Cycling Towards Cleaner Cities? Evidence from New York City's Bike Share Program

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The Economics of Air Pollution Workshop · Stockholm School of Economics

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Why do we care about air pollution?

- Air pollution is harmful
  - → In US: 100K–200K excess deaths annually (Tessum et al., 2019; Lelieveld et al., 2019)
  - → Other health impacts: chronic respiratory diseases (asthma, $50 billion/year (Nurmagambetov et al., 2018)), cardiovascular diseases, diabetes, size of newborns, (Guarnieri and Balmes, 2014; Rajagopalan and Brook, 2012; Ibald-Mulli et al., 2001)
  - → Decreases cognitive performance, productivity, alteration to decision-making (Lavy, et al., 2014; Hanna and Oliva, 2015; Shehab and Pope, 2019, Aguilar-Gomez et al., 2022)
  - → Worse in cities: individuals are more exposed (Carozzi and Roth, 2021; Strosnider et al., 2017)

Manhattan, ©Lerone Pieters

The potential of bike share

- Road transport is a major source of air pollution
  - → Most road vehicle are powered by internal-combustion engines and emit air pollutants
  - → Transportation emits 30% of local air pollutants in New York City (NYC) (Matte et al., 2013)
  - → Road transport is a interesting area to tackle for cities

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  - → Road transport is a interesting area to tackle for cities

- Bike share has the potential to substitute motor vehicle trips and reduce air pollution
  - → Riding a bike does not pollute...
  - → ... however, new cyclists might be substituting public transport and walking, not cars
  - → ... or bike share creates new trips previously not made, inducing no substitution

- The impact of bike share on air quality is uncertain

This paper

Research question

Does bike share reduce local air pollution?

This paper

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Does bike share reduce local air pollution?

- Evaluates the impact of bike share on local air pollution concentrations
  - → Using the gradual roll-out of NYC's bike share program as identification strategy
  - → Combined with ten years of high-resolution, ground-level measures of air pollution
  - → To estimate the causal impact of bike share using a staggered difference-in-differences (DD) analysis

Preview of results

- In bike share's area of influence:
  - → 13% reduction in nitric oxide (vs pre-treatment mean concentrations)
  - → 5% reduction in black carbon
  - → Back-of-the-envelope social benefits valued to up to $320 million

Preview of results

- In bike share's area of influence:
  - → 13% reduction in nitric oxide (vs pre-treatment mean concentrations)
  - → 5% reduction in black carbon
  - → Back-of-the-envelope social benefits valued to up to $320 million
- Does bike share reduce car traffic? Using taxi trips:
  - → Suggestive evidence of fewer short taxi trips in areas served by bike share

Contribution

Previous literature

- Air quality impacts of other urban transportation interventions: e.g. underground expansion, congestion tolls, electric vehicles (Gendron-Carrier et al., 2018; Green et al., 2020, Basagaña et al., 2018; Levy et al., 2018; De Borger et al., 2013; Kheirbek et al., 2016)

- Scarce causal evidence on the impacts of bike share on air quality (Shr et al., 2022; Wang and Zhou, 2017; Hamilton and Wichman, 2018)

Contribution

Previous literature

- Air quality impacts of other urban transportation interventions: e.g. underground expansion, congestion tolls, electric vehicles (Gendron-Carrier et al., 2018; Green et al., 2020, Basagaña et al., 2018; Levy et al., 2018; De Borger et al., 2013; Kheirbek et al., 2016)

- Scarce causal evidence on the impacts of bike share on air quality (Shr et al., 2022; Wang and Zhou, 2017; Hamilton and Wichman, 2018)

→ First paper to estimate the causal impact of bike share on air quality using high-resolution, ground-level measures of air pollution over ten years. Focusing a global city with the largest bike share program in North America.

