April 10, 2013 until September 29, 2015). Table O.B.2 represents the results of the placebo difference-in-differences. All of the treatment effects are nonsignificant, once again lending support to the identification strategy.

The common trend assumption is represented in figure A.1, where the occupancy rates are aggregated at the year level. Control and treated units present, at least visually, parallel trends before 2016. In addition to graphical support, I test for the significance of the pre-treatment estimates. Figure 3 display the estimates of equation (2) and validates the presence of parallel trend.

4 Main Results

In this section, I estimate the baseline difference-in-difference model to empirically test whether the riverbank shutdown displaced traffic to the ring roads around Paris. The outcome is the occupancy rate described in Section 2. The analysis is performed on the south ring roads, which should be the most direct substitute for the riverbank route. In the Online Appendix O.C, I provide the results of the analysis on the full sample.

4.1 Average and dynamic impacts of the riverbank shutdown

I estimate equation (1) to evaluate the average impact of the riverbank shutdown on the traffic situation of the south ring roads. On average, shutting down 3.3 kilometers of the GP riverbank caused an increase of 1.8 p.p. on the southern treated roads (Column (1) of Table 2). The estimate is significant at the 1% level. Given that the occupancy rate was 18% on the south outer ring road the year before the pedestrianization, the estimate of column (1) represents an increase of 10% compared to the year prior to the shutdown. Similarly, the entire treatment group experiences an increase of 1 p.p., which represents a 7% increase compared to the year before (see column (1) of Table O.C.1). These results reveal the riverbank users' preferences in terms of substituting their itinerary, confirming that the south outer ring road is a better substitute for the riverbank.

If car users have non-sticky behaviors, we expect them to adapt their itineraries to the traffic situation if other alternatives are proposed; hence, we could expect a decrease in the impact across the years. Figure 3 plots the coefficients of equation (2) with each coefficient representing the treatment effect of the corresponding year and shows that the impact remains stable. As of September 2016, occupancy rates increased substantially by almost 1.5 p.p. on the southern treated sections compared to the control. The formal estimates are represented in Table O.C.2. The results suggest that the riverbank policy negatively impacted the traffic situation on eastward ring roads over the years.

4.2 Robustness Checks

In what follows, I perform a number of checks and tests for the occupancy rate effects I estimate. In Table O.C.1, I show that the robustness checks performed on the full sample lead to the same conclusions.

Fixed effects – I check that the result is not the spurious outcome resulting from a too saturated model. To this end, I first add the dummy variable $\mathbb{1}_{treated_i=1}$ to equation (1) and drop the arc fixed effects (Column (2) of Table 2). The estimate for the treatment effect is barely affected and the significance remains the same. Second, instead of including time fixed effects that control for the differences between each hour of each day, I separately include year, month of the year, day of the week and hour of the day fixed effects. Column (3) of Table 2 represents the estimates while changing the fixed effects. The inclusion of additive, instead of multiplicative, time fixed effects decreases the R-squared by 13 p.p. but leaves the treatment effect virtually unaffected.

Clustering – Since road users are likely to drive on several sections of the same road, there might be reasons to believe that unobserved components of the occupancy rate may be correlated between arcs. For instance, we could think of accidents on a road that affect the occupancy rate of several sections of the same road. To address this concern, I cluster the standard errors to a group of arcs level. Each group of arcs represents the road sections between two entries. Each southern ring road is decomposed into 10 groups. Results are displayed in column (4), and show that the significance of the effect stays the same.

Outliers – Some outliers can distort the occupancy rate measures and hence the estimates. We could think of two-wheelers exceeding the average speed of four-wheeled vehicles. This kind of behavior would appear at the bottom of the occupancy rate distribution. On the other hand, if a car stops on the road, say due to stalling, the sensor would register a very high occupancy rate on the relevant road sections. This would therefore appear on the top of the distribution. To take this into account, I winsorize the top and bottom of the occupancy rate distribution at the 1% level[15]. Results are shown in column (5). The estimate drops by 0.1 p.p., which suggests that outliers do not drive the results.

[15]Table O.B.3 represents the different values of the occupancy rate at each percentile. I drop all observations where the occupancy rate is either lower than 0.3% or higher than 55%.

Table 2: Occupancy rate : Main results and robustness checks - south ring roads

	(1)	(2)	(3)	(4)	(5)
			Occupancy rate		
Treatment	1.798	1.862	1.797	1.798	1.670
	(0.304)	(0.314)	(0.301)	(0.404)	(0.277)
Constant	16.921	16.075	17.157	16.921	16.708
	(0.078)	(0.863)	(0.083)	(0.103)	(0.070)
Observations	1,991,696	1,991,696	1,991,699	1,991,696	1,951,417
R^2	0.703	0.631	0.573	0.703	0.711
Arc FE	Yes	No	Yes	Yes	Yes
Time FE	Yes	Yes	No	Yes	Yes
Additive time FE	No	No	Yes	No	No
Winsorized data	No	No	No	No	Yes
Cluster level	Arc	Arc	Arc	Group of arcs	Arc

Notes: Standard errors are in parentheses. The outcome is the occupancy rate, which is a percentage of an hour. It represents the fraction of time a road section has been occupied by cars. Column (1) represents the main estimation. Columns (2) to (5) represent the different robustness checks performed to validate the results. In column (2), I include the dummy variable Treated instead of arc fixed effects. In column (3), the fixed effects are decomposed into year, month of the year, day of the week and hour of the day referred to as *additive time FE*. In column (4) the standard errors are clustered at the group level where each group of arcs is composed of the road segments between two entries. Column (5) adds up a restriction to the data. The data is winsorized at the 1% level.

4.3 Heterogeneity Analyses

The GP riverbank description of Section 2.3 motivates most of the following heterogeneity analyses. The increase in occupancy rate is always higher when the road sections were already saturated and when the riverbank was mostly used. Therefore, the time of day or day of the week highlights a heterogeneity dimension in the estimated effect. To determine which of these time windows drives the increase in occupancy rate, I run different estimations on subsamples. Finally, I perform a spatial heterogeneity analysis on the south ring road to verify that most ex-riverbank drivers were using the entire GP riverbank to cross Paris.

Time heterogeneity – The magnitude of the effect on the traffic situation depends on the time window we are considering. The *daytime* represents all the hours between 8 AM and 9 PM, the hours with the highest flow on the riverbank as noted in Figure 2a. Conversely, *Nighttime* is defined as the hours from

10 PM to 7 AM. We should expect a difference in the treatment effect between the two groups for two reasons. First, car users mainly commute during the day and Figure O.B.5 shows that the ring roads were already saturated during these hours. Second, since the riverbanks were mostly taken during the day, the extra vehicles on the ring roads would appear during the daytime. Table 3 gathers all the estimates depending on time. Column (2) represents the impact during the daytime. I find an increase of 2.6 p.p, confirming that the effect is largest during the day. The impact during nighttime is represented in column (3). The size effect is very small, explained by a low average occupancy rate at night before the 2016 shutdown (7.1% for the control group). The impact is, however, significant at the 1% level. Furthermore, Figure 2a reveals that the riverbank path was taken more during the evening hours (5 PM to 8 PM) than during the morning hours (7 AM to 10 AM). Columns (4) and (5) report a higher impact in the evening, which suggests that the closure affected more commuters living in eastern suburbs. In addition, if riverbank users are mostly commuters, we should expect a higher impact during weekdays than during weekends. I therefore run separate regressions for weekdays and weekends (Saturday and Sunday). As shown in column (6) and column (7), the impact is much higher during weekdays (2.2 p.p. versus 0.9 on weekends), displaying an increase of 11% during weekdays and 6% during weekends compared to the pre-shutdown period. Almost the entire impact is therefore driven by week-days. Table O.C.3 sums up the average treatment effect on each day of the week and shows that Sunday is the only day of the week with nonsignificant treatment effects.

Table 3: Time heterogeneity - south ring roads

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Occupancy rate						
	All	Daytime	Nighttime	Evening	Morning	Weekdays	Weekends
Treatment	1.798	2.621	0.641	2.729	1.798	2.166	0.910
	(0.304)	(0.466)	(0.117)	(0.634)	(0.340)	(0.335)	(0.284)
Constant	16.921	23.893	7.170	28.193	18.863	17.977	14.306
	(0.078)	(0.119)	(0.030)	(0.162)	(0.087)	(0.086)	(0.073)
Observations	1,991,696	1,161,355	830,341	332,771	333,107	1,4179,89	573,707
R^2	0.703	0.553	0.718	0.568	0.745	0.705	0.703
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Arc FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The outcome is the occupancy rate, which is a percentage of an hour. It represents the fraction of time a road section has been occupied by cars. Column (1) represents the main estimation. In columns (2) to (7), I select subsamples and show the different results. In column (2), I perform the regression on the hours from 8 AM to 9 PM. Column (3) includes the hours from 10 PM to 7 AM. Columns (4) and (5) include evening (5 PM to 8 PM) and morning (7 AM to 10 AM) hours, respectively. In columns (6) and (7), I look at the impact on weekdays and weekends, respectively.

