Displacing Congestion: Evidence from Paris

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(NBER)

EPOP

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Motivation

- ⋆ Policy-makers all agree on the urge to ↓ greenhouse gas emissions and local pollution
- ⋆ Yet, the type of policy that would do it best is still an open debate
- ⋆ Car-free streets have become the paradigm of contemporary urbanism
  - e.g. Market Street in San Francisco (2020), 14^{th} street in NYC (2019), Center of Madrid (2018), Center of Oslo (2019), GP expressway in Paris (2016)...
- ⋆ Restricting cars for even tiny stretches of road spaces can be extremely contentious
  - Benefits: often concentrated in wealthier parts of the city
  - Leakage in externalities: often toward poorer areas of the city

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  - Benefits: often concentrated in wealthier parts of the city
  - Leakage in externalities: often toward poorer areas of the city
  - **Overall effects on the environment remains an open question: non-linear relationship between traffic and pollution**

Research Questions

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2. What are the distributional impacts of this policy?

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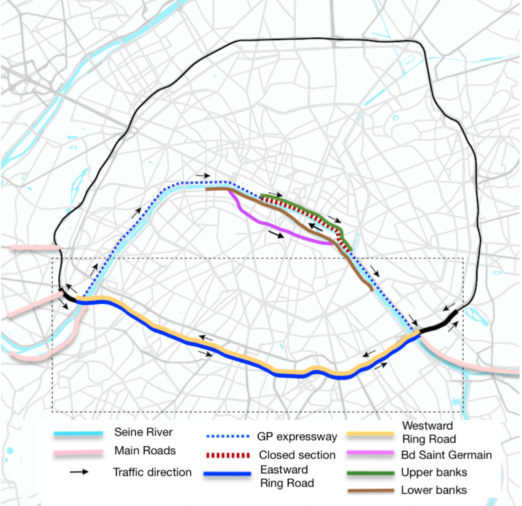
Reform Exploited: Closure of a 3.3-km segment of the expressway along the Seine's right riverbank on September 1, 2016: the "Voie Georges Pompidou" (GP)

1. Leakage in congestion and pollution:
   - How does it affect nearby roads?
   - How does it affect major roads at the periphery of the city?
2. Cost quantification in terms of time loss and exposure to pollution for low-income and high-income

The 2016 Road Closure Policy



Riverbank road (GP):

- ⋆ 13-kilometer road
- ⋆ Only expressway to cross the city
- ⋆ Unique flow direction: eastward
- ⋆ 40k vehicles per day
- ⋆ Average travel time during daytime on the GP: 22min
- ⋆ Average travel time south ring road: 26min
- ⋆ Fastest road to cross the city
- ⋆ Part of a road network of general interest

▸ Travel Time

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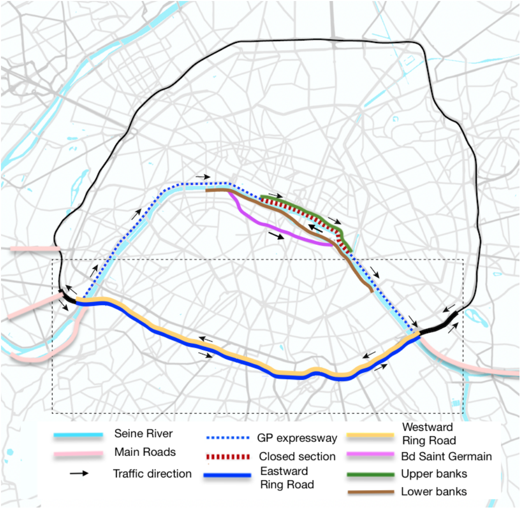


Closed section:

- ⋆ 3.3km pedestrianized in the center in September 2016
- ⋆ Tourist area: near the *Notre-Dame Cathedral*

GP Expressway Before Closure

Closed section:

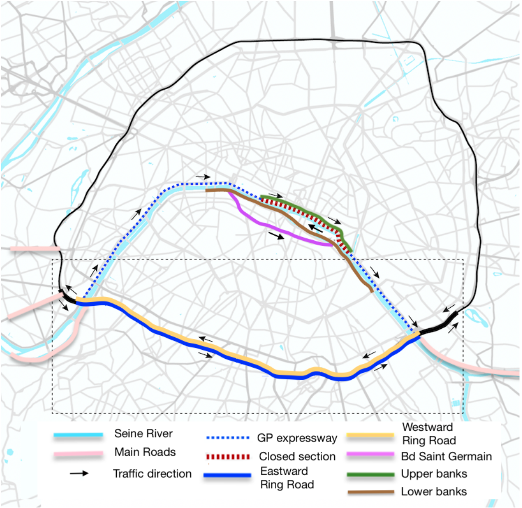
- ⋆ 3.3km pedestrianized in the center in September 2016
- ⋆ Tourist area: near the *Notre-Dame Cathedral*
- ⋆ It was a two-lane road
- ⋆ Along the Seine river

GP Expressway After Closure

Closed section:

- ⋆ 3.3km pedestrianized in the center in September 2016
- ⋆ Tourist area: near the *Notre-Dame Cathedral*
- ⋆ It was a two-lane road
- ⋆ Along the Seine river
- ⋆ **Increase in amenities: 1M pedestrians and cyclists a year**

3 Itineraries of Substitution



Zoom on Local Roads:

What I do: Reduced-Form

- **Traffic**:
  - Setting: Evaluation of the pedestrianization of 3.3km of the Georges Pompidou (GP) riverbank in Paris in 2016
  - Key features for identification: flow direction and timing of traffic
  - Outcomes: occupancy rate, flow of cars, average speed, probability of congestion
- **Pollution**:
  - Estimation of the elasticity of air pollution with respect to average speed on nearby roads using pre-shutdown data

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  - Estimation of the elasticity of air pollution with respect to average speed on nearby roads using pre-shutdown data
  - Imputation of the impact on pollution using results on the average speed

What I do: Model of Shortest Route Choice with Endogenous Congestion

- **Cost Analysis**: Pollution and Time Costs
  - A model of shortest route choice where I estimate the congestion elasticity of each road
  - Quantify the number of extra commuters on each road
- **Distributional effects**
  - I distinguish between inner-city and suburban commuters
  - I distinguish between low-income and high-income residents
- **Counterfactual scenarios**
  - Predict the impacts of other potential situations:
    - Wider car-free area
    - Optimal length closure under no mode switch
    - Zero net pollution costs

Contribution to the literature (1/2)

- Congestion policies:
  - Demand-side policies:
    - congestion pricing: *Liu & McDonald, 1999; Santos et al., 2008; Tirachini & Hensher, 2012; Winston & Langer, 2006*
  - Supply-side policies:
    - road-space rationing: *de Grange & Troncoso, 2011; Gallego et al., 2013; Kornhauser & Fehlig, 2003*
    - urban rail-transit expansions: *Adler & van Ommeren, 2016; Gonzalez-Navarro & Turner, 2018; Gu et al., 2021*
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- Expanding the road supply unlikely to relieve congestion:
  - If you build it they will come *Downs, 1962; Duranton & Turner, 2011*

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  - If you build it they will come *Downs, 1962; Duranton & Turner, 2011*

→ **First study to ask (in the short-run):** If you demolish it, will they not come?

Contribution to the literature (2/2)

- Traffic and Pollution:
  - Quantification of the negative consequences of urban road traffic on health: *Anderson, 2020; Currie & Walker, 2011; Gibson & Carnovale, 2015; Prud'homme et al., 2011; Bhalla et al., 2014; Davis, 2008*

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→ **Evidence on the unintended pollution cost of traffic calming policies**

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- Characterization of traffic congestion:
  - Two approaches: the static speed-flow curve and the dynamic deterministic bottleneck model: *Small & Verhoef, 2007*
  - Effect of vehicle density on travel flows either on selected segments *(Ardekani & Herman, 1987; Geroliminis & Daganzo, 2008)* or for an entire city *(Akbar & Duranton, 2017)*

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→ **Use model developed by *Akbar & Duranton, 2017* and extend it to the case of a road closure**

Plan

Introduction

Context and Data

Reduced-Form

A Model of Route Choice

Conclusion

Data sets

- **Traffic counting data**
  - Occupancy Rate: time vehicles stay on a loop as a percentage of an hour
  - Flow of cars: number of cars that pass by a point in an hour
  - Data from 2013 to 2019
- **Other data sets**
  - **Pollution levels (Airparif)**: emission levels of various pollutants
  - **Population Census**: workplace, home, mode of transportation
  - **Housing Transactions (DVF)**: exhaustive data recording all housing transactions in France from January 2014 to December 2018

0.5% of the Road Network is Reduced

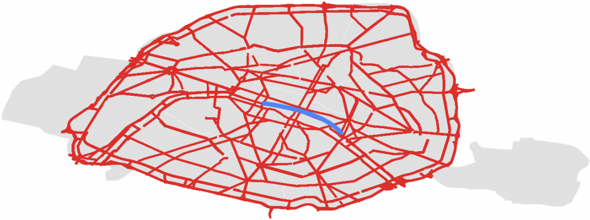

Figure: Traffic sensors in Paris

- ⋆ 1,300km of main road lanes in Paris
- ⋆ 3.3km of road closed with 2 lanes ⇒ 6.6km of road lanes pedestrianized: **0.5% of the road network**