Data

Air pollution I

- NYC Community Air Survey (NYCCAS), 2009–2019
  - → For 300-by-300 meters cells (units of analysis)
  - → Yearly annual average concentrations of six air pollutants
  - → Pollutant selection: associated with road traffic + measured close to emission source

Air pollution I

- NYC Community Air Survey (NYCCAS), 2009–2019
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  - → Yearly annual average concentrations of six air pollutants
  - → Pollutant selection: associated with road traffic + measured close to emission source

- Nitric oxide (NO) and nitrous dioxide (NO_2)
  - → Common marker of vehicular traffic
  - → 30% of emissions attributed to on-road traffic
  - → NO marker of fresh combustion emissions: steeper gradient near busy roadways

Air pollution II

- Particulate matter (PM 2.5) and black carbon (BC)
  - → Significant proportions of PM 2.5 from outside the city, but local variation likely due to local emissions
  - → 35% of PM emissions attributed to traffic in high-traffic locations
  - → BC is a subset of PM 2.5 (4–11% in US cities), but up to 75% of PM 2.5 from diesel exhaust

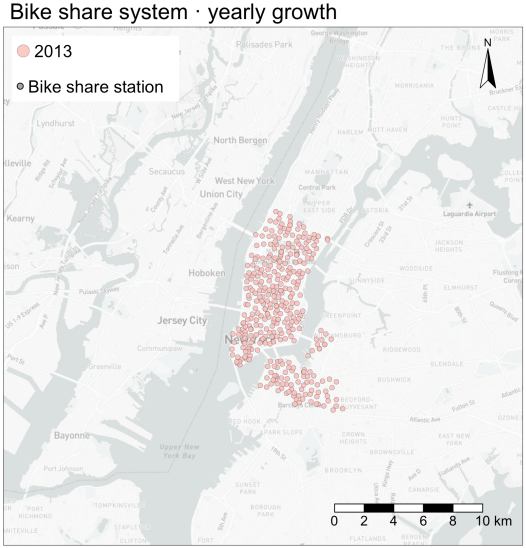
▸ NO concentrations 2013

Bike share system in NYC

- Opened in May 2013
- Fixed docking stations, 24/7
- Stations and bikes
  - → **2013** 332 stations, 6K bikes
  - → **2019** 780 stations, 13K bikes
- Average daily bike share trips
  - → **2013** 22K trips
  - → **2019** 56K trips (+154%)
  - → Vast majority of trips by annual subscribers

▸ Cycling statistics

Bike share system roll-out



Construction of treatment

- I construct a yearly spatial variable mapping the areas where motor vehicle trips most likely decreased due to bike share

- For each year:
  1. Identify pairs of bike share stations (i.e., at least one trip between the two stations)
  2. Compute optimal car route for each pair stations ▸ Routing
  3. Aggregate the routes at the cell level

  → Obtain the spatial extent of bike share's influence on car traffic

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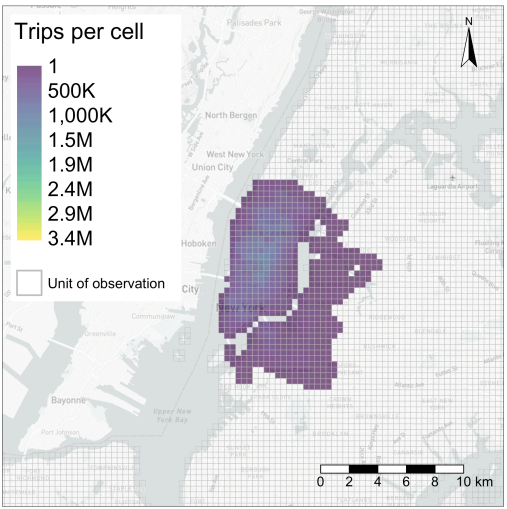
  → Obtain the spatial extent of bike share's influence on car traffic

- Captures the areas where we expect pollution to reduce after bike share

Bike share treatment



Estimation strategy and Results

Estimating equation

Staggered difference-in-differences: comparing cells treated by bicycle share with untreated ones, before and after the treatment (Two-Way Fixed Effects):

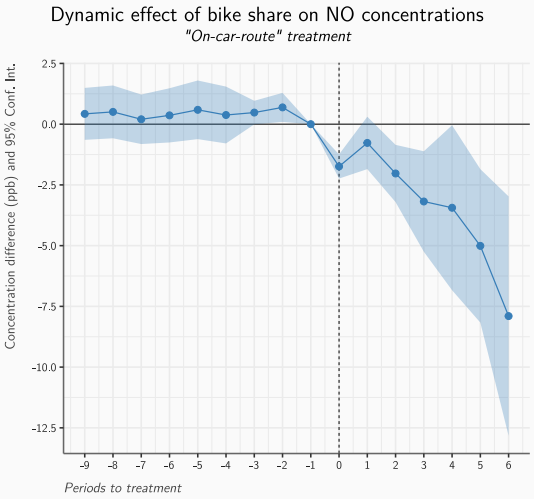
$$Y_{ct} = \beta Treat_{ct} + year_t + cell_c + \boldsymbol{C}_{ct} + \varepsilon_{ct}, \tag{1}$$

for cell c at year t

- Y_{ct}: a pollutant's concentration
- $Treat_{ct}$: one of the treatment definition
- $year_t + cell_c$: year and cell fixed effects
- $\boldsymbol{C}_{ct}$: vector of control variables