In Table O.C.4, I show that the heterogeneity analysis on the entire sample yields similar outcomes.

Spatial heterogeneity – Since we are unable to track vehicles on the road and therefore incapable of explicitly evaluating substitution effects, this analysis aims to provide evidence on the substitutability of the riverbank with the south ring road. In fact, we should not observe heterogeneity in the occupancy rate impact across the road if we believe that ex-riverbank users would drive all along the riverbank to cross Paris. I thus breakdown the south ring road into three parts and run a regression on each separately. All the estimates are statistically significant (see Table 4), and even though the coefficients associated with segments farther away from the juncture with the riverbank are lower, the differences between the treatment effects are not statistically significant. Hence, we cannot rule out that the riverbank shutdown impacts the entire southern lane the same way.

Table 4: Spatial heterogeneity - south ring roads

	(1)	(2)	(3)
		Occupancy rate	
	[0km , 2.9km]	[2.9km , 6.7km]	[6.7km , 10.4km]
Treatment	2.326	1.603	1.579
	(0.440)	(0.385)	(0.460)
Constant	15.275	17.691	17.442
	(0.111)	(0.102)	(0.115)
Observations	559,460	707,283	724,951
R^2	0.741	0.735	0.717
Arc FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The south ring road is decomposed into three groups. Group 1 represents the first 2.9 km of the south ring road following the flow direction from west to east. Group 2 represents the following 3.8 km and group 3 the last 3.7 km.

5 Evidence on the cost of a car-free zone

The results so far suggest that riverbank shutdown is responsible for an increase in vehicle presence time in the outskirts of the city. This section explores the broad consequences of such ripple by imposing stronger assumptions, leading to a rough computation of commuters' welfare. However, I do not include in my analysis the fact that a green amenity in the center of a city (i) may increase housing prices near the river, (ii) reduce stress-related psychosocial symptoms and (iii) might motivate urban growth and development by attracting tourists (Lanzara and Minerva, 2019). Instead, I focus on shortrun and direct impacts linked to the increase in occupancy rate. To this matter, I estimate the relationship between occupancy rates and hourly flow to be able to infer conclusions on the probability of congestion. Furthermore, by making an assumption on the average vehicle length, I compute the average speed on each road section using Athol's formula (Hall, 1996). Last, I provide an approximation of the time lost by commuters once the GP was prohibited from car circulation.

5.1 Congestion

The increase in occupancy rates is not a problem per se. In fact, if the traffic is initially fluid, increasing the occupancy might not be harmful. The efficiency loss, if any, comes from congestion. To measure congestion, I make use of the fact that traffic flow per lane and occupancy rate are linked via a concave relationship known as the *fundamental diagram* in transportation economics (Immers and Logghe, 2002). When a traffic situation is initially fluid, adding more vehicles on the road increases their present time by less than when the situation is already congested. Figure A.2 represents the concave relationship for each of the four roads and Table O.C.5 gathers the formal estimates. This gives road-specific indicators of traffic congestion (k^*). Whenever the occupancy rate reaches the road critical point (k^*), one can say that the road is congested. I create a dummy variable that takes the value 1 if the road is congested and 0 otherwise. I therefore estimate the impact of the 2016 riverbank shutdown on the probability of congestion of the ring roads[16]. If the ring roads' occupancy rates are close to or already passed the threshold prior to 2016, we expect the impact to be significant and positive. The riverbank shutdown increased the probability of congestion by 3.6 p.p. on all treated roads and by of 5.7 p.p. on the south ring roads (Columns (1) and (2) of Table 5), both representing an increase of 15% compared to the pre-shutdown period. In Appendix O.C.2, I perform all the robustness checks and heterogeneity analysis done previously for the occupancy rate and find similar conclusions.

5.2 Speed

Given the increase in occupancy rates on the treated road sections, I now turn my analysis to the impact on average speed. However, speed calculation requires several input variables especially the vehicle length, that are not available in the

[16]The outcome here is based on the estimated variable k^*. This might cause some measurement errors. However, as shown in Table O.C.5, the coefficients are quite precisely estimated.

data. I assume the average length of vehicles to be 4.5 meters[17]. Using the flow per lane as well as the occupancy rate, the average speed can be computed with Athol's formula (Hall, 1996):

$$Speed_{it} = \frac{Flow_{it} \times (L + K_i)}{Occupancy_{it}} \tag{3}$$

where $Speed_{it}$ represents the average speed (km/h) on road section i at time t, $Flow_{it}$ and $Occupancy_{it}$ are the flow per lane of the road and the occupancy rate on section i at time t. L represents the average length of vehicles (here 0.0045 km) and K_i is the length in km of road section i. Columns (3) and (4) of Table 5 represent the estimates of the treatment effect on the average speed on the full sample and the south ring roads during daytime[18]. On average, the average speed decreased by 1.7 km/h on the treated road sections. The impact is almost twice as large on the south ring roads, with a decrease of 3.2 km/h on average. This is consistent with the larger impact on the probability of congestion on the south ring roads.

[17]By assuming this length, I do not take trucks into consideration and exclude them from the analysis. However, one of the robustness checks consists of dropping outliers by winsorizing the data. The results reported in Table O.C.9 show that the effect remains unchanged.

[18]I restrict the speed impact on the daytime traffic to eliminate the likelihood of having trucks on the road as much as possible. Since trucks are larger than 4.5 meters, it could bias our estimates. However, in Table O.C.10, I estimate the impact on the unrestricted sample (column (1)) and find statistically significant results.

Table 5: Impact on the probability of congestion and the average speed

	(1)	(2)	(3)	(4)
	Probability of congestion		**Speed**	
	All	South ring roads	All	South ring roads
Treatment	0.036***	0.057***	-1.736***	-3.152***
	(0.006)	(0.009)	(0.449)	(0.776)
Constant	0.201***	0.304***	38.878***	33.412***
	(0.001)	(0.002)	(0.114)	(0.193)
Observations	6,636,280	1,991,696	3,231,213	952,526
R^2	0.443	0.565	0.694	0.627
Arc FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The outcome of the first two columns is a dummy variable that takes the value 1 if the occupancy rate is passed (k^*), and 0 otherwise. On average, it represents the probability of congestion. The outcome of the last two columns is the average speed in km/h. However, the impact on speed is restricted to the daytime. The first column of each outcome includes all the samples and the second column focuses on the south ring roads.

In Appendix O.C.3, I perform all the robustness checks and heterogeneity analyses on the speed impact and end up with the same conjecture as to the occupancy rate, which corroborates, once again, the tight link between occupancy rate and average speed.

5.3 Time lost

I compute commuting times for each of the following itineraries: (i) the south ring road after September 1^{st}, 2016 (ii) the south ring road in the absence of the riverbank pedestrianization after September 1^{st}, 2016, and (iii) the express-road (GP riverbank). To compute (ii), I first estimate the main difference-in-difference without any fixed effect during the daytime and on the south ring road; then, I predict the counterfactual had the treatment not occurred. The main concern that should be addressed in computing the travel time on the express-road is the lack of data concerning traffic flow on this road. To this matter, I rely on the assumption that the average speed is 50 km/h, the speed limit of the road. This assumption is likely to hold since in 2015, the occupancy rate was on average

4.8% during daytime[19].

As shown in Table O.B.4, driving onto the road along the bank is quicker than taking the south ring road before the implementation of a car-free riverbank. Hence, if we suppose that all individuals opt for the quickest route to get to the destination, we can conclude that one would always take the riverbank to join the southeast from the southwest. After riverbank pedestrianization, two types of individuals will lose time when commuting. First, former riverbank users are directly impacted by this policy. If they substitute their path with the south ring road after September 2016, they lose up to 6 minutes on a 10 km trip for the same start-end travel. Second, hypothetical individuals using the south ring road for the eastward trip prior to the closure put up with a 2-min increase in travel time.

6 Did the policy achieve its intended goals?

This section discusses whether the policy has succeeded in (i) provoking a shift away from car-based transportation and (ii) decreasing pollution.

6.1 Modal shift

This section explores whether some people have shifted on public transportation and, more precisely, on the line A of the rail network that cuts across the Paris region from the west to the east with several stations in the suburbs and Paris. By shutting down roads in Paris, one might expect commuters to shift to using public transportation when the cost of congestion becomes too high. For this purpose, I study the effect of the 2016 shutdown on a train line (RER-A) that crosses Paris in the same way as the GP riverbank. The RER-B links the north and south of the region and will be considered the control group since commuters who suffer from the policy are located in the west or east of the city. Hence, the RER-B cannot be considered as a credible alternative to the riverbank itinerary

[19]Since the average length of a riverbank section is 320 meters, the average occupancy rate indicates that the road section is occupied 3 minutes per hour during the daytime.

(Figure O.B.9). By using the RATP data on the annual traffic, I estimate another version of equation (1), where Y_{it} now represents the number of daily entries of station i at time t. λ_t and ψ_i are year and station fixed effects, respectively. The indicator variable $\mathbb{1}_{post=1}$ equals 1 if the reform has been adopted (year after 2016) and 0 otherwise. The dummy $\mathbb{1}_{treated_i=1}$ takes the value 1 if station i is on RER-A and 0 if it is on RER-B. I remove all the train stations inside Paris to capture the effect of suburban commuters impacted by the riverbank shutdown and avoid network spillovers.