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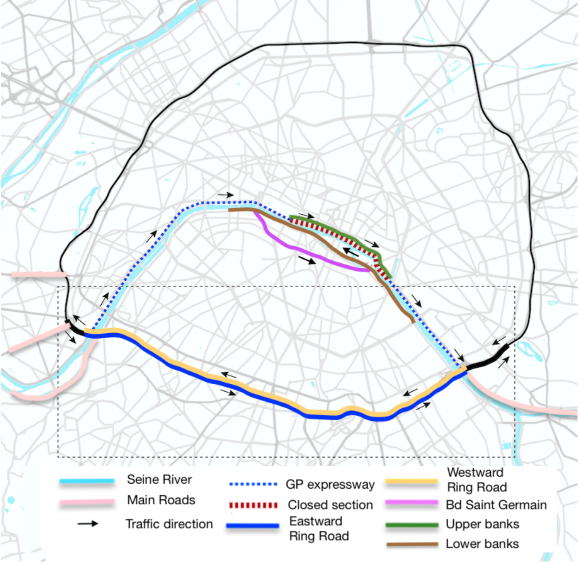
Identification Strategy: Key Element 1



Direction of traffic:

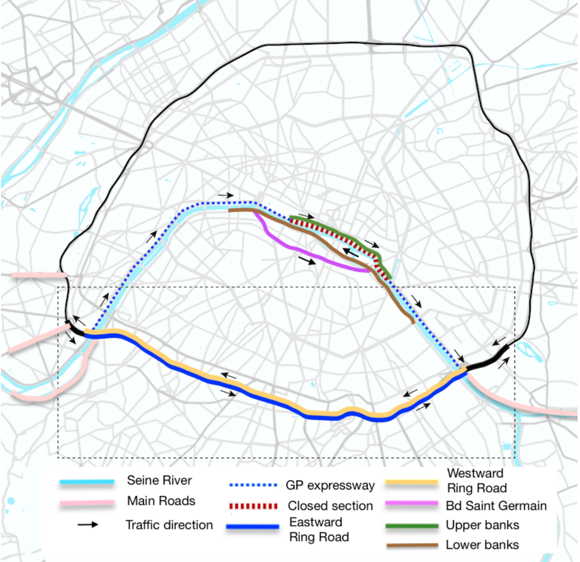
- ⋆ Treated: Local substitute roads (eastward):
  - Upper Banks —
  - Bd St Germain —

  → Control: Lower Banks — (westward)
- ⋆ Treated: Substitute to the full GP (eastward):
  - South outer ring road —

  → Control: South inner ring road — (westward)

⇒ **Absence of contamination**

Identification Strategy: Key Element 2



Timing of traffic:

- ⋆ Treated roads: morning hours (home-to-work trip)
- ⋆ Control roads: evening hours (work-to-home trip)
- ⋆ and vice versa...

⇒ **Comparability of both groups**

Specification

- Basic equation :

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

where i represents the arc (a segment of a road) and t the time

- Dynamic equation:

$$Y_{it} = \alpha + \sum_{k=-2, k\neq 0}^{+3} \beta_k 1_{treated_i=1} 1_{T(t)=k} + \lambda_t + \psi_i + \epsilon_{ist} \quad (2)$$

where $1_{t=k}$ is an indicator variable equals to 1 for year k relative to year Sept2015-Aug2016

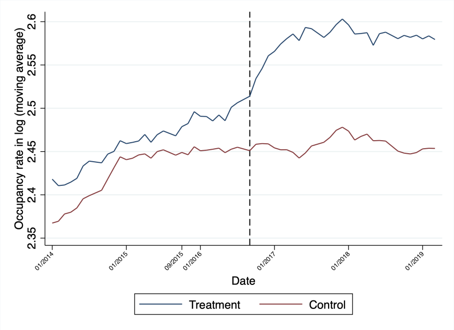
- Y_{it} denotes the outcome considered on arc i at date t, and T(t) represents the relative year compared to the year the GP riverbank was pedestrianized
- Standard errors clustered at the arc level
- β_k represents the **incremental impact** of the policy on year k, compared to the year before the GP riverbank was pedestrianized

Threats to Identification

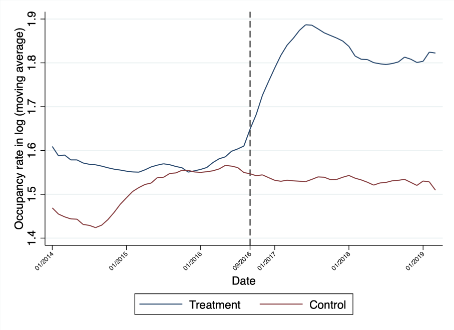
1. **Local control road:**
   - If the car-free area attracts more jobs or other activities ▸ Placebo control road
2. **Mode switch:**
   - Indirect treated commuters (commuters using the ring road) ▸ Treated/Control ▸ Treated/ non-Control
     $\rightarrow$ No statistically significant evidence of $\uparrow$ public transit usage ▸ Public Transit ▸ Trip simulation
   - Direct treated commuters (commuters using the GP) ▸ GP/Control Roads
     $\rightarrow$ the model estimation validates the absence of significant mode switch
3. **Anticipation effects:**
   - Reform announced in December 2015 ▸ Dynamic Impact on Occupancy Rate
4. **Simultaneous urban modifications to promote alternatives to car:**
   - ex: *Plan Vélo 2015-2020* or increase in gasoline price ▸ Details

Common Trends

Ring Road



Local Roads



Flow ↑ on local roads and ↓ on ring road

	(1)	(2)	(3)
		Flow (in log)	
	Morning	Evening	Daytime
		Ring Roads	
Treatment	-0.061***	-0.081***	-0.061***
	(0.013)	(0.020)	(0.013)
Constant	8.387***	8.366***	8.395***
	(0.003)	(0.005)	(0.003)
Observations	14,4155	97,405	627,122
		Local Roads	
Treatment	0.331***	0.212***	0.264***
	(0.050)	(0.051)	(0.048)
Constant	7.125***	7.331***	7.189***
	(0.017)	(0.017)	(0.017)
Observations	335,934	227,045	1,461,499
Arc FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

* p<.10, ** p<.05, *** p<.01

- ⋆ The flow increases linearly as everyone continues to drive the posted speed limit and there are more cars on the road
- ⋆ As vehicles on the road increase to a congested state, they start to drive slower
- ⋆ Difference in signs stems from this non-monotonicity

▸ Flow/Occ rate curve ▸ Dynamic Impact on Flow

Occupancy rates ↑

	(1)	(2)	(3)
	Occupancy rate (in log)		
	Morning	Evening	Daytime
	Ring Roads		
Treatment	0.094***	0.142***	0.112***
	(0.017)	(0.026)	(0.018)
Constant	3.141***	3.264***	3.146***
	(0.004)	(0.007)	(0.005)
Observations	176,038	118,781	765,044
	Local Roads		
Treatment	0.321***	0.328***	0.339***
	(0.078)	(0.083)	(0.080)
Constant	2.158***	2.365***	2.233***
	(0.024)	(0.025)	(0.024)
Observations	397,931	268,689	1,729,726
Arc FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

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▸ GP by hour ▸ Dynamic Impact on Occupancy Rate

Impact on congestion and average speed

- ⋆ Cannot fully understand the traffic situation through occupancy rates only
- ⋆ Occupancy rate + flow data → probability of congestion ▸ Fundamental diagram
- ⋆ Athol's formula (Hall, 1996) → average speed on each road section ▸ Details

Probability of Congestion ↑

	(1)	(2)	(3)
	Probability of congestion		
	Morning	Evening	Daytime
		Ring Roads	
Treatment	0.106***	0.107***	0.119***
	(0.032)	(0.018)	(0.022)
Constant	0.359***	0.444***	0.421***
	(0.009)	(0.004)	(0.005)
Observations	120,788	204,004	627,123
		Local Roads	
Treatment	0.033	0.100***	0.101***
	((0.025)	(0.031)	(0.031)
Constant	0.053***	0.075***	0.079***
	(0.010)	(0.011)	(0.011)
Observations	292,243	474,426	1,461,657
Arc FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

* p<.10, ** p<.05, *** p<.01

- ⋆ Probability of Congestion ↑ by 21% on the ring road
- ⋆ Probability of Congestion ↑ by 50% on local roads

▸ Dynamic Impact on Congestion

Average Speed ↓ on both sets of roads

	(1)	(2)	(3)
	Average Speed (in log)		
	Morning	Evening	Daytime
		Ring Roads	
Treatment	-0.154***	-0.175***	-0.165***
	(0.032)	(0.033)	(0.029)
Constant	3.325***	3.220***	3.243***
	(0.009)	(0.008)	(0.007)
Observations	120,788	204,004	627,122
		Local Roads	
Treatment	-0.113	-0.170**	-0.175**
	(0.083)	(0.080)	(0.083)
Constant	2.421***	2.480***	2.420***
	(0.033)	(0.027)	(0.028)
Observations	292,214	474,261	1,461,407
Arc FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes

* p<.10, ** p<.05, *** p<.01

- ⋆ Impact almost similar on both sets of roads
- ⋆ Results will be used to compute the time loss

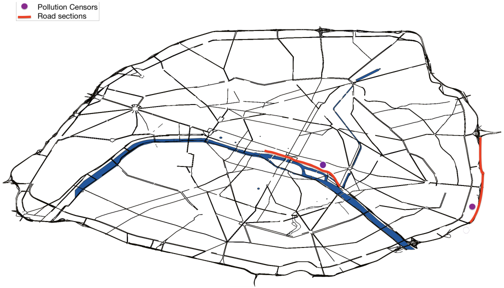
▸ Dynamic Impact on Speed
▸ Impact at night & week-end ▸ FE, Clustering, Winsorize
▸ Different Control Group ▸ Impact on north ring road

Pollution: Empirical Strategy

In the **pre-shutdown** period and for each monitor, I estimate:

$$ln(NO_{2t}) = \alpha ln(Speed_t) + \beta Flow_t + \theta W_t' + \delta_{h(t)} + \delta_{m(t)} + \epsilon_t$$

W_t' a vector of weather characteristics. $\delta_h(t)$ and $\delta_m(t)$ are resp. hour of the day and month of the sample fixed effects.