Standard errors clustered at the community district level (neighbourhood) ▸ Estimation parameters

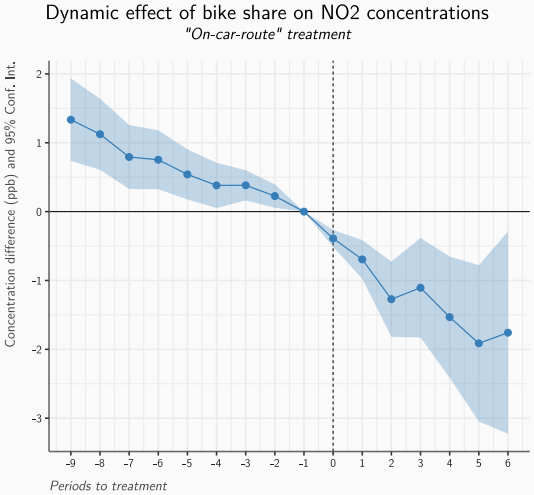
Nitric Oxide



	NO	
	(1)	(2)
On-car-route	-2.5360***	-2.7281***
	(0.8595)	(0.8543)
Baseline controls		✓
Cell FE	✓	✓
Year FE	✓	✓
Mean concentration pre-treat.	20.322	20.353
% mean concentration pre-treat.	-12.479	-13.404
Observations	91,710	90,898
R^2	0.906	0.908
Within R^2	0.049	0.066

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

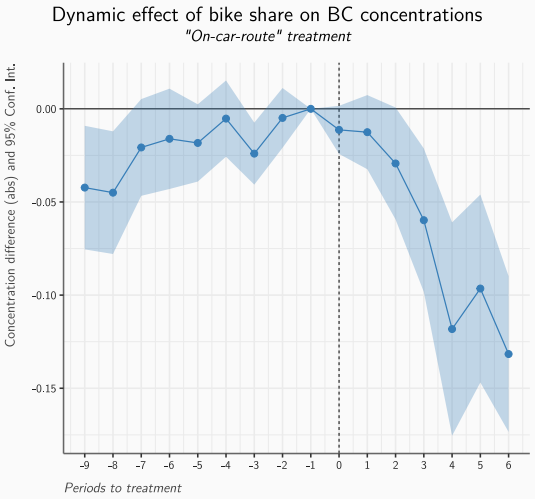
Nitrogen Dioxide



	NO2	
	(1)	(2)
On-car-route	-1.1489***	-1.2554***
	(0.2771)	(0.2759)
Baseline controls		✓
Cell FE	✓	✓
Year FE	✓	✓
Mean concentration pre-treat.	19.950	20.007
% mean concentration pre-treat.	-5.759	-6.275
Observations	91,710	90,898
R^2	0.978	0.979
Within R^2	0.081	0.123

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

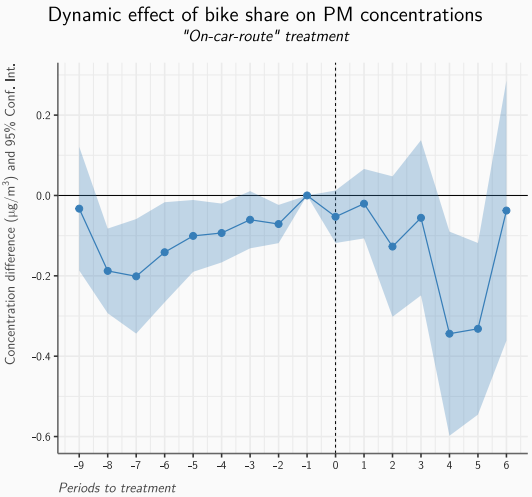
Black Carbon



	BC	
	(1)	(2)
On-car-route	-0.0253*	-0.0280**
	(0.0128)	(0.0129)
Baseline controls		✓
Cell FE	✓	✓
Year FE	✓	✓
Mean concentration pre-treat.	1.015	1.017
% mean concentration pre-treat.	-2.494	-2.757
Observations	91,710	90,898
R^2	0.956	0.956
Within R^2	0.006	0.011