Figure O.C.1 validates the pre-trend assumption since the coefficients prior to 2016 are statistically nonsignificant and close to zero[20]. Table A.1 demonstrates a modal shift in RER A by approximately one thousand individuals per day with an increasing impact across the years (Figure O.C.1). However, to be able to judge the magnitude of this effect, we should take a look at the range of people affected by the policy. To this end, I use the population census of 2015 to approximate the number of people affected by the riverbank shutdown. Individuals potentially impacted by the policy are commuters who use private vehicles as a means of transportation and commute from the west to the east and vice versa. I restrict my analysis to the area inside the A86 circle (Figure O.B.4) since people living outside this bypass can circumvent Paris by using the A86 highway. I determine an upper bound and a lower bound of individuals potentially impacted by the increase of congestion on the ring roads[21]. I then show that between 20k and 127k individuals are impacted by the riverbank shutdown (Table O.B.6)[22].

Even if we stick to the lower bound, the number of people shifting from driving to using the RER-A remains small. This is consistent with the positive and significant impact we observe on ring road traffic. This result suggests that,

[20] The estimates are represented in Table O.C.12.

[21] I compute the percentage of people traveling by car from one side to the other from the data "Logements, individus, activité, mobilités scolaires et professionnelles, migrations résidentielles en 2015". I then use the 2015 population data to impute the total number of people impacted.

[22] The upper bound is composed of all the municipalities situated inside the A86 circle since all commuters living outside this bypass can circumvent Paris through the A86. The lower bound focuses on individuals living near the entrance or exit of the GP riverbank at the south periphery of Paris. Table O.B.5 gathers the information needed to compute the two bounds.

at least in the shortrun, the policy mostly displaced congestion.

6.2 Exposure to pollution

Finally, I turn to the question of air quality. Ideally, I would want to study the causal impact of the riverbank shutdown on pollutant emission levels by comparing a set of pollution sensors near the ring roads with another set that is close to the unaffected roads, before and after September 1^{st}, 2016. However, ring roads are equipped with only two sensors detecting local pollutant emissions. While we might not be able to assess the causal impact on pollutant emissions, we can look at residents' exposure to pollution.

I proceed in three steps[23]. First, I use Airparif's study of 2017 to identify the change in pollution emissions on the GP riverbank road sections before and after the pedestrianization of its center. Second, drawing on Airparif's pollution sensor located east of the ring road, I combine the traffic data of the nearest 12 road sections with the nitrogen dioxide levels. I document the relationship between speed and pollution using pretreatment data (see Figure B.1) and show a negative correlation. Last, I select the IRIS next to the riverbank and the south ring roads (numbers are shown in Table B.2) and compute the number of residents suffering from downgraded air quality, and the number of residents who benefit from cleaner air.

Due to the speed decrease on the south ring roads, the residents of the nearby southern-suburbs suffer from an increase in pollutant emissions, which comes on top of already high exposure (see Table B.1)[24]. I estimate that approximately 67k residents around the south ring road suffer from a deterioration of air quality. Conversely, a car-free zone decreases the pollution level of the area, as well as on other, less used, sections of the GP. I estimate that approximately 22k residents around the riverbank benefit from better air quality. In addition, some traffic may have been diverted towards the upper bank road, leading to a de-

[23] Further details are provided in Appendix B

[24] The European Union legislation states that the maximum acceptable level of NO_2 is fixed to 40 microgram per cubic meter (Lorente et al., 2019).

crease in air quality for approximately 9k residents (see Table B.2 for details)[25]. Therefore, even though both roads are similar in length, I estimate that residents who suffer from downgraded air conditions outnumber beneficiaries one to three. This discrepancy is explained by the fact that the area immediately next to the south ring road is more densely populated than the area near the riverbank. Although the riverbank has been freed from some car users, which leads to an improvement in air quality on these areas, it is not enough to compensate for the displacement of some individuals on either the upper banks or the south ring roads.

7 Conclusion

This paper sheds light on the effects of road reductions at the heart of a city. Drawing on the data source of the town's City hall, I identify the causal effect of the *Georges Pompidou* riverbank pedestrianization, initially aimed at reducing pollution and encouraging alternative modes to car transportation, on the traffic and pollution conditions of the *Boulevard Périphérique*. Using a difference-in-difference research design, I show that the expressroad shutdown contributed to an increase in the occupancy rate and the probability of congestion of eastward flowing ring roads (roads with the same flow direction as the riverbank) compared to westward flowing ring roads. Consequently, the average speed decreased on the treated road sections translating into significant time loss.

Last, the paper discusses the two intended goals and proves that they have ambiguous effects. Although the suburban train line linking the western and eastern suburbs of Paris was subject to a small increase in passengers, when compared to the range of people impacted by the policy, it becomes quickly negligible. Furthermore, I show that a larger fraction of residents suffer from a downgraded air quality compared to residents profiting from fewer emissions near the riverbank.

[25] This analysis should have been done based on the time individuals are exposed to pollution. However, I can only look at the residents due to data constraints.

While this paper focuses on the impact of a car-free area on a specific *boulevard*, it is likely that other roads inside or outside the city were subject to traffic and/or pollution disruptions. This raises the question of the road capacity one should keep in a city as well as the choice of roads to be tailed off. It also gives room for future research to identify the environmentally optimal transport network of a city.

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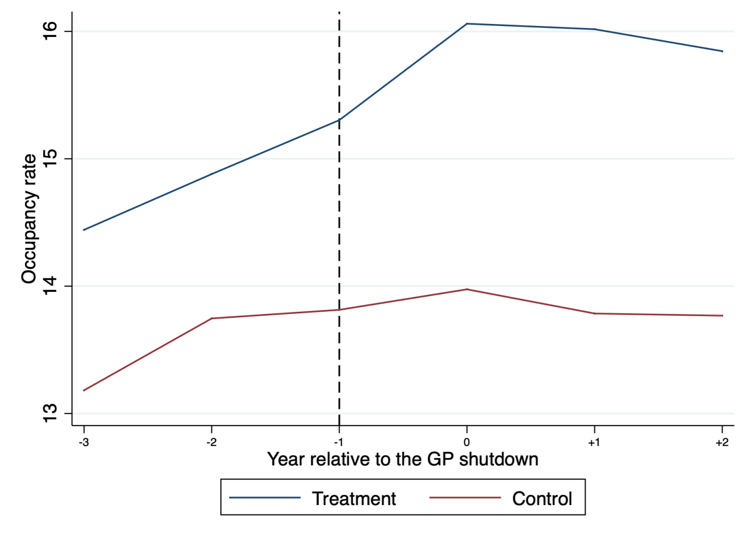
Appendix

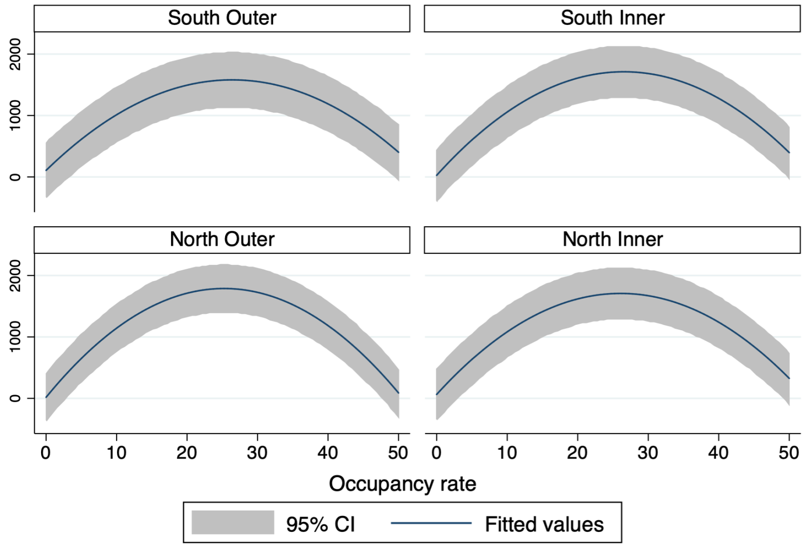
A Additional Tables and Figures

Figure A.1: Parallel trend - Yearly average



Notes: This graph represents the common trend assumption of the difference-in-difference research design. Observations are represented by year relative to the GP closure. Year 0 represents the first year the GP got closed to vehicle circulation, from September 2016 to end of July 2017.

Figure A.2: Relationship between traffic flow per lane and occupancy rate



Notes: These graphs illustrate the relationship between the occupancy rate and the flow per lane for each road of the sample. The quadratic estimation is done through a simple regression without any fixed effect. The 95% confidence intervals are represented by the gray area.