▸ Link bw Speed and NO_2 ▸ Pollution levels

↑ in NO_2, higher near the ring road

	(1)	(2)	(3)	(4)
	NO_2 concentrations (in log)			
Ring Roads				
Speed (in log)	-0.293***	-0.275***	-0.346***	-0.256***
	(0.019)	(0.018)	(0.021)	(0.022)
Flow (1000 v/h)	0.043***	0.034***	0.077***	0.073***
	(0.003)	(0.003)	(0.006)	(0.006)
Constant	6.053***	5.502***	5.579***	5.214***
	(0.100)	(0.100)	(0.104)	(0.108)
Observations	75,551	7,551	7,551	7,551
Upperbanks				
Speed (in log)	0.062***	0.064***	-0.084***	-0.091***
	(0.023)	(0.022)	(0.020)	(0.020)
Flow (1000 v/h)	0.361***	0.367***	0.357***	0.290***
	(0.010)	(0.010)	(0.017)	(0.017)
Constant	5.440***	5.181***	5.376***	5.470***
	(0.076)	(0.079)	(0.069)	(0.068)
Observations	10,170	10,170	10,170	10,170
Weather Characteristics	Yes	Yes	Yes	Yes
Month of Sample FE	No	Yes	Yes	Yes
Hour FE	No	No	Yes	Yes
Day of the week FE	No	No	No	Yes

* p<.10, ** p<.05, *** p<.01

- ⋆ Local roads:
  - $\alpha_{local} = -0.08\%$
  - Speed ↓ 17.5%

  ↑ 1.5% in nitrogen dioxide
- ⋆ Ring roads:
  - $\alpha_{ringroad} = -0.35\%$
  - Speed ↓ 16.5%

  ↑ 5.8% in nitrogen dioxide

▸ Housing Prices

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Assumptions

1. I only consider the intensive margin: individuals can change itineraries (no mode shift)
2. I only focus on the short-run: relocation of jobs/home do not kick in
3. Car-commuters optimize their travel time
4. I abstract from second order effects: only commuters on the road closed can divert from their initial itinerary

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- Consider a city and its nearest suburbs, composed of different neighborhoods $j \in J$, served by several roads $r \in R$ of direction d

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  - they differ in their characteristics and technical performance
  - affects levels of congestion

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- $S_{rt}(N_{rt}) = \overline{S_r} N_{rt}^{-\sigma_{\mu(r)t}(N_{rt})}$ (Akbar & Duranton, 2017), where:
  - $S_{rt}(N_{rt})$ and N_{rt} average speed and density of cars on road r at time t
  - $\overline{S_r}$ theoretical maximal speed on road r
  - $\sigma_{\mu(r)t}(N_{rt})$ elasticity of congestion

$$\sigma_{\mu(r)}(N_r) \begin{cases} < 1 \ if \ N_r < N_r^{max} \\ > 1 \ if \ N_r > N_r^{max} \end{cases}$$

Commuters

- ⋆ Consider two types of commuters:
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  2. Suburban commuters (O): cross the city line to commute to work

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  2. Suburban commuters (O): cross the city line to commute to work

- Total number of commuters on each road r inside the city is $N_r = O_r + I_r$

- The travel time of a trip using a set of roads $C \in R$ can be expressed as:

$$\sum_{r \in C} T_{rt} = \sum_{r \in C} \frac{D_r}{S_{rt}(N_{rt})}$$

Reduction in the road supply

Consider a fraction x of the expressway is permanently closed

$\rightarrow$ Commuters who were using the expressway (N_e^{pre}) need to shift to other roads

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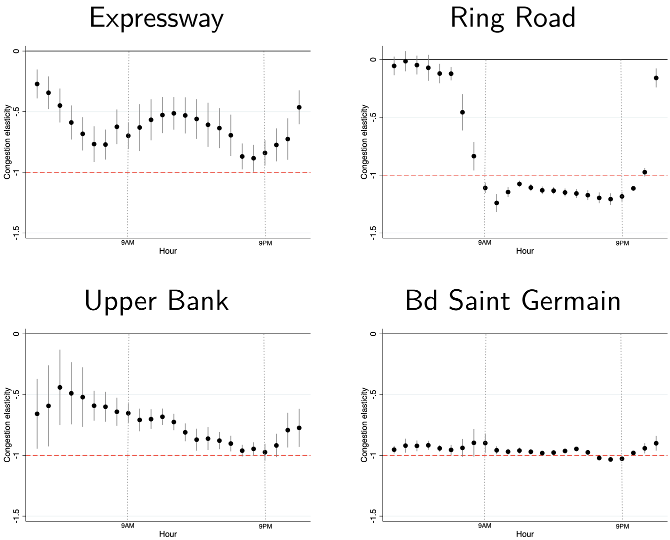
- ⋆ Inner-city commuters shift to substitute arterial roads: $r \in A$
- ⋆ Suburban commuters can either shift to substitute arterial roads or to freeways: $r' \in F$
- ⋆ An arterial road is considered as a direct substitute if:
  - It is of the same **length** of the closed section
  - It has the same **flow direction**
  - It shares an **entrance** and **exit** with the expressway
- ⋆ A freeway is considered as a direct substitute if:
  - It is of the **same length** as the entire expressway
  - It has the same **flow direction**
  - It shares an **entrance** and **exit** with the expressway

Interpretation

- ⋆ The $\downarrow$ in the average speed on substitute roads impacts:
  - Commuters: $\uparrow$ in travel time
  - City-dwellers living near the substitute roads: $\uparrow$ in air pollution ▸ Pollution in the model
- ⋆ The pattern of commuter sorting therefore depends on several parameters:
  - the number of alternative substitute roads
  - the relative technical performance of roads (elasticity of congestion)
  - the initial conditions on each road (number of commuters, number of lanes, length...)
- ⋆ **Even if the policy achieves some traffic evaporation, overall congestion and pollution levels can still increase if (some) cars are reallocated from less congested roads to more congested roads!**

Estimating σ_r: $ln(S_{it}) = \alpha - \sigma_t ln(N_{it}) + \gamma_t + \gamma_i + \epsilon_{it}$



Cost of the policy: 44M € per year

- **Travel Cost:** 0.22 € per minute (French Ministry of Environment) ▸ Time Loss
  - 4 categories of commuters face an increase in travel time:
    1. Ex-riverbank commuters (inner-city): 56h → 740 €/pers
    2. Ex-riverbank commuters (suburbans): 17h → 224 €/pers
    3. Commuters initially on local substitute roads: 11.2h → 149 €/pers
    4. Commuters initially on south ring road: 17.3h → 229 €/pers

    → Annual Total cost: 37M €
- **Pollution:** 1 $\mu g/m^3 = 15.08$€ per day per postcode (*Mink, 2022*)
  - Residents near the south ring road
  - Residents near local roads

    → Annual cost: 7.2M €
- Every car removed from the GP costs 1,400€ per year
- Every visitor should spend at least 44€ per visit

Low-income people bear 90 % of the pollution cost

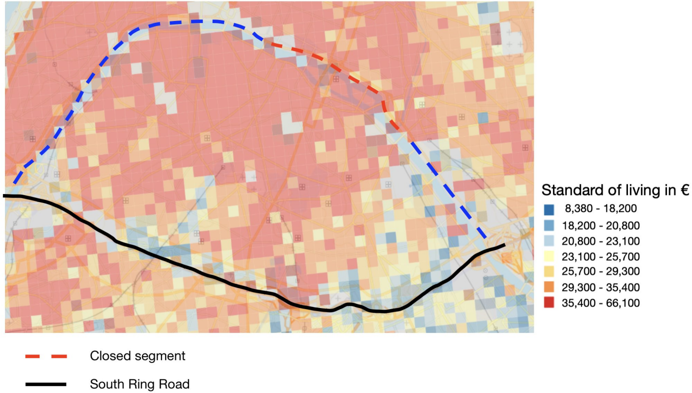


Figure: Spatial sorting of residents

- ⋆ **High-income people**
  - 60% of the time cost
  - 10% of pollution cost
- ⋆ **Low-income people**
  - 40% of the time cost
  - 90% of the pollution cost

Counterfactuals

3 variables define the number of road substitutes:

- ⋆ Flow direction
- ⋆ Length of the closed segment
- ⋆ Starting point of the pedestrianization

Counterfactual situations:

- ⋆ Optimal closure under no mode switch ▸ Details
- ⋆ Minimal mode switch for zero net pollution costs ▸ Details
- ⋆ Potential impacts of a wider car-free area ▸ Details

Plan

Introduction

Context and Data

Reduced-Form

A Model of Route Choice

Conclusion

Policy Implication

- Potential benefits of car-free areas:
  - $\downarrow$ noise and air pollution in the car-free area
  - $\uparrow$ in amenities: attract tourists, visitors
  - $\uparrow$ in the quality of urban life
- In this paper, I show that road-reduction policies, if not managed thoroughly can:
  - unintentionally have negative effects on the environment
  - increase the inequality gap
- Policy-makers should ensure that their actions address both mitigation and adaptation in ways that are as fair and inclusive as possible, leaving no one behind
  - offer credible alternatives
  - make sure that traffic is not diverted to MORE congested roads