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

PM 2.5



	PM	
	(1)	(2)
On-car-route	-0.0097	-0.0320
	(0.0686)	(0.0688)
Baseline controls		✓
Cell FE	✓	✓
Year FE	✓	✓
Mean concentration pre-treat.	9.433	9.441
% mean concentration pre-treat.	-0.103	-0.339
Observations	91,710	90,898
R^2	0.978	0.979
Within R^2	0.000	0.018

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Results discussion

- Contrast with Shr et al. 2022 who find no effect of bike share on nitric oxides concentrations after one year
- Back-of-the-envelope valuation of social benefits from reduction in NO concentrations
  → up to $327 million ▸ Valuation
- Robustness checks
  → Alternative treatment definitions ▸ Service area ▸ Stations
  → Intensity of treatment ▸ NO ▸ NO2 ▸ BC ▸ PM
  → Borusyak, Jaravel and Spiess (2022) estimator robust to variation in treatment timing and heterogenous treatment effects ▸ Plots

Mechanism

Taxis in NYC

- Taxis are a popular transport mode in NYC. In 2014:
  - → 485K trips/day, 55% of trips < 3km, average price $4/km
  - → 70% of passengers $\leqslant$35 years old, 55% male
  - → In Midtown, >50% of all vehicles are taxis

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  - → 70% of passengers ⩽35 years old, 55% male
  - → In Midtown, >50% of all vehicles are taxis

- Bike share trips are comparable to many taxi trips
  - → Most trips are less than 3km
  - → Median age is 33 years old, 70% male

▸ Midtown taxi vs bike share

Testing the substitution mechanism

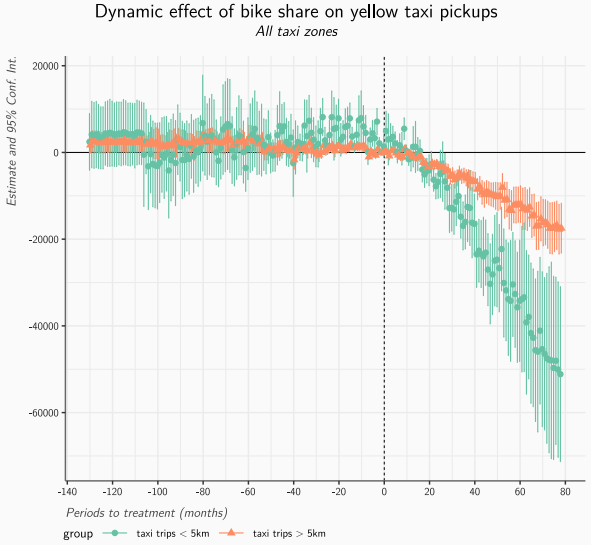
- Previous research
  - → Taxis are a good approximation of motor traffic in general (Castro et al., 2012; Peng et al., 2016)
  - → Taxis ridership increases when bike share stations go out of service in NYC (Molnar and Ratsimbazafy, 2017)

Testing the substitution mechanism

- Previous research
  - → Taxis are a good approximation of motor traffic in general (Castro et al., 2012; Peng et al., 2016)
  - → Taxis ridership increases when bike share stations go out of service in NYC (Molnar and Ratsimbazafy, 2017)

- This paper
  - → Use the universe of NYC taxi trips: geolocated, timestamped, measure of distance
  - → Identify most substitutable taxi trips
    - 85% of bike share trips are less than 5km
    - distinguish short (<5km) taxi trips from long (>5km) ones
  - → Same identification strategy: does the staggered roll-out of bike share reduce short taxi trips?