Table A.1: Impact on public transportation

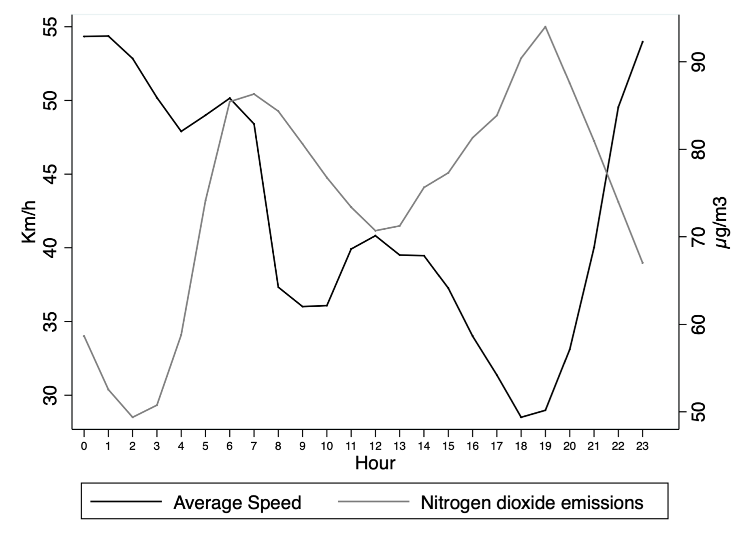
	Daily Traffic
Treatment	1107.548
	(411.280)
Constant	15351.304
	(112.167)
Observations	330
R^2	0.997
Station FE	Yes
Year FE	Yes

Notes: Standard errors are in parentheses and clustered at the municipality level. The annual traffic data is divided by the average number of working days, here considered as 212 days, in order to have an estimation of the daily traffic flow. The treatment group is the RER-A of the rail network. The control group is the RER-B. Only stations outside Paris are kept.

B Pollution impact

To study the impact of the riverbank shutdown on pollution levels, I make use of the nitrogen dioxide emissions data from Airparif combined with the speed computed from the traffic data. Several pollution stations are provided, each of which registers local pollutant emissions at the hourly level. Regarding the ring roads, two stations can be found: one in the west called *Boulevard Périphérique Auteuil* and one in the east called *Rue Edouard Lartet*. Road sections near the west station fail to measure hourly vehicle flow levels and only register occupancy rate levels. Therefore, the average speed cannot be computed in this sample. Consequently, I focus on the eastern station and I select the 12 road sections around it[26]. The correlation between nitrogen dioxide emissions and average speed is provided in Figure B.1.

Figure B.1: No_2 emissions and average speed - per hour



Notes: I plot the levels of nitrogen dioxide and the average speed per hour registered east of the periphery involving 12 road sections of the northern ring roads. The sample includes September to November of years 2013 to 2015, the pretreatment period.

Regarding the riverbank, no permanent pollution station can be found. There-

[26]6 from the North outer ring road and 6 from the North inner ring road.

fore, I use Airparif's study of 2017[27] to show the impact of pollution on the riverbank after its shutdown.

Finally, I select the population at the IRIS level next to the 9.5 kilometers of the riverbank from the beginning of the *Quais Georges Pompidou* to the *Quais Henry IV* on which Airparif has done its evaluation as well as next to the south ring road. The south ring road is 10 kilometers long, which makes it comparable to the 9.5 km of the riverbank taken. Furthermore, the south riverbank suffers the most from an increase in traffic due to the riverbank shutdown. Further detail can be found in Table B.2. I compare the number of residents experiencing a deterioration of air quality and those benefiting from improved air quality. The area pedestrianized is situated on the lower banks from the *Quai de Tuileries* to *Quais Henri IV*. It has benefited from a decrease in pollution of 15-20%. However, I do not include it in my analysis since I consider that only individuals walking on these banks benefit from the improvement in air quality. In fact, the lower banks are far from habitations and do not affect directly the inhabitants of the area.

Table B.1: Yearly levels of nitrogen dioxide

Year	Mean	Std. Dev.
2013	75.625	37.044
2014	74.657	36.479
2015	67.022	34.767
2016	66.236	34.792
2017	64.8	34.259
2018	67.441	32.979

[27]In 2017, Airparif conducted a study to evaluate the impact of the riverbank shutdown on pollution. In 2017, they installed several pollution tubes that detect the emission levels every hour of the day. They placed many stations on the riverbank as well as on the first ring periphery. They then calculated the pollution level that would have prevailed during the same period in 2016 by using the same weather conditions of 2017.

Table B.2: Population at the IRIS level and associated change in pollution - 2016

IRIS Code	IRIS label	Population in 2016	Pollution impact
	Riverbank		
751166101	Auteuil 1	2517	- 1 to 5%
751166102	Auteuil 2	2662	- 1 to 5%
751166115	Auteuil 15	3573	- 1 to 5%
751166129	Auteuil 29	1572	- 1 to 5%
751166130	Auteuil 30	2357	- 1 to 5%
751166201	Muette 1	1859	- 1 to 5%
751166213	Muette 13	2460	- 1 to 5%
751166221	Muette 21	1925	- 1 to 5%
751166222	Muette 22	0	- 1 to 5%
751166401	Chaillot 1	1566	- 1 to 5%
751166410	Chaillot 10	400	- 1 to 5%
751082902	Champs Elysees 2	679	- 1 to 5%
751082907	Concorde Jar Chps Elysees	16	- 1 to 5%
751010101	Saint-Germain l'Auxerrois 1	976	+ 1 to 5%
751010103	Saint-Germain l'Auxerrois 3	237	- 1 to 5%
751010104	Saint-Germain l'Auxerrois 4	3	- 1 to 5%
751010105	Tuileries	0	- 1 to 5%
751041304	Saint-Merri 4	241	+ 1 to 5%
751041401	Saint-Gervais 1	3291	+ 1 to 5%
751041502	Arsenal 2	1544	+ 1 to 5%
751041501	Arsenal 1	3285	+ 5 to 10%
	South ringroad		
751156001	Javel 1	2768	+ 1 to 5%
920400101	Les Varennes Foucher Lepelletier	3090	+ 1 to 5%
920400102	Matrat Voisembert	2127	+ 1 to 5%
920750107	Parc des Expositions	2602	+ 1 to 5%
920750109	Louis Vicat	2118	+ 1 to 5%
920750111	Brancion	2159	+ 1 to 5%
920460102	Nord	3696	+ 1 to 5%
920460101	Renovation	3002	+ 1 to 5%
920490101	Centre Administratif-Mairie	2366	+ 1 to 5%
920490106	Bibliotheque Municipale	4377	+ 1 to 5%
920490110	Aristide Briand	5315	+ 1 to 5%
940370106	Chaperon Vert	2921	+ 1 to 5%
940370105	Plateau 2	2246	+ 1 to 5%
940370104	Plateau 1	2455	+ 1 to 5%
940370101	Centre Ville 1	1624	+ 1 to 5%
940370103	Victor Hugo	2222	+ 1 to 5%
940430102	Les Sablons	2964	+ 1 to 5%
940430108	Les Perichets	2310	+ 1 to 5%
940430101	Les Plantes	2309	+ 1 to 5%
940410202	Petit Ivry Nord	2868	+ 1 to 5%
940410203	Petit Ivry Sud	4521	+ 1 to 5%
940410207	Mirabeau	2684	+ 1 to 5%
940410301	Ivry Port Nord	4500	+ 1 to 5%

Note: The third column of the table represents the number of people living in the IRIS right next to the section of the road. Focusing on the riverbank, I select the IRIS on the upper section (*River Droite*), since the banks on the other side did not experience any change. As for the south ring road, I take the population outside of Paris since the south outer ring road suffered from a speed decrease due to congestion. The fourth column represents the pollution impact on these road sections, evaluated by *Airparif* in 2017.

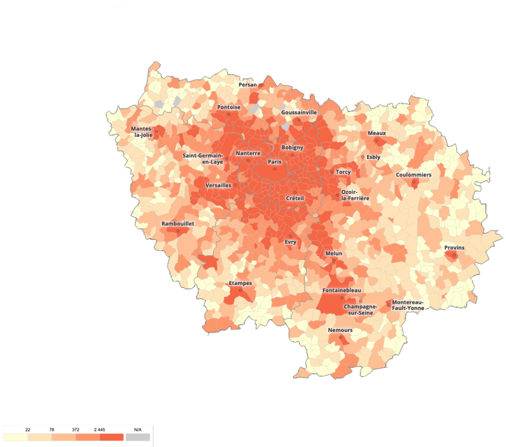
Online Appendix

O.A Chronology of the *Georges Pompidou* riverbank closure decision

In December 2015, the Paris Council shared the thoughts of a plan concerning the pedestrianization of some riverbanks. The shutdown of 3.3 kilometers of the Georges Pompidou riverbank from the Tuileries to the Henry IV tunnel was first declared the 26^{th} of September 2016 through deliberation. The October 18^{th}, 2016 decree formalized the creation of a pedestrian area; however, it was contested due to the displacement of pollution and noise generated by this decision. On February 21^{st} 2018, the administrative tribunal of Paris canceled the Paris Council's September 26, 2016 deliberation, and the town hall's 18^{th} of October 2016 decree creating a public walk on the location of this riverbank. However, on the 6^{th} of March 2018, a decree was created forbidding vehicle circulation on a segment of the riverbank for reasons related to site protection and enhancement for touristic and aesthetic purposes. Many associations and individuals asked for the annulment of this decree at the administrative tribunal of Paris. Their voices were heard and on October 22^{nd}, 2018 the annulment was confirmed due to doubts concerning the environmental consequences of this project. Lastly, on June 21^{st} 2019, the Paris Council confirmed the 6^{th} of March 2018 decree while rejecting all the related annulment appeals.