Faster to take the GP than the south outer ring road

◂ Back

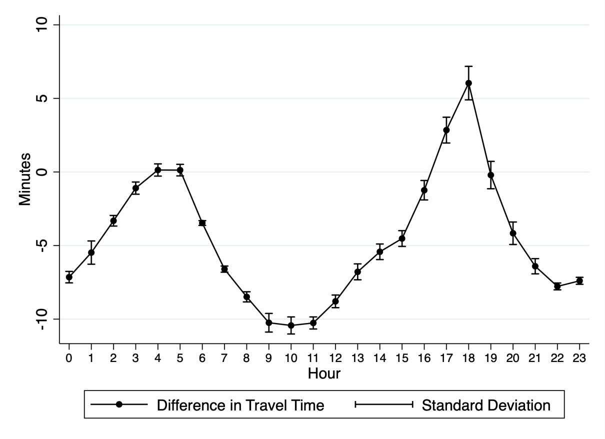


Figure: Difference in travel time between the GP and the south outer ring road

3.3-km Closure

◂ Back

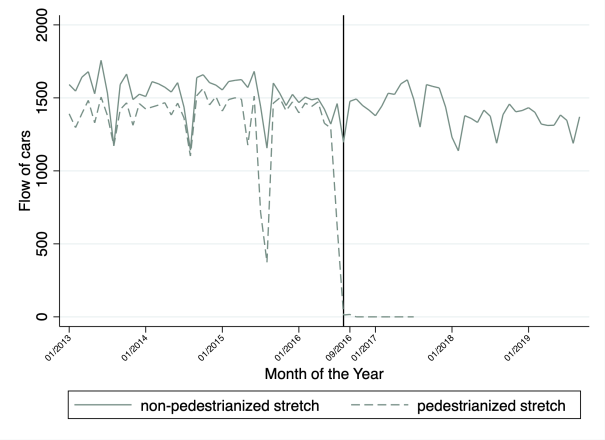
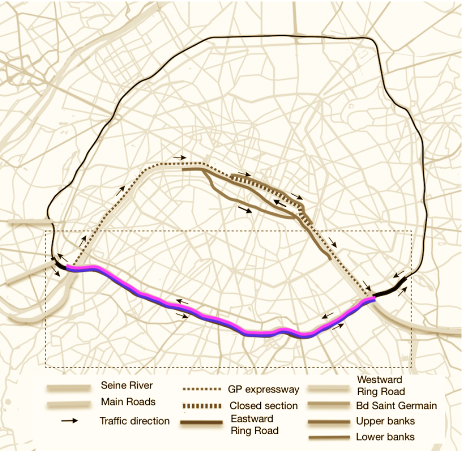


Figure: Flow per hour on the GP riverbank

Threat: Mode switch among indirect treated commuters (1/2)

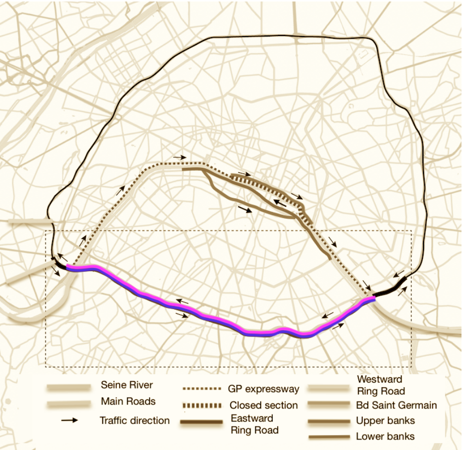
Back



- **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y

Threat: Mode switch among indirect treated commuters (1/2)

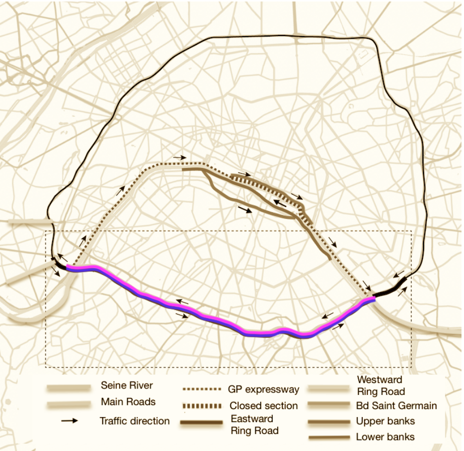
Back



- **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y
- **Post-shutdown:** δx drop their cars
  - Total number of commuters on south outer ring road: (x - δx) + GP commuters
  - Total number of commuters on south inner ring road: (y - δx)

Threat: Mode switch among indirect treated commuters (1/2)

Back

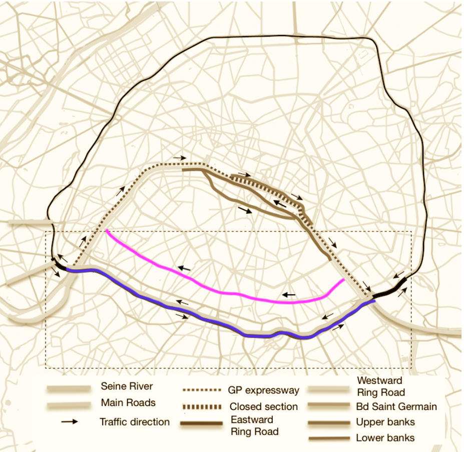


- **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y
- **Post-shutdown:** δx drop their cars
  - Total number of commuters on south outer ring road: (x - δx) + GP commuters
  - Total number of commuters on south inner ring road: (y - δx)

$\rightarrow \gamma_{did}$ = GP commuters

Threat: Mode switch among indirect treated commuters (2/2)

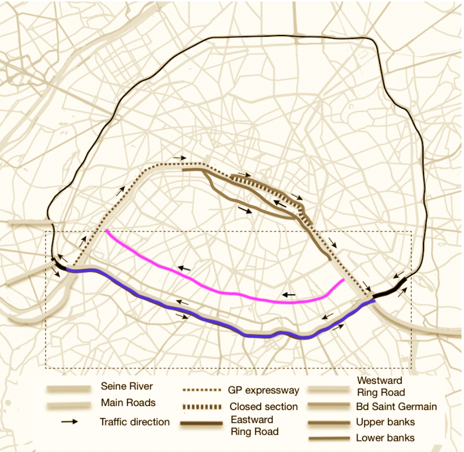
◂ Back



- **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y

Threat: Mode switch among indirect treated commuters (2/2)

Back



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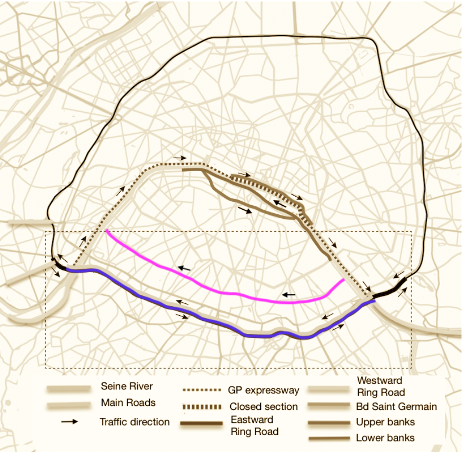
  - Total number of commuters on south inner ring road: y

Threat: Mode switch among indirect treated commuters (2/2)

Back

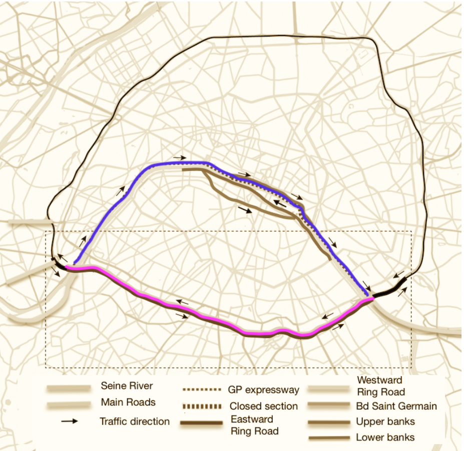


- ⋆ **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y
- ⋆ **Post-shutdown:**δx drop their cars
  - Total number of commuters on south outer ring road: (x - δx) + GP commuters
  - Total number of commuters on south inner ring road: y

$\rightarrow \gamma_{did} =$ GP commuters - δx

Threat: Mode switch among direct treated commuters

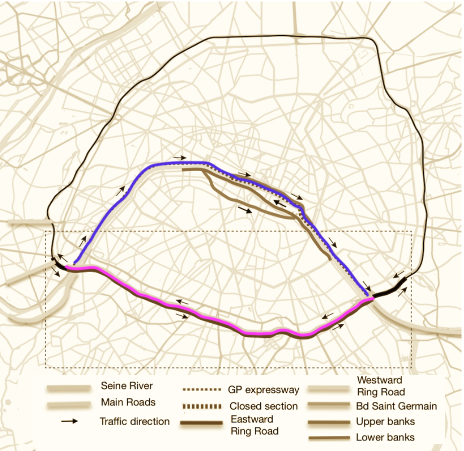
Back



- **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y

Threat: Mode switch among direct treated commuters

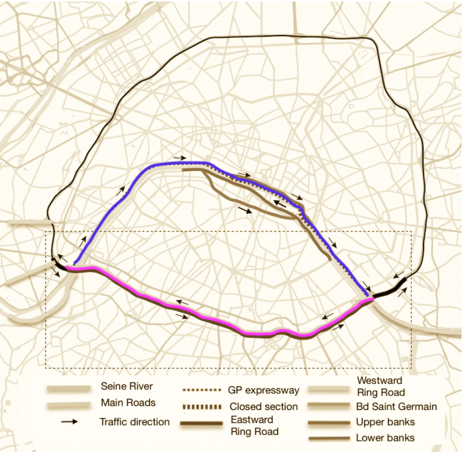
Back



- ⋆ **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y
- ⋆ **Post-shutdown:** All GP commuters drop their cars
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y - GP commuters

Threat: Mode switch among direct treated commuters

Back

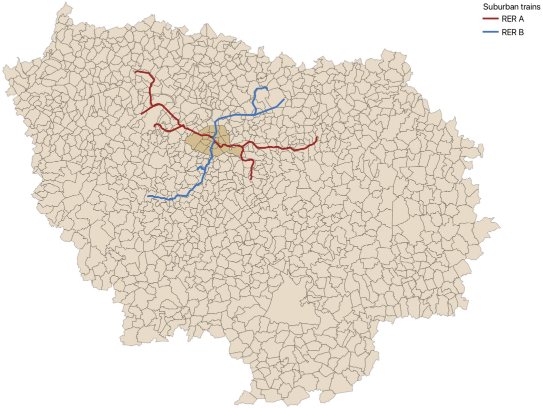


- **Pre-shutdown:**
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y
- **Post-shutdown:** All GP commuters drop their cars
  - Total number of commuters on south outer ring road: x
  - Total number of commuters on south inner ring road: y - GP commuters

$\rightarrow \gamma_{did} = +$ GP commuters $\neq 0$!