Mechanism · results



Conclusion

This paper

- Estimated the causal impacts of bike-share on air quality in NYC from 2013 to 2019
- Found that bike-share decreased the concentrations of NO by up to 13.4% and BC by up to 2.7% compared to average concentrations before bike share
  - $\rightarrow$ Avoided social damages valued at up to $327 million dollars
- Shed light on the substitution mechanism by showing that short taxi trips decreased faster in bike share areas after the arrival of bike share compared to long taxi trips

Thank you

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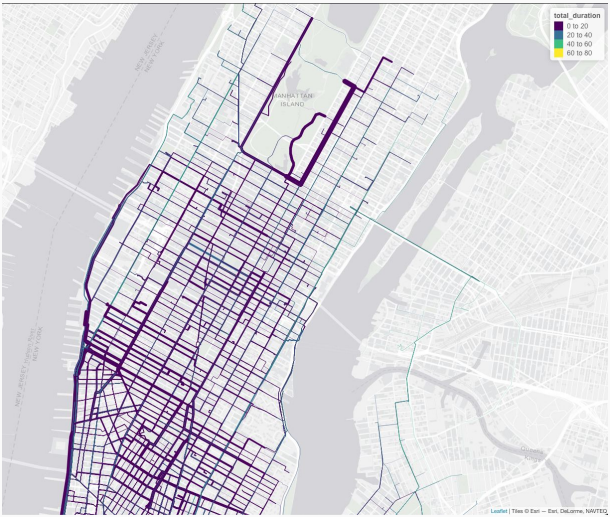
Routing illustration



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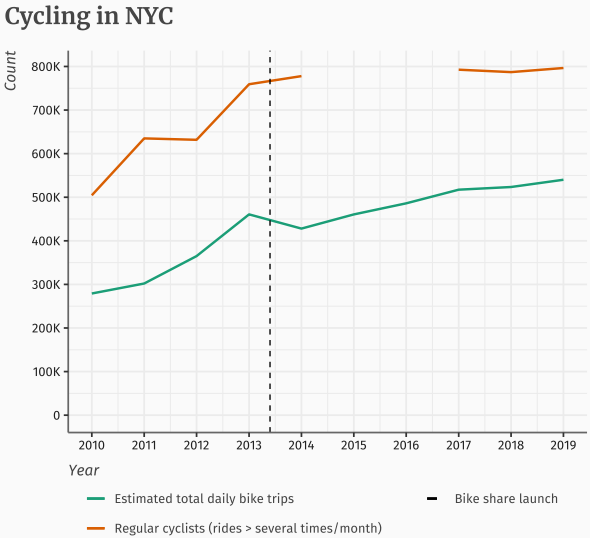
Cycling in NYC

- NYC DOT Mobility Survey: daily bike trips estimates
  - → **2010** 280K trips
  - → **2019** 520K trips (+85%)
- NYC Community Health Survey: rides at least several times a month
  - → **2010** 504K cyclists
  - → **2019** 793K cyclists (+57%)



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NYC Cycling growth compared to peer cities