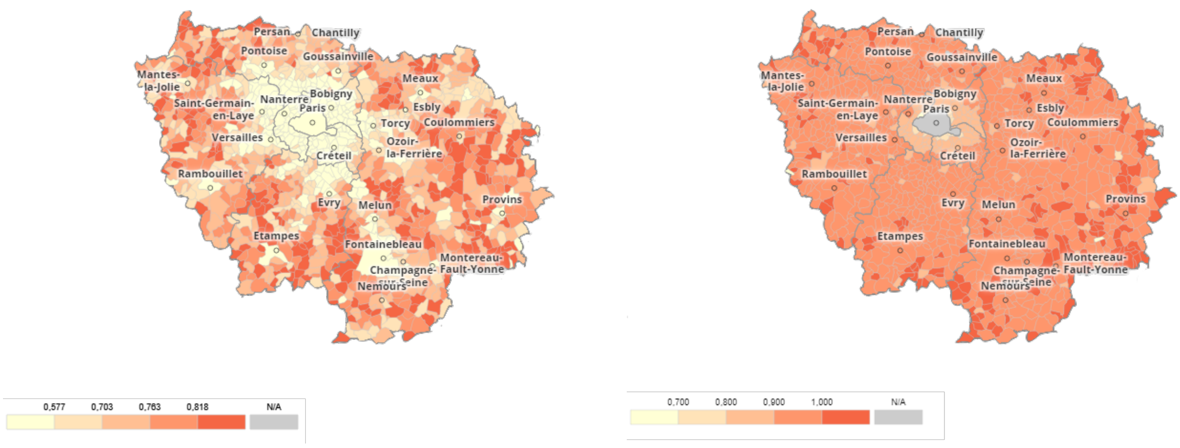
O.B Additional tables and figures

Figure O.B.1: Job concentration in 2015



Notes: The job concentration is represented on this graph which is the absolute value of the number of jobs taken from the DADS (Déclaration Annuelle de Données Sociales). The brighter the color, the fewer the numbers of jobs in the region.

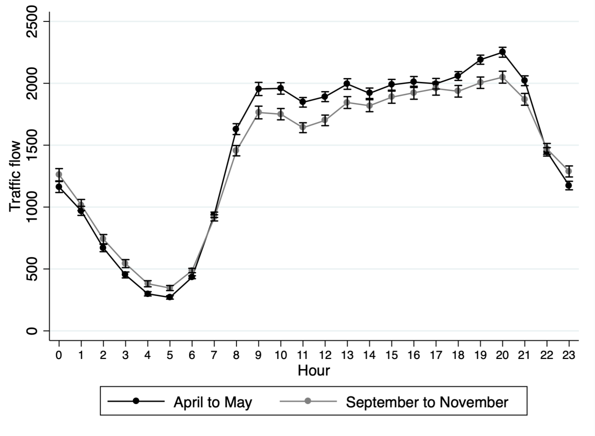
Figure O.B.2: Fraction of people commuting by car in Ile-de-France (2015)



(a) All journeys **(b)** Suburb-to-suburb journeys

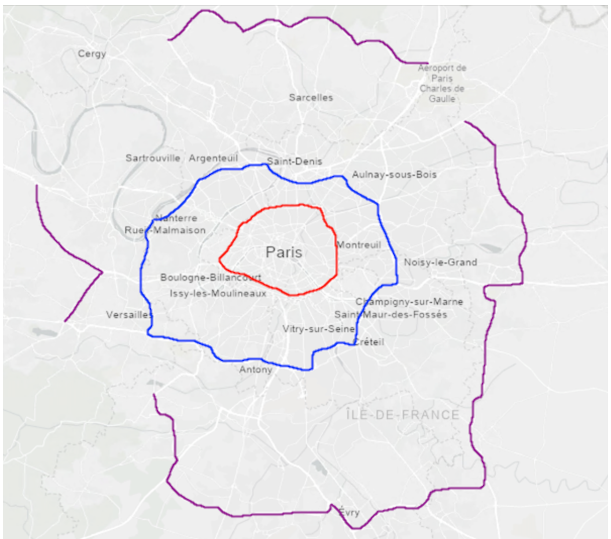
Notes: These graphs represent the fraction of individuals commuting by car in Ile-de-France. The data is taken from INSEE - "Recensement 2015". A low fraction of car commuters is represented by a brighter color.

Figure O.B.3: Flow difference of the non-pedestrianized stretch, before and after the 2016 shutdown



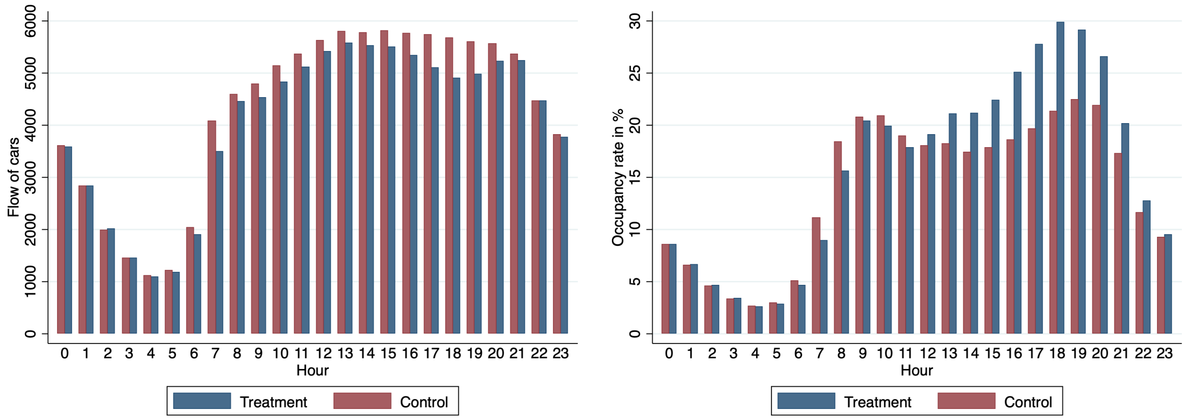
Notes: The sample excludes the 7 road sections that are pedestrianized as of 2016. The outcome is the flow of cars averaged on a 3-month window from April to May 2016 and from September to November 2016.

Figure O.B.4: The three bypasses encircling Paris



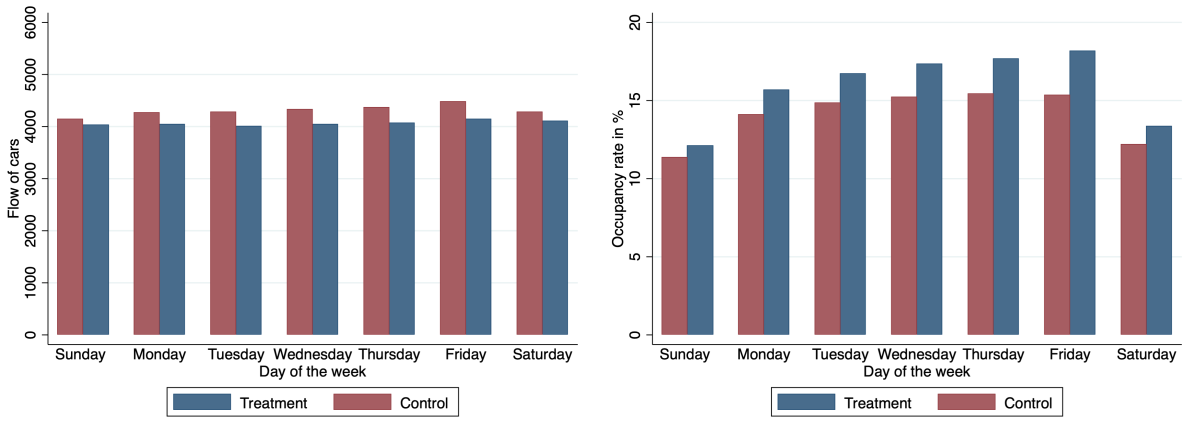
Notes: The red bypass represents the ring roads called *Boulevard Périphérique*. The second bypass (blue) is the A86 highway. The third and incomplete one (purple) represents the *Francilienne*.

Figure O.B.5: Descriptive statistics - by hour and group



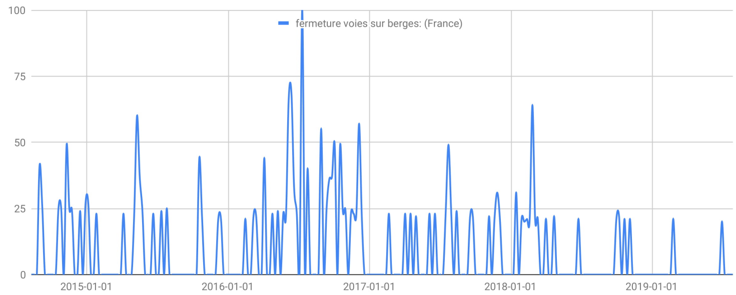
Notes: The sample is composed of the 6,636,280 observations. The treatment group represents the south outer and north inner ring roads. The control group is the south inner and north outer ring road. Observations are averaged over each hour of the day by group.