Public Transportation

◂ Back



Impact on public transportation

- ⋆ Treatment group: pass validations for train stations on the west and east of Paris
- ⋆ Control group: pass validations for train stations on the north and south of Paris

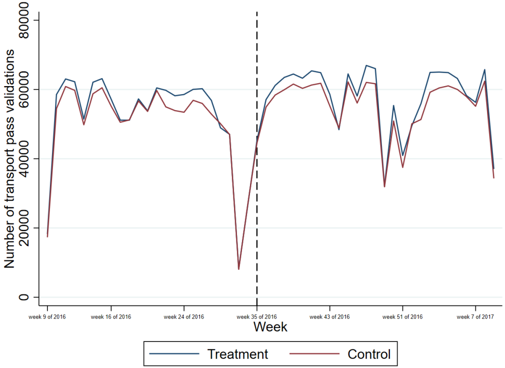


Figure: Number of pass validations on the RER A (treatment) and the RER B (control)

No suggestive evidence of modal shift

Back

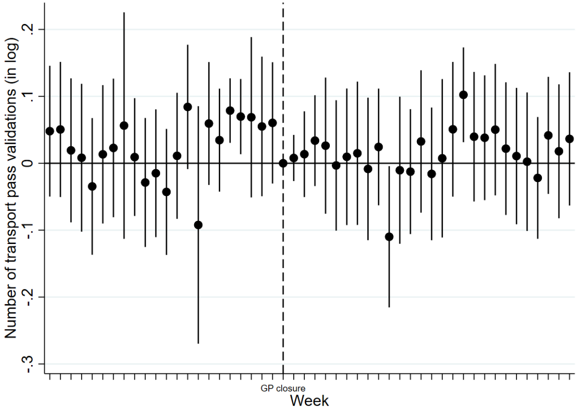
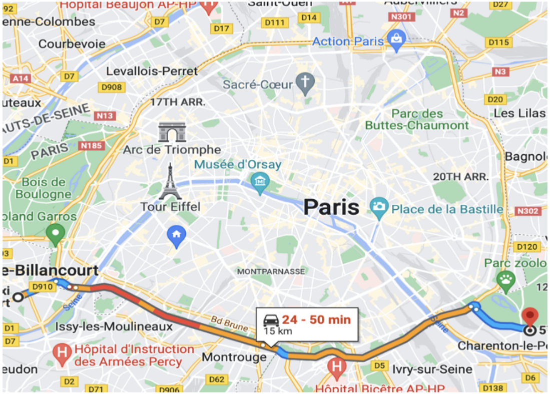
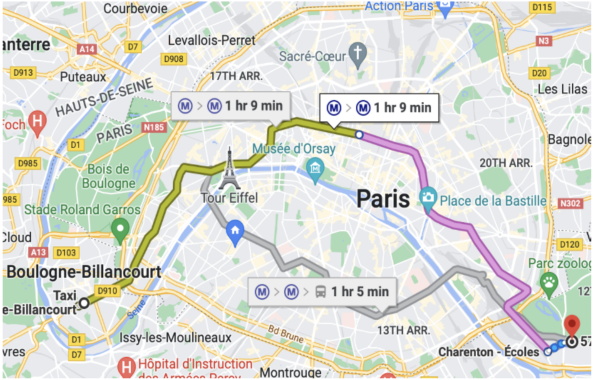


Figure: Treatment effects on the number of pass validation of the RER A

Google Maps Trips - close suburbs

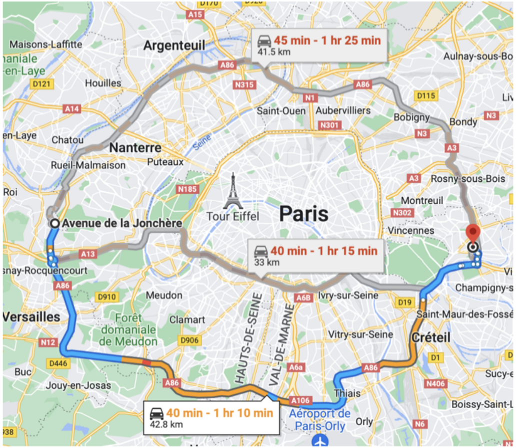
Back

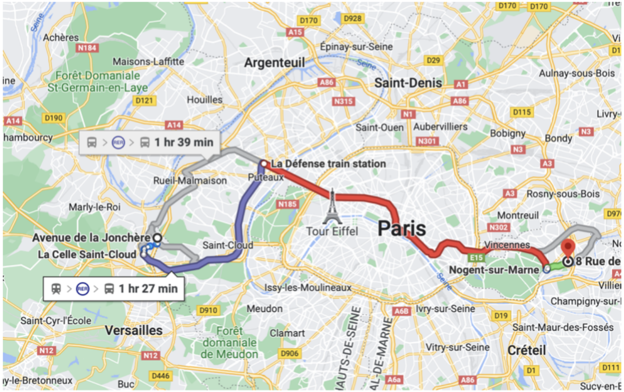




Google Maps Trips - far suburbs

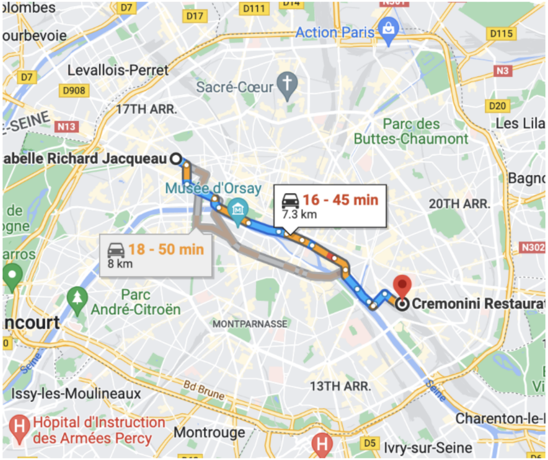
Back

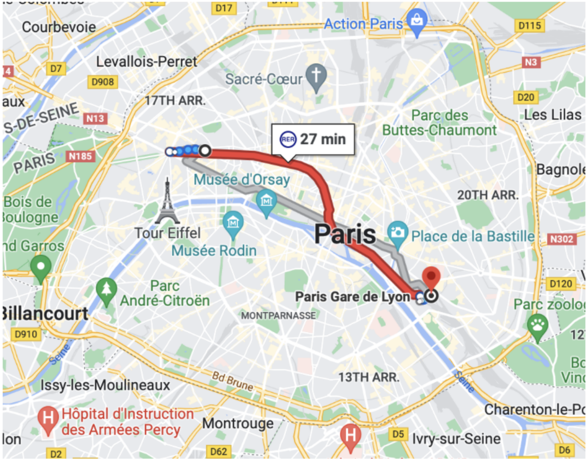




Google Maps Trips - inner-city

Back

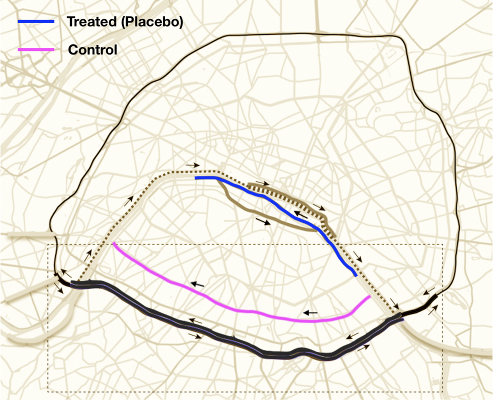




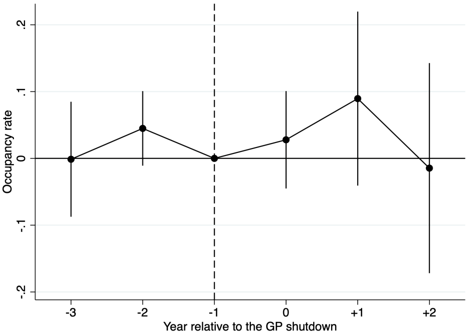
Is the local control road impacted by the GP closure?