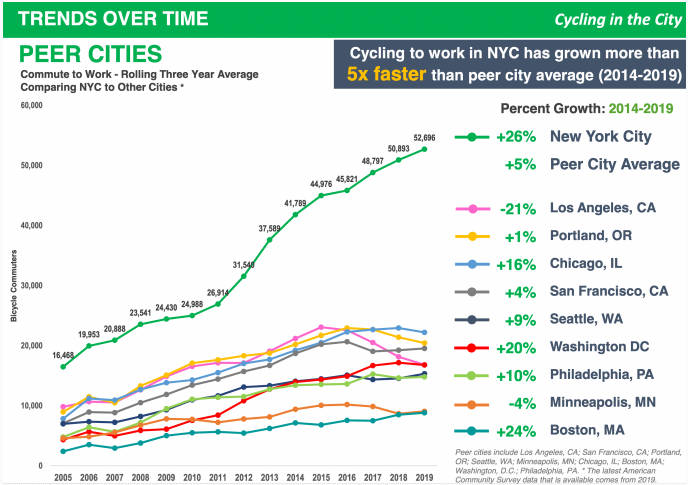

Figure 1: Cycling in the City Report, 2020, NYC DOT

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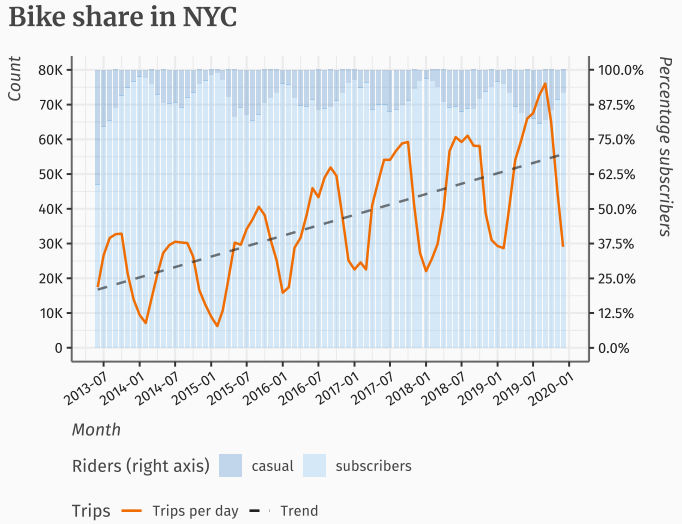
Bike share statistics

- Stations and bikes
  - → **2013** 332 stations, 6K bikes
  - → **2019** 780 stations, 13K bikes
- Average daily bike share trips
  - → **2013** 22K trips
  - → **2019** 56K trips (+154%)
- Seasonal variation
- Mostly subscribers, especially in winter



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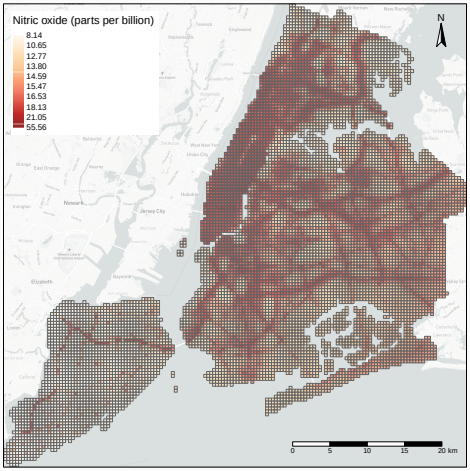
Mapping air pollution · nitric oxide (NO) 2013

2013



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NYCCAS details

Concentrations of PM 2.5, black carbon, nitrogen oxides (NO and NO^2), sulfur dioxide (SO^2) and ozone (O^3)

- 150 measurement stations: 120 randomly placed, 30 at purposeful sites
- Overlays a grid over the city made up of square cells 300m wide
- For each cell, estimates the annual average concentration of pollutant using a land-use regression (LUR) model

Land-use regression (LUR) model:

$$Concentration_{it} = \beta_0 + \beta_1 RefStation_{it} + \beta_2 Source1_i + \beta_3 Source2_i + \beta_3 Source1_i \times SiteCharac_{it} + \varepsilon_{it}$$

Back

Estimation parameters

- Panel dataset
  - → **units** grid cells (9,171)
  - → **time** years (10, 2010–2019)
  - → **treatment** cell treated by bike share: within "traffic footprint" of bike share

- Covariates
  - → population (American Community Survey, ACS)
  - → fraction of college graduates (ACS)
  - → household income (ACS)
  - → meters of bicycle lanes (NYC Department of Transportation)
  - → built surface (NYC Department of City Planning)

▸ Back

Social benefits valuation

- Are the results economically significant?
- Concentration-response function from the epidemiology literature between NO and
  - → mortality
  - → asthma related emergency department (ED) visits and hospitalisations
- Bike share saved up to 33 deaths, 1,122 ED visits and 412 hospitalisations
- Avoided social damages valued at up to \$327 million ($\$320 + \$1.2 + \$6.2$)
- Does not take into account other outcome or other pollutants
  - → likely a lower bound

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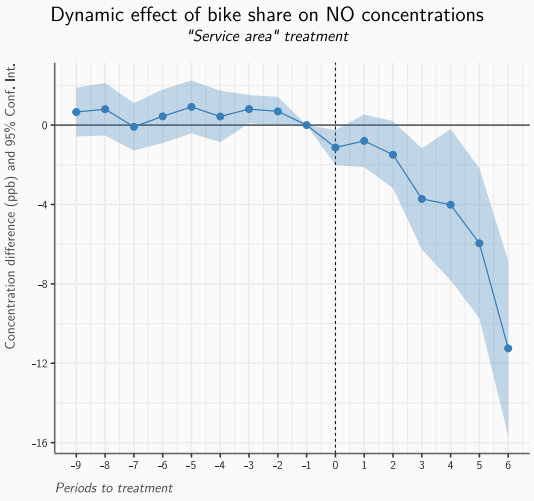
Nitric Oxide · Service area