Figure O.B.6: Descriptive statistics - by day of the week and group



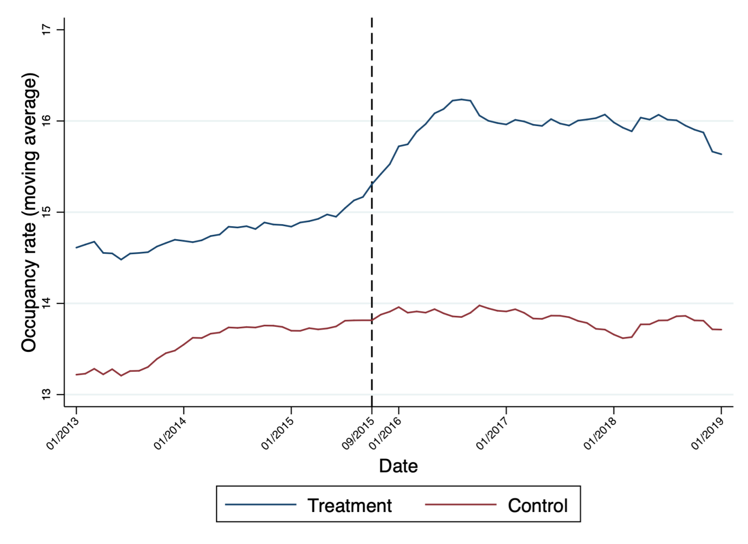
Notes: The sample is composed of the 6,636,280 observations. The treatment group represents the south outer and north inner ring roads. The control group is the south inner and north outer ring road. Observations are averaged over each day of the week by group.

Figure O.B.7: Google trend



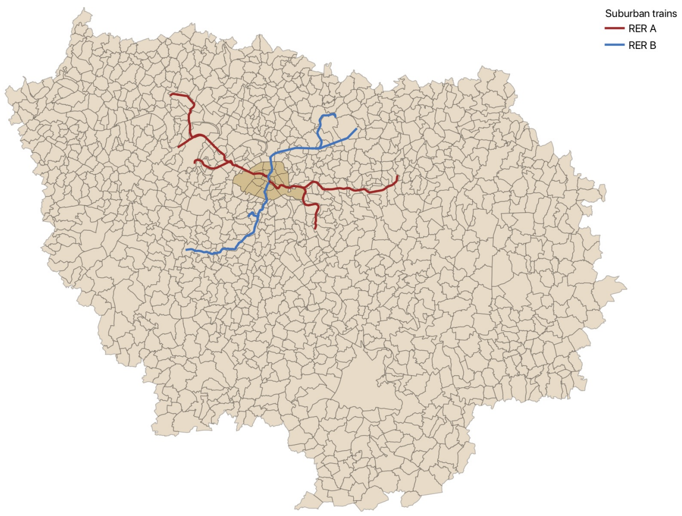
Notes: This graph represents the *Google trend* of the number of times that people in France googled "Fermeture des voies sur berges", which literally means "Riverbanks closure".

Figure O.B.8: Parallel trend - Moving average of occupancy rates



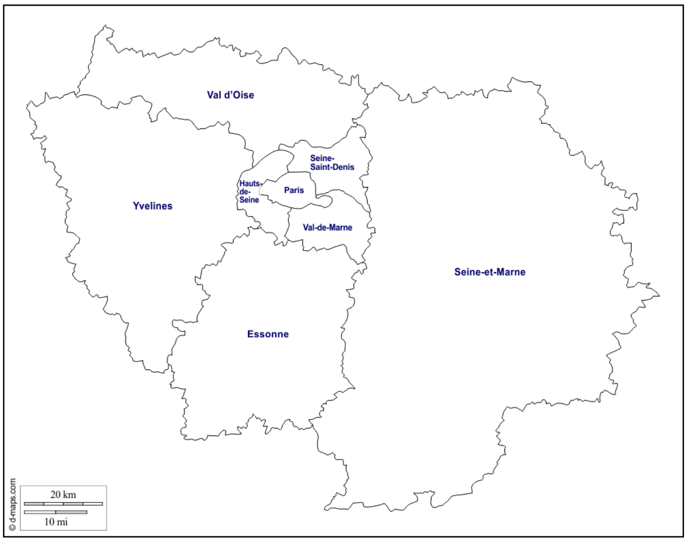
Notes: This is done using the sample from 2013 to end of August 2019. The average occupancy rate is calculated with a moving average of a window of (0 1 11) : the window includes the current month as well as the next 11 months. The increase in the occupancy rate of the treatment group compared to the control group starts in September 2015.

Figure O.B.9: Public Transportation - RER A and RER B



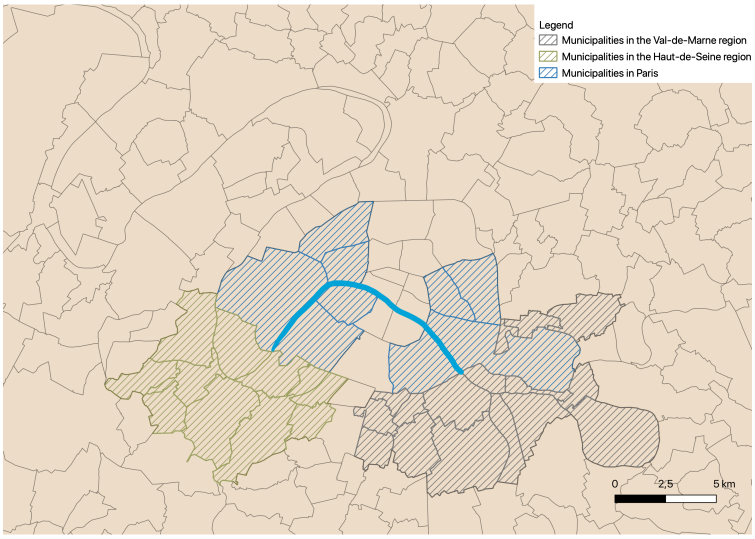
Notes: This figure represents the two train lines used in the analysis. The treatment group is composed of the stations along the RER-A, represented by the red line. The control group is composed of all the stations on the RER-B, the blue line.

Figure O.B.10: Ile de France



Notes: This figure represents the different *départements* of the Ile-de-France region

Figure O.B.11: Ile de France - Lower Bound



Notes: This figure represents the different *communes* (municipalities) of the Ile-de-France region. The colored regions are the one used for the lower bound computation. The dashed blue areas are the weast and east of Paris. The dashed green area represents the area of the *Haut-de-Seine* region that is close to the entrance of the riverbank (92075, 92077, 92064, 92072, 92012, 92022, 92048, 92040, 92046, 92023, 92020). The dashed gray area represents the *Val-de-Marne* region close to the exist of the riverbank (94041, 94018, 94081, 94002, 94046, 94068, 94042, 94043, 94080, 94067, 94033, 64076, 94016, 94037, 94069, 94003).

Table O.B.1: Descriptive statistics of the occupancy rate - time heterogeneity

	Occupancy rate					
	Before			After		
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.
Daytime	2,536,469	20.162	11.515	1,645,532	21.119	11.749
Nighttime	1,820,723	5.929	4.762	1,224,197	6.991	5.505
Evening	728,088	23.9	12.48	471,939	24.795	12.775
Morning	729,006	16.978	12.391	471,162	17.505	12.546
Week-days	3,101,549	15.27	12.472	2,008,530	16.173	12.781
Week-end	1,255,643	11.608	8.831	861,199	12.571	8.914

Notes: This table represents the descriptive statistics with time heterogeneity of the treatment and control groups combined before and after the riverbank closure. *Daytime* represents the hours between 8 AM and 9 PM and *Nighttime* from 10 PM to 7 AM. *Evening* takes into account the hours between 5 PM and 8 PM and *Morning* are the hours between 7 AM and 10 AM.

Table O.B.2: Placebo tests

Phantom event	Average Treatment effect	P-value
10/04/2013	0.207	0.486
10/05/2013	0.151	0.588
09/06/2013	0.159	0.560
09/07/2013	-0.0201	0.934
08/08/2013	-0.143	0.573
07/09/2013	-0.068	0.788
07/10/2013	-0.124	0.608
06/11/2013	-0.115	0.621
06/12/2013	-0.141	0.532
05/01/2014	-0.125	0.578
04/02/2014	0.013	0.950
06/03/2014	0.095	0.652
05/04/2014	0.128	0.529
05/05/2014	0.090	0.652
04/06/2014	0.104	0.593
04/07/2014	0.032	0.866
03/08/2014	-0.001	0.995
02/09/2014	0.079	0.683
02/10/2014	0.069	0.717
01/11/2014	0.032	0.868
01/12/2014	0.087	0.648
31/12/2014	0.153	0.430
30/01/2015	0.227	0.244
01/03/2015	0.302	0.126
31/03/2015	0.357	0.072
30/04/2015	0.304	0.128
30/05/2015	0.320	0.128
29/06/2015	0.274	0.163
29/07/2015	0.256	0.196
28/08/2015	0.258	0.203
27/09/2015	0.279	0.156

Notes: The sample selected includes all observations from the 1^{st} of September 2013 to the 31^{st} of August 2016. I run equation (1) with phantom policy implementation dates every 30 days.