Back

Placebo



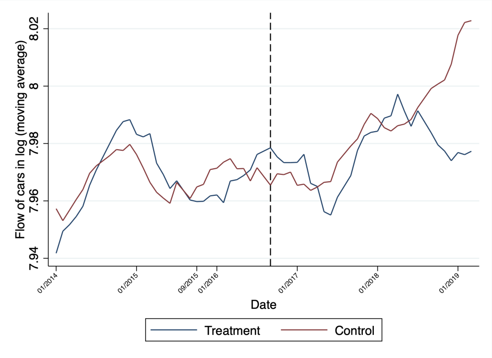
Impact on the Occupancy Rate (log)



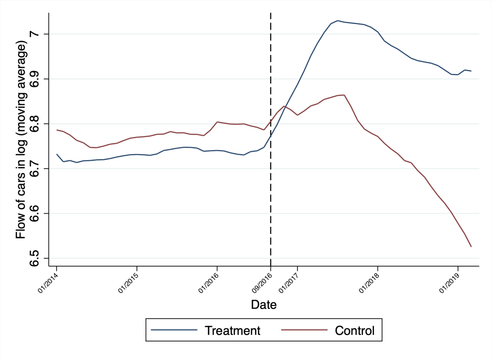
Common Trends - Flow of cars

◂ Back

Ring Road



Local Roads



Density Low - Speed High

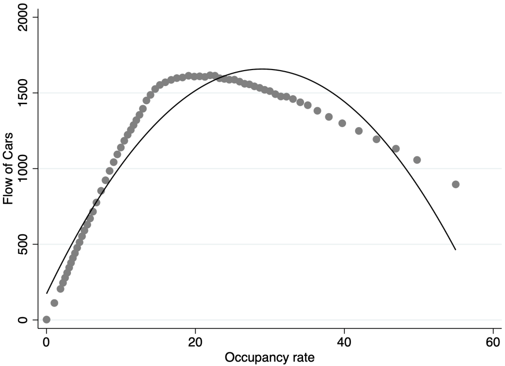
Back

Density High - Speed High

Density High - Speed Low

Fundamental Diagram

Back

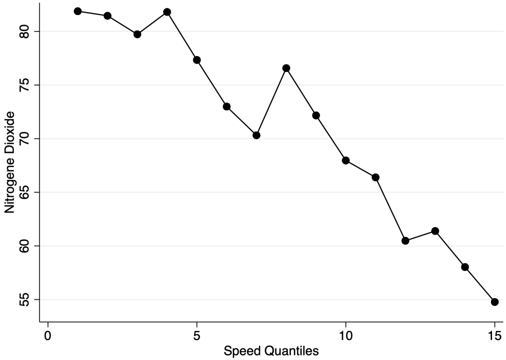


- ⋆ Vehicle Density is linked to both speed and flow
- ⋆ Vehicle Density affects speed (non linearly)
- ⋆ After reaching a certain point: as density increases, speed decreases.
- ⋆ As speed decreases, flow of cars (per hour) decreases

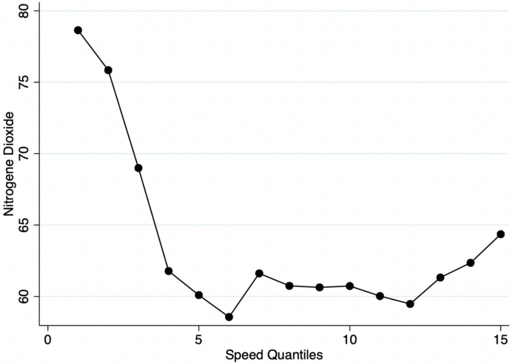
Pollution-Speed Relationship

◂ Back

Ring Road

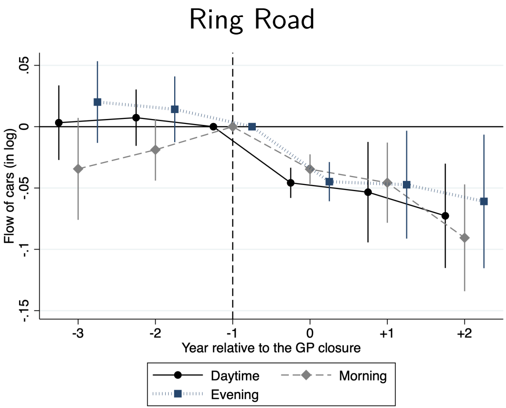


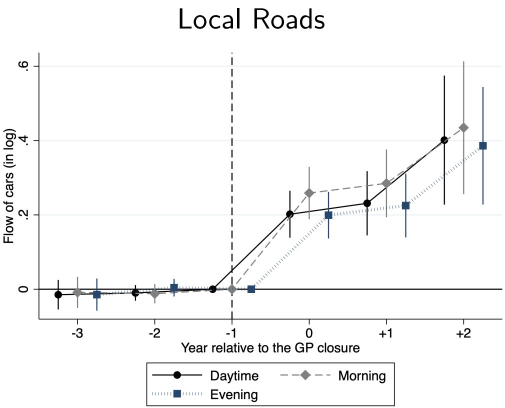
Local Roads



Dynamic Impact on the Flow of Cars

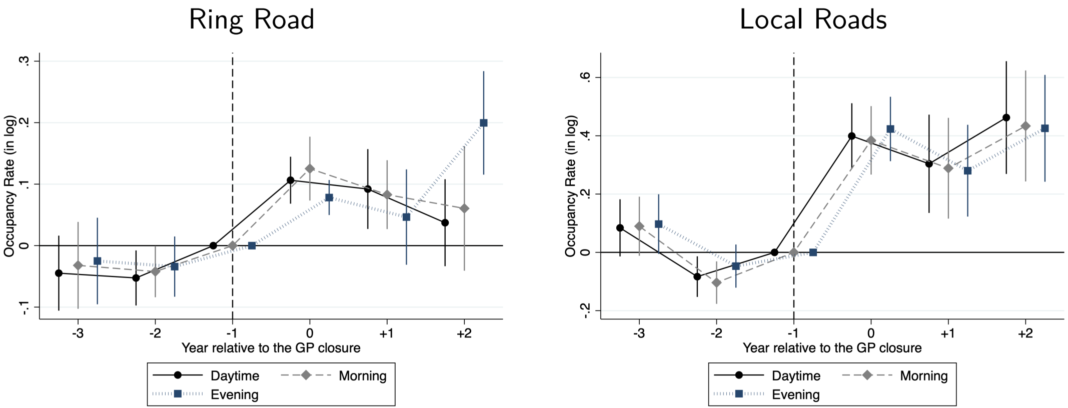
Back





Dynamic Impact on Occupancy Rate

Back



Estimation of the Fundamental Diagram

Back

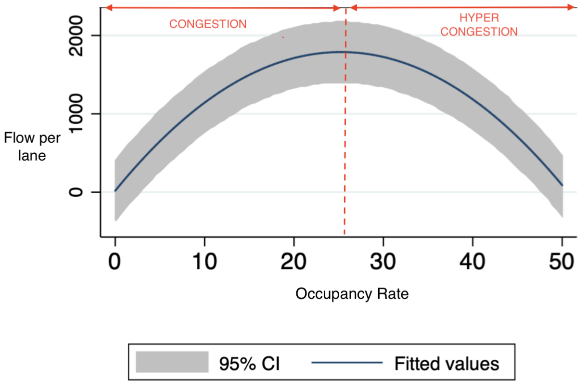


Figure: Quadratic relationship between flow and occupancy rates on one arc of the south outer ring road

Speed

Back

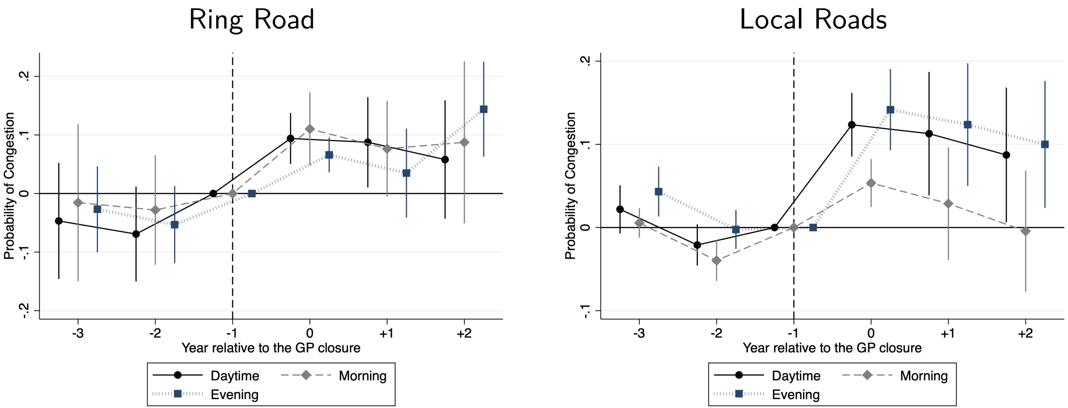
- Athol's formula

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

  - $Speed_{it}$ represents the average speed (km/h) on road section i at time t
  - $Flow_{it}$ and $Occupancy_{it}$ are the flow per lane of road and the occupancy rate on section i at time t
  - L represents the average length of vehicles and K_i is the length in km of the road section i
- *Assumption* : average length of vehicles equals to 4.5 meters

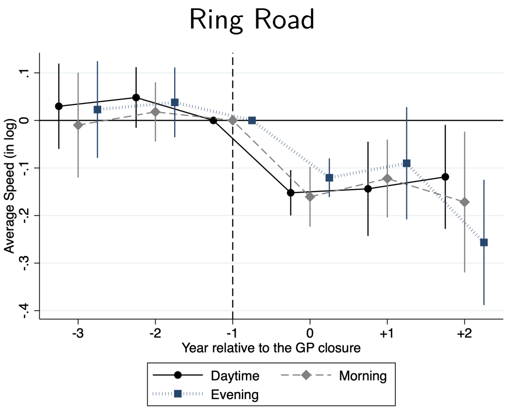
Dynamic Impact on Congestion

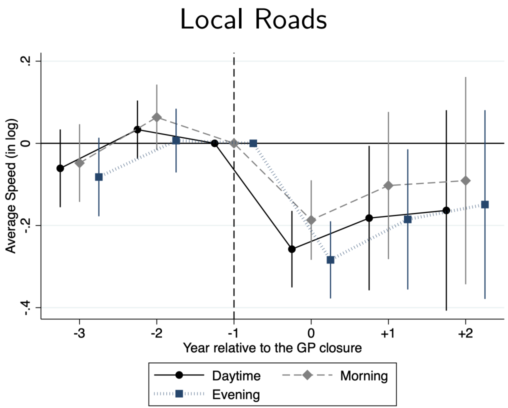
Back



Dynamic Impact on Speed

Back





Concentrations at the periphery already higher than in the center

Back

Table: Yearly levels of NO_2

	Ring Road		Upper Banks	
Year	Mean	Sd. Dev.	Mean	Sd. Dev.
2013	75.6	47	66.7	31.7
2014	74.7	36.5	62.08	30.5
2015	67	34.8	60.4	30.6
2016	66.2	34.8	59,3	28.7
2017	64.8	34.3	58.6	30.05
2018	67.4	33	59	29.8