	NO		
	(1)	(2)	(3)
Convex polygon	-2.7534**	-0.1855	-0.3325
	(1.0736)	(0.6438)	(0.5012)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	20.353	20.353	20.353
% mean concentration pre-treat.	-13.528	-0.911	-1.633
Observations	90,898	90,898	90,898
R^2	0.907	0.959	0.936
Within R^2	0.058	0.008	0.008

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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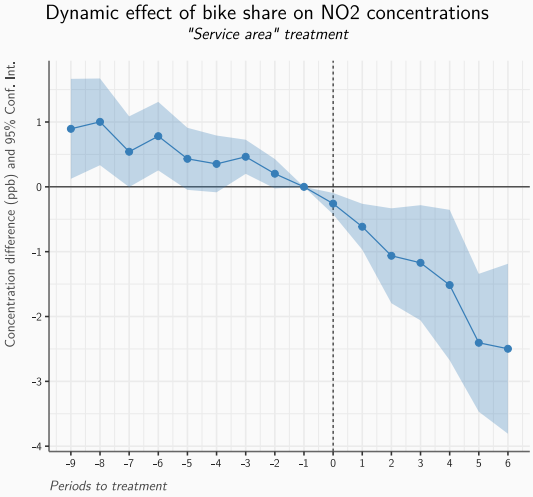
Nitrogen Dioxide · Service area

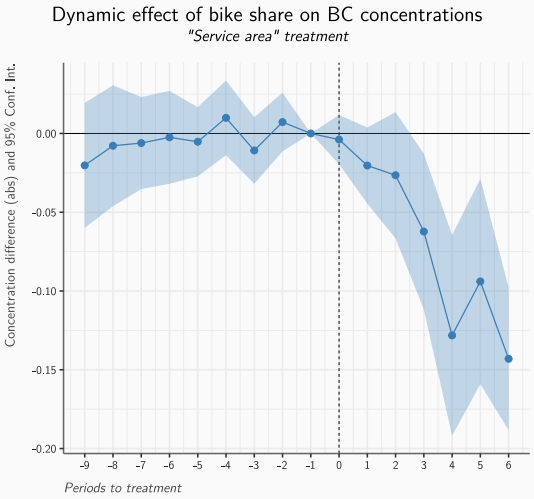


	NO2		
	(1)	(2)	(3)
Convex polygon	-1.1882***	0.0989	-0.2136
	(0.3380)	(0.1864)	(0.2059)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	20.007	20.007	20.007
% mean concentration pre-treat.	-5.939	0.494	-1.067
Observations	90,898	90,898	90,898
R^2	0.979	0.994	0.985
Within R^2	0.100	0.010	0.016

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

▸ Back

Black carbon · Service area

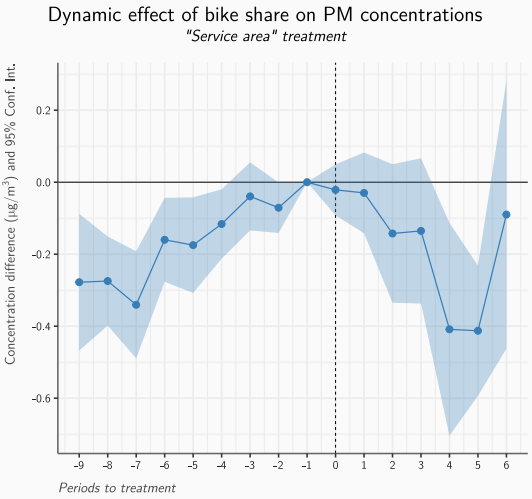


	BC		
	(1)	(2)	(3)
Convex polygon	-0.0379**	-0.0170***	-0.0167*
	(0.0143)	(0.0051)	(0.0093)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	1.017	1.017	1.017
% mean concentration pre-treat.	-3.729	-1.669	-1.638
Observations	90,898	90,898	90,898
R^2	0.957	0.979	0.970
Within R^2	0.015	0.002	0.004