Table O.B.3: Occupancy rate by percentile

	Occupancy rate											
	Obs	Mean	Std. Dev.	1%	5%	10%	25%	50%	75%	90%	95%	99%
All ring roads	6,619,923	14.548	11.762	0.35	1.95	2.85	6	11.75	20.15	33.1	40	51.3
South ring roads	1,991,699	17.381	13.419	0.3	2.05	3.1	6.8	13.25	25.7	37.4	44.1	55
Riverbank	1,348	4.85	3.56	0.05	0.6	0.9	1.8	4.3	7.2	9.7	11.3	13.23

Notes: The first row represents the occupancy rate of the ring roads per percentile, both groups combined. The second row restricts the sample to the south ring roads. The third row represents the occupancy rate of the riverbank per percentile in 2015, a year before its shutdown.

Table O.B.4: Difference in travel time between itineraries after September 1^{st}, 2016 during the daytime

Riverbank shutdown	Itinerary	Distance	Average Speed (km/h)	Travel time
No	South ring roads	10.472km	31.7	20 minutes
Yes	South ring roads	10.472km	28.3	22 minutes
Time lost		**2 minutes**		
No	Riverbanks	13km	50	15 minutes 35 seconds
Time lost		**6 minutes**		

Notes: This table represents a back-of-the-envelope computation on the time lost by two groups of commuters. The average speed of the ring roads is computed with Athol's formula. As for the travel time, I compute it using $time = \frac{speed}{distance}$.

Table O.B.5: Population inside the A86 circle

Location	Sample	Population in 2015
Total	407,891	5,062,867
East	179,011	1,342,612
West	228,880	1,513,767
East of Paris	126,063	679,329
West of Paris	120,727	673,210
Lower 92	85,766	463,965
Lower 94	115,491	667,479

Notes: The population of the east and west of Paris are from the data census of 2014. The population census of 2015 did not present population data for each *arrondissement* of Paris.

Table O.B.6: Number of people impacted by the riverbank shutdown

Home location	Work location	% of car users	Number of people
	Upper Bound		
West	East	41.95	36,449
East	West	27.13	40,126
West of Paris	East	25.24	7,132
East	West of Paris	13.90	23,483
East of Paris	West	10.43	7,458
West	East of Paris	18.23	12,718
Bound limit			**127k**
	Lower Bound		
Lower 92	East of Paris	19.23	3,451
East of Paris	Lower 92	12.09	2,500
Lower 94	West of Paris	14.71	10,224
West of Paris	Lower 94	26.19	2,738
Bound limit			**19k**

Notes: I consider people living in the east, individuals living in the following suburbs : *Saine-Saint-Denis (93)*, *Val-de-Marne (94)* and *Seine-et-Marne (77)*. As for the west, I select *Val-d'Oise (95)*, *Yvelines (78)*, *Haut-de-Seine (92)* and *Essone (91)*. I consider as the east of Paris, the following "*arrondissements*" : 75013, 75012, 75011, 75020 and the west of Paris : 75015, 75007, 75016, 75008 and 75017. As for the lower bound, I select some *départements* (represented in Figure O.B.11) from *Haut-de-Seine (92)* and from *Val-de-Marne (94)* as well as the east and west of Paris.

O.C Additional Results

O.C.1 Occupancy rate

Table O.C.1: Occupancy rate: Main results and robustness checks - full sample

	(1)	(2)	(3)	(4)	(5)
			Occupancy rate		
Treatment	1.068	1.047	1.067	1.068	0.943
	(0.162)	(0.165)	(0.162)	(0.257)	(0.143)
Constant	14.689	14.051	14.763	14.689	14.455
	(0.041)	(0.374)	(0.044)	(0.065)	(0.036)
Observations	6,636,280	6,636,280	6,636,283	6,636,280	6,504,455
R^2	0.673	0.578	0.551	0.673	0.687
Arc FE	Yes	No	Yes	Yes	Yes
Time FE	Yes	Yes	No	Yes	Yes
Additive time FE	No	No	Yes	No	No
Winsorized data	No	No	No	No	Yes
Cluster level	Arc	Arc	Arc	Group of arcs	Arc

Notes: Standard errors are in parentheses. The outcome is the occupancy rate, which is a percentage of an hour. It represents the fraction of time a road section has been occupied by cars. Column (1) represents the main estimation. Columns (2) to (5) represent the different robustness checks performed to validate the results. In column (2), I include the dummy variable Treated instead of arc fixed effects. In column (3),the fixed effects are decomposed into year, month of the year, day of the week and hour of the day referred to as *additive time FE*. In column (4) the standard errors are clustered at the group level where each group of arcs is composed of the road segments between two entries. Column (5) adds up a restriction to the data. The data is winsorized at the 1% level.

Table O.C.2: Yearly impact on the occupancy rate

	Occupancy rate	
	Full Sample	South ring roads
Treated x Year -3	-0.105	-0.303
	(0.198)	(0.480)
Treated x Year -2	-0.180	-0.618
	(0.137)	(0.342)
Treated x Year 0	0.896	1.517
	(0.122)	(0.262)
Treated x Year +1	1.082	1.535
	(0.185)	(0.501)
Treated x Year +2	0.939	1.421
	(0.229)	(0.616)
Constant	14.737	17.078
	(0.053)	(0.159)
Observations	6,636,280	1,991,696
R^2	0.673	0.703
Arc fixed effect	Yes	Yes
Time fixed effect	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. This table gathers the estimates of Figure 3 by running equation (2) on the occupancy rates on the full sample and then on the south ring roads.

Table O.C.3: Average treatment effect on the occupancy rate on each day of the week - south ring roads

	Occupancy rate						
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Treatment	0.438	1.952	2.336	2.142	2.244	2.176	1.379
	(0.281)	(0.326)	(0.383)	(0.350)	(0.331)	(0.344)	(0.307)
Constant	13.757	16.659	17.574	18.295	18.523	18.844	14.856
	(0.072)	(0.084)	(0.098)	(0.089)	(0.084)	(0.088)	(0.079)
Observations	287,001	284,996	284,788	283,100	282,593	282,512	286,706
R^2	0.713	0.713	0.713	0.699	0.708	0.695	0.694
Arc fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The riverbank shutdown impact is evaluated on each day of the week separately. I include the observations of the 2 roads that compose the south ring roads for the entire time period.

Table O.C.4: Time heterogeneity - full sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Occupancy rate						
	All	Daytime	Nighttime	Evening	Morning	Weekdays	Weekends
Treatment	1.068	1.586	0.337	1.637	1.225	1.333	0.428
	(0.162)	(0.251)	(0.062)	(0.316)	(0.211)	(0.187)	(0.128)
Constant	14.689	20.609	6.419	24.464	16.664	15.719	12.141
	(0.041)	(0.064)	(0.016)	(0.080)	(0.053)	(0.047)	(0.033)
Observations	6,636,280	3,868,068	2,768,212	1,108,784	1,109,378	4,724,570	1,911,710
R^2	0.673	0.535	0.694	0.548	0.706	0.672	0.682
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Arc FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The outcome is the occupancy rate, which is a percentage of an hour. It represents the fraction of time a road section has been occupied by cars. Column (1) represents the main estimation. In columns (2) to (7), I select subsamples and show the different results. In column (2), I perform the regression on the hours from 8 AM to 9 PM. Column (3) includes the hours from 10 PM to 7 AM. Column (4) and (5) include respectively evening (5 PM to 8 PM) and morning (7 AM to 10 AM) hours. In columns (6) and (7), I look at the impact on weekdays and weekends respectively.

O.C.2 Probability of congestion

Table O.C.5: Congestion indicators

	(1)	(2)	(3)	(4)
	Flow			
	South ring road		North ring road	
	Outer	Inner	Outer	Inner
Occupancy rate	12.860	43.242	41.318	46.741
	(5.247)	(7.758)	(3.924)	(3.649)
Occupancy rate^2	-0.348	-0.883	-0.894	-0.940
	(0.089)	(0.126)	(0.082)	(0.067)
Constant	994.341	774.474	835.485	711.057
	(50.881)	(77.569)	(30.422)	(32.067)
Observations	817,537	815,915	1,905,074	2,002,472
R^2	0.943	0.938	0.947	0.934
Arc FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Threshold (k*)	**18.482**	**24.498**	**23.106**	**24.866**

Notes: Standard errors are in parentheses and clustered at the arc level. The outcome is the flow per lane, which is the number of vehicles that pass through the sensor in an hour. Columns (1) to (4) represent the estimation of the fundamental diagram on each road. The threshold k* represents the optimum of the quadratic curve. Once the occupancy exceeds k*, the road becomes congested.