- European Environment Agency: yearly levels should be below 40 $\mu g/m^3$

Housing Prices: Identification

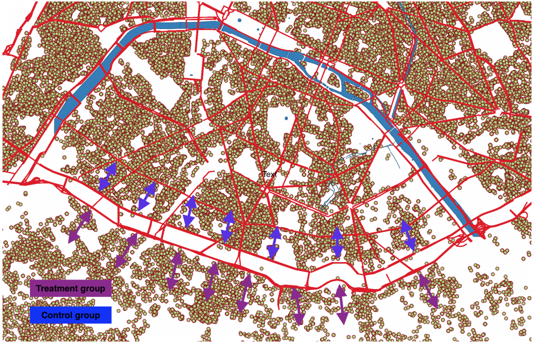


Figure: Housing Transactions between 2014 and 2018

- ⋆ 350-meters of social housings between the ring road and another boulevard **inside Paris**
- ⋆ Housing transactions in Paris *less impacted* by the increase in congestion on the ring road

Housing Prices: Identification

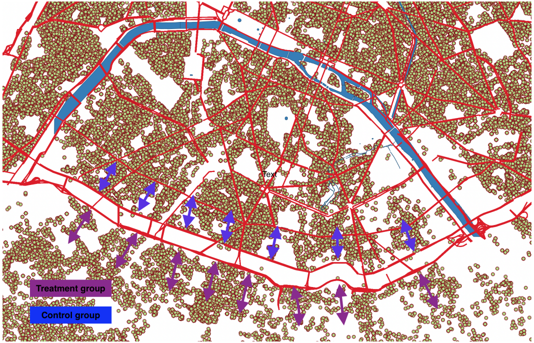


Figure: Housing Transactions between 2014 and 2018

- ⋆ 350-meters of social housings between the ring road and another boulevard **inside Paris**
- ⋆ Housing transactions in Paris *less impacted* by the increase in congestion on the ring road

⇒ Strategy: Difference-in-difference at the boundary

Back

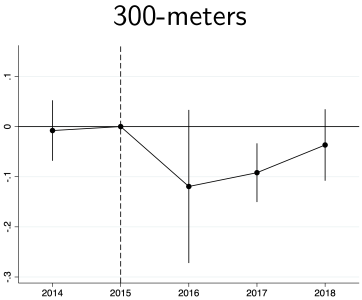
Housing Prices: Empirical Strategy

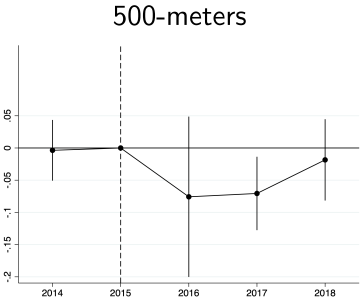
$$ln(HV_{it}) = \beta ln(Area_i) + \theta Rooms_i + \sum_{k=-2,k\neq-1}^{+2} \gamma_k Treated_i * Year_{k(t)} + \delta_{m(t)} + \delta_{n(i)} + \epsilon_{it}$$

- ⋆ HV_{it} is the housing value of transaction i at time t
- ⋆ $Treated_i$ is a dummy variable that takes the value 1 if transaction i is outside the limits of Paris and 0 otherwise
- ⋆ k year relative to the year the GP was closed
- ⋆ $\delta_{m(t)}$ and $\delta_{n(i)}$ are respectively month of the sample and neighborhood fixed effects

Significant ↓ in Housing Values in 2017

◂ Back



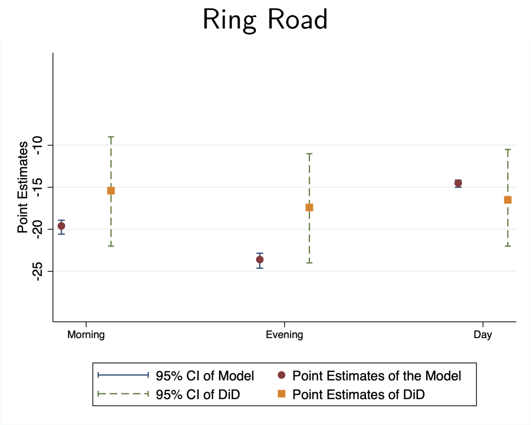


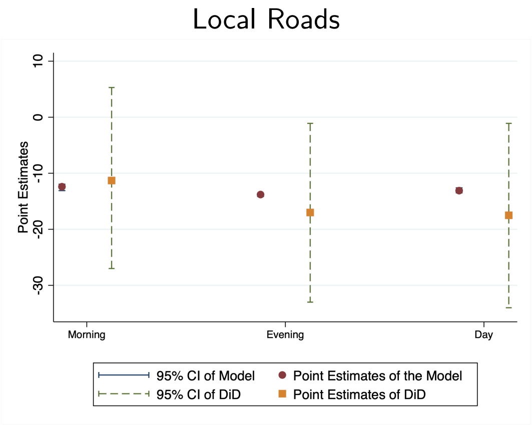
- ⋆ Announcement of new metro lines in the south suburbs early 2018
- ⋆ Sullivan (2016) finds that an ↑ in 1 $\mu g/m^3$ in NO_2 emissions → housing values ↓ by 0.7%
- ⋆ Near the ring road, NO_2 increased by 3.8 $\mu g/m^3$

  ⇒ Impact on housing prices is much larger than the one reflected in the literature

Model validates DiD results on speed

◂ Main





Pollution Cost

The upper banks are spread over 2 municipalities, the boulevard saint germain over 3 and the south ring roads over 10

I assume that half of the residents in each municipality suffers from higher exposure to air pollution. I consider that a 1 $\mu g/m^3$ increase in NO_2 emissions is responsible for 727 €in health cost expenditure in every postcode area per day.

Robustness Checks

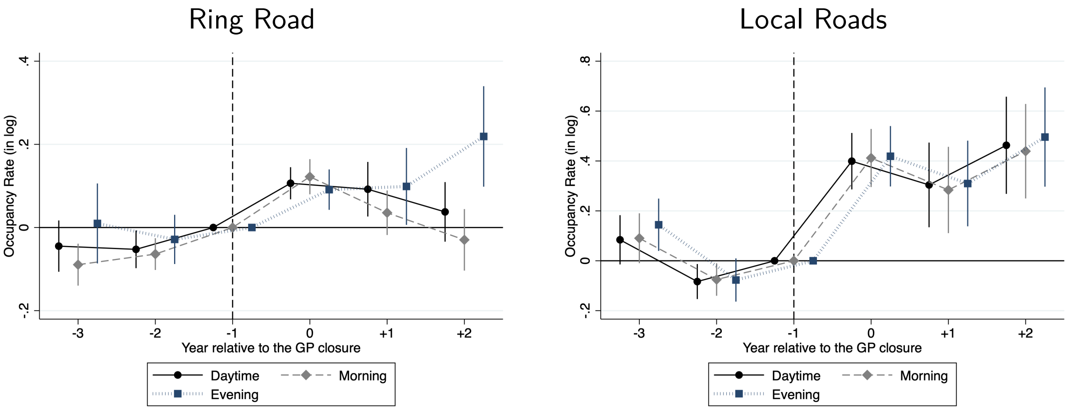
◂ Back

	(1)	(2)	(3)	(4)	(5)
			Occupancy rate (in log)		
			Ring Roads		
Treatment	0.112***	0.117***	0.112***	0.112***	0.112***
	(0.018)	(0.018)	(0.018)	(0.000)	(0.018)
Constant	3.146***	3.071***	3.158***	3.146***	3.146***
	(0.005)	(0.068)	(0.006)	(0.000)	(0.005)
Observations	765,044	765,044	765,047	765,044	765,044
R^2	0.569	0.297	0.372	0.569	0.569
			Local Roads		
Treatment	0.339***	0.357***	0.339***	0.339*	0.339***
	(0.080)	(0.084)	(0.079)	(0.108)	(0.080)
Constant	2.233***	2.142***	2.247***	2.233***	2.233***
	(0.024)	(0.091)	(0.015)	(0.033)	(0.024)
Observations	1,729,726	1,729,726	1,729,733	1,729,726	1,729,726
R^2	0.579	0.250	0.482	0.579	0.579
Arc FE	Yes	No	Yes	Yes	Yes
Time FE	Yes	Yes	No	Yes	Yes
Additive time FE	No	No	Yes	No	No
Clustering	Arc	Arc	Arc	Road	Arc
Winsorized data	No	No	No	No	Yes

* $p<.10$, ** $p<.05$, *** $p<.01$

Changing control groups - Occupancy rate

Back



No Simultaneous Policies Impacting the Estimates

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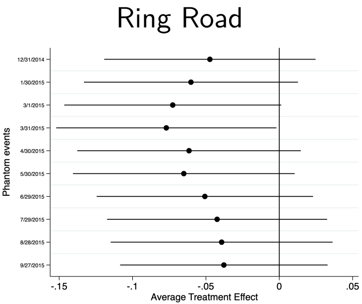