Table O.C.6: Probability of congestion: Main results and robustness checks - full sample

	(1)	(2)	(3)	(4)	(5)
			Probability of congestion		
Treatment	0.036	0.035	0.036	0.036	0.035
	(0.006)	(0.006)	(0.006)	(0.008)	(0.006)
Constant	0.201	0.161	0.205	0.201	0.196
	(0.001)	(0.013)	(0.002)	(0.002)	(0.001)
Observations	6,636,280	6,636,280	6,636,283	6,636,280	6,504,455
R^2	0.443	0.336	0.342	0.443	0.431
Arc FE	Yes	No	Yes	Yes	Yes
Time FE	Yes	Yes	No	Yes	Yes
Additive time FE	No	No	Yes	No	No
Winsorized data	No	No	No	No	Yes
Cluster level	Arc	Arc	Arc	Group of arcs	Arc

Notes: Standard errors are in parentheses. The outcome is a dummy variable that takes the value 1 if the occupancy rate is passed the threshold of the relevant road (k*), and 0 otherwise. On average, it represents the probability of congestion. Column (1) represents the main estimation. Columns (2) to (5) represent the different robustness checks performed to validate the results. In column (2), I include the dummy variable Treated instead of arc fixed effects. In column (3),the fixed effects are decomposed into year, month of the year, day of the week and hour of the day referred to as *additive time FE*. In column (4) the standard errors are clustered at the group level where each group of arcs is composed of the road segments between two entries. Column (5) adds up a restriction to the data. The data is winsorized at the 1% level.

Table O.C.7: Probability of congestion: Impact depending on time - full sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Probability of congestion			
	All	Daytime	Nighttime	Evening	Morning	Weekdays	Weekends
Treatment	0.036	0.053	0.011	0.042	0.043	0.042	0.021
	(0.006)	(0.009)	(0.002)	(0.011)	(0.007)	(0.006)	(0.005)
Constant	0.201	0.337	0.011	0.465	0.245	0.237	0.113
	(0.001)	(0.002)	(0.000)	(0.003)	(0.002)	(0.002)	(0.001)
Observations	6,636,280	3,868,068	2,768,212	1,108,784	1,109,378	4,724,570	1,911,710
R^2	0.443	0.426	0.202	0.449	0.541	0.455	0.367
Arc FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: Standard errors are in parentheses and clustered at the arc level. The outcome is a dummy variable that takes the value 1 if the occupancy rate is passed the threshold of the relevant road (k^*), and 0 otherwise. On average, it represents the probability of congestion. Column (1) represents the main estimation. In columns (2) to (7), I select subsamples and show the different results. In column (2), I perform the regression on the hours from 8AM to 9PM. Column (3) includes the hours from 10 PM to 7 AM. Column (4) and (5) include respectively evening (5 PM to 8 PM) and morning (7 AM to 10 AM) hours. In columns (6) and (7), I select the weekdays and weekends respectively.

Table O.C.8: Probability of congestion: Spatial Heterogeneity - south ring roads

	(1)	(2)	(3)
		Occupancy rate	
	[0km , 2.9km]	[2.9km , 6.7km]	[6.7km , 10.4km]
Treatment	0.081	0.049	0.055
	(0.015)	(0.014)	(0.015)
Constant	0.208	0.334	0.315
	(0.004)	(0.004)	(0.004)
Observations	558,040	705,510	723,079
R^2	0.563	0.620	0.586
Arc FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The outcome is the probability of congestion. The south ring road is decomposed into three groups. Group 1 represents the first 2.9km of the south ring road following the flow direction from west to east. Group 2 represents the following 3.8km and group 3 the last 3.7km.

O.C.3 Speed

Table O.C.9: Speed: Main results and robustness checks - full sample

	(1)	(2)	(3)	(4)	(5)
			Speed		
Treatment	-1.212	-1.272	-1.227	-1.212	-1.123
	(0.380)	(0.467)	(0.378)	(0.448)	(0.366)
Constant	44.210	45.702	44.192	44.210	44.499
	(0.096)	(2.335)	(0.071)	(0.113)	(0.092)
Observations	5,514,597	5,514,597	5,514,600	5,514,597	5,444,358
R^2	0.765	0.178	0.617	0.765	0.775
Arc FE	Yes	No	Yes	Yes	Yes
Time FE	Yes	Yes	No	Yes	Yes
Additive time FE	No	No	Yes	No	No
Winsorized data	No	No	No	No	Yes
Cluster level	Arc	Arc	Arc	Group of arcs	Arc

Notes: Standard errors are in parentheses. The outcome is the average speed in km/h. For the same reasons mentioned in Section 5.2, the analysis is restricted to daytime. Column (1) represents the main estimation. Columns (2) to (5) represent the different robustness checks performed to validate the results. In column (2), I include the dummy variable Treated instead of arc fixed effects. In column (3),the fixed effects are decomposed into year, month of the year, day of the week and hour of the day referred to as *additive time FE*. In column (4) the standard errors are clustered at the group level where each group of arcs is composed of the road segments between two entries. Column (5) adds up a restriction to the data. The data is winsorized at the 1% level.

Table O.C.10: Speed: Impact depending on time - full sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Speed			
	All	Daytime	Nighttime	Evening	Morning	Weekdays	Weekends
Treatment	-1.212	-1.736	-0.452	-1.394	-1.648	-1.528	-0.456
	(0.380)	(0.449)	(0.376)	(0.481)	(0.383)	(0.388)	(0.386)
Constant	44.210	38.878	51.751	33.565	43.063	42.389	48.668
	(0.096)	(0.114)	(0.095)	(0.122)	(0.097)	(0.098)	(0.098)
Observations	5,514,597	3,231,213	2,283,384	926,184	927,020	3,914,763	1,599,834
R^2	0.765	0.694	0.900	0.651	0.790	0.734	0.847
Arc FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The outcome is the average speed in km/h. For the same reasons mentioned in Section 5.2, the analysis is restricted to daytime. Column (1) represents the main estimation. In columns (2) to (7), I select subsamples and show the different results. In column (2), I perform the regression on the hours from 8 AM to 9 PM. Column (3) includes the hours from 10 PM to 7 AM. Column (4) and (5) include respectively evening (5 PM to 8 PM) and morning (7 AM to 10 AM) hours. In columns (6) and (7), I select the weekdays and weekends respectively.

Table O.C.11: Speed: Heterogeneity in distance - south ring roads

	(1)	(2)	(3)
		Speed	
	[0km , 2.9km]	[2.9km , 6.7km]	[6.7km , 10.4km]
Treatment	-4.918	-1.344	-2.258
	(1.693)	(0.535)	(0.801)
Constant	46.688	39.826	34.493
	(0.374)	(0.142)	(0.197)
Observations	408,379	604,347	608,725
R^2	0.684	0.716	0.757
Arc FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

Notes: Standard errors are in parentheses and clustered at the arc level. The outcome is the average speed in km/h. For the same reasons mentioned in Section 5.2, the analysis is restricted to daytime. The south ring road is decomposed into three groups. Group 1 represents the first 2.9 km of the south ring road following the flow direction from west to east. Group 2 represents the following 3.8 km and group 3 the last 3.7 km.

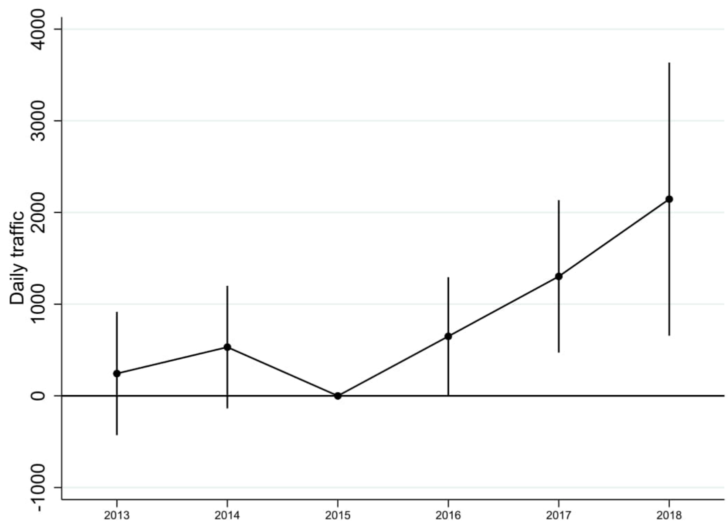
O.C.4 Public Transportation: RER-A

Table O.C.12: Yearly impact on public transportation

	Daily traffic
Treated x 2013	243.353
	(331.92)
Treated x 2014	531.53
	(330.14)
Treated x 2016	649.05
	(318.26)
Treated x 2017	1302.82
	(410.56)
Treated x 2018	2145.65
	(735.02
Constant	15210.42
	(164.73)
Observations	330
R^2	0.996
Station FE	Yes
Year FE	Yes

Notes: Standard errors are in parentheses and clustered at the municipality level. This table gathers the estimates of Figure O.C.1.

Figure O.C.1: Impact on the RER-A



Notes: This graph plots the estimates and 95% confidence intervals of equation (2) on the number of daily entries on the RER-A.