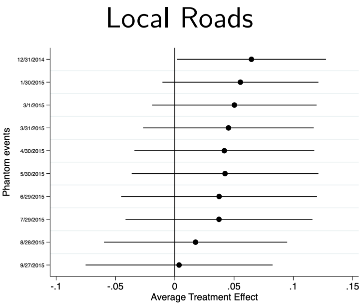

Figure: Placebo Tests on the Average Speed

Impact at night & week-end

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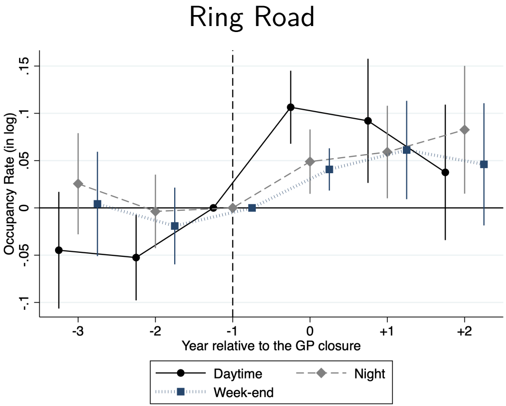

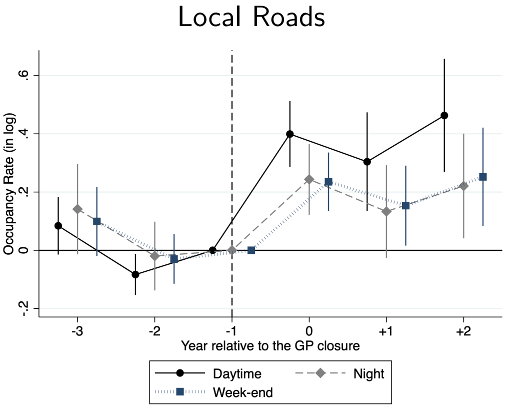

Impact on north ring road

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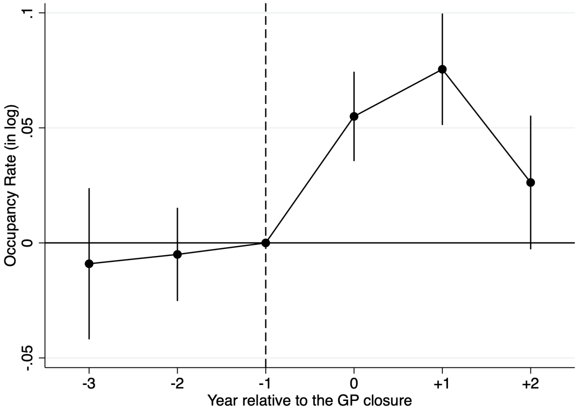

GP - summary statistics

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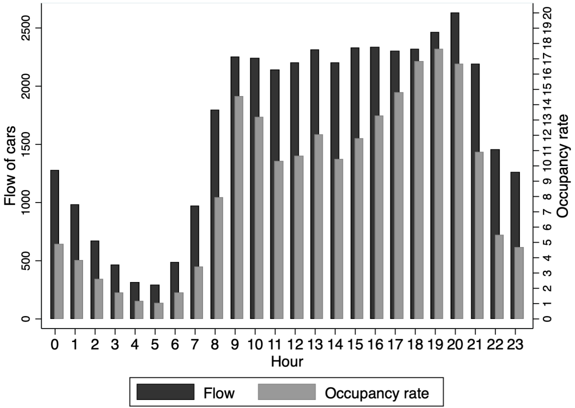

Pollution

Back

- ⋆ The presence of cars on the road increases air pollution
  1. the number of cars
  2. the level of congestion

Pollution

◂ Back

- ⋆ The presence of cars on the road increases air pollution
  1. the number of cars
  2. the level of congestion

- ⋆ The level of pollutant emissions:

$$A_j(\mu(r')) = \begin{cases} S_{r'}(N_{r'})^{-\alpha_{\mu(r')}} \; if \; S_{r'} < \tilde{S_{r'}} \\ S_{r'}(N_{r'})^{\zeta_{\mu(r')}} \; if \; S_{r'} > \tilde{S_{r'}} \end{cases}$$

  - $\tilde{S_{r'}}$ is the threshold above which an increase in the average speed increases emissions
  - $\alpha_{\mu(r')}$ is the elasticity of pollution with respect to the speed whenever $S_{r'} < \tilde{S_{r'}}$
  - $\zeta_{\mu(r')}$ the elasticity of pollution with respect to the speed whenever $S_{r'} > \tilde{S_{r'}}$

Time Loss

◂ Back

Table: Time Loss in Euro Value

Commuters	Time lost	Daily Cost in €	Yearly Cost in €
Ex-riverbank diverted to the ring road	4	0.88	228.8
Ex-riverbank diverted to local roads	13	2.86	743.6
Commuters on ring road	4	0.88	228.8
Commuters on local roads	2.6	0.57	148.72

Notes: I consider that commuters experience an increase in travel time only during weekdays. I multiply the daily cost by 260 days to obtain the yearly cost. Since the expressway is a unique flow direction road, only one way of the commuting trip is impacted. The westward trip of each commuter remains unchanged with no additional cost associated to it.

Changing the length of the closed segment

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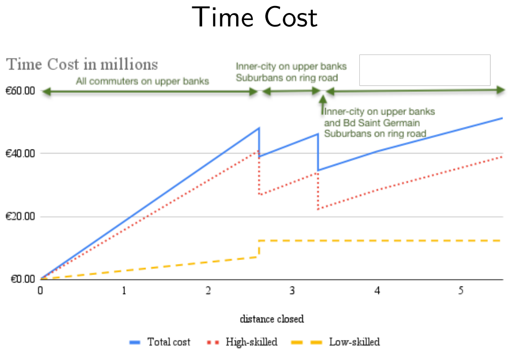

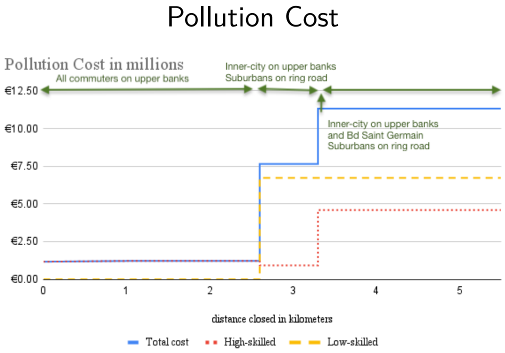

⇒ Below **2.6-kilometers**, suburbans choose local roads

Closing 1.8-kilometers to avoid 90% of pollution costs

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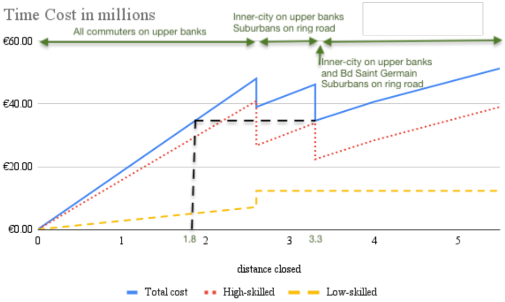
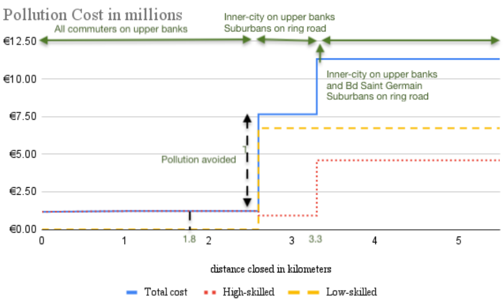
Time Cost



Pollution Cost



$\Rightarrow$ By closing **1.8-kilometers**: time cost is unchanged but pollution cost $\downarrow$ by 90%

Minimal mode switch for zero net pollution costs

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- Two potential scenarios:
  1. All commuters shift on local roads
  2. Suburban commuters shift on the ring road

Minimal mode switch for zero net pollution costs

◂ Back

- Two potential scenarios:
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- First Scenario: All commuters shift on local roads
  - Suburban commuters prefer local roads instead of ring road
  - Average speed on local roads should be > 35 km/h

Minimal mode switch for zero net pollution costs

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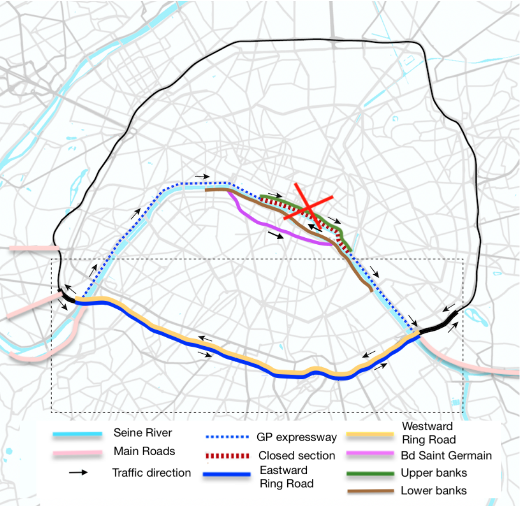
- ⋆ Two potential scenarios:
  1. All commuters shift on local roads
  2. Suburban commuters shift on the ring road

- ⋆ First Scenario: All commuters shift on local roads
  - Suburban commuters prefer local roads instead of ring road
  - Average speed on local roads should be > 35 km/h

  $\rightarrow$ Impossible to achieve!

- ⋆ Second Scenario: Suburban commuters on the ring road
  - 10% of suburban commuters need to drop their car
  - 50% of inner-city commuters need to drop their car

Potential impacts of a wider car-free area



- ⋆ The upper banks no longer belong to the set of substitute roads
- ⋆ *Boulevard Saint Germain* becomes the only road on which commuters can switch to
- ⋆ Density of cars ↑ by 34%, ↓ speed by 33.7%

⇒ Time cost of 60.5M and a pollution cost of 7M

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