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

▸ Back

PM 2.5 · Service area



	PM		
	(1)	(2)	(3)
Convex polygon	-0.0353	0.0399	0.0748
	(0.0802)	(0.0378)	(0.0535)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	9.441	9.441	9.441
% mean concentration pre-treat.	-0.374	0.423	0.792
Observations	90,898	90,898	90,898
R^2	0.979	0.992	0.984
Within R^2	0.018	0.004	0.018

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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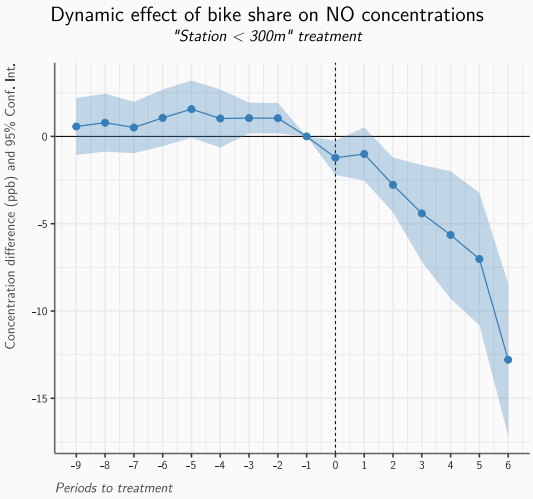
Nitric Oxide · Stations



	NO		
	(1)	(2)	(3)
Station	-3.8915***	-2.1059***	-1.5368***
	(1.1872)	(0.5868)	(0.5721)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	20.353	20.353	20.353
% mean concentration pre-treat.	-19.120	-10.347	-7.551
Observations	90,898	90,898	90,898
R^2	0.910	0.960	0.937
Within R^2	0.089	0.028	0.021

Clustered (Community district) standard-errors in parentheses
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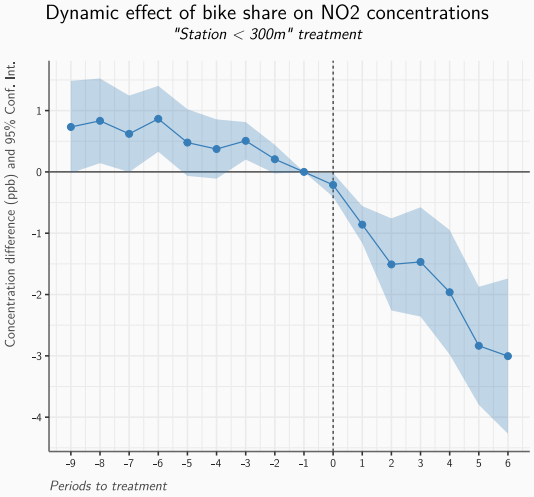
Back

Nitrogen Dioxide · Stations

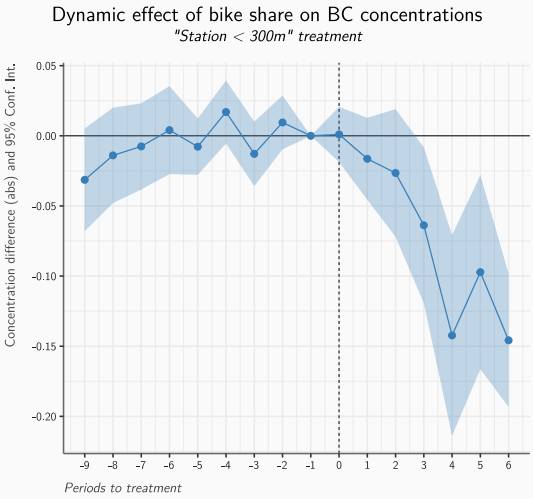


	NO2		
	(1)	(2)	(3)
Station	-1.4994***	-0.4007***	-0.5309***
	(0.3277)	(0.1384)	(0.1807)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	20.007	20.007	20.007
% mean concentration pre-treat.	-7.494	-2.003	-2.654
Observations	90,898	90,898	90,898
R^2	0.979	0.994	0.985
Within R^2	0.122	0.018	0.028

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Back

Black carbon · Stations



	BC		
	(1)	(2)	(3)
Station	-0.0404**	-0.0170*	-0.0153
	(0.0162)	(0.0098)	(0.0093)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	1.017	1.017	1.017
% mean concentration pre-treat.	-3.978	-1.668	-1.506
Observations	90,898	90,898	90,898
R^2	0.957	0.979	0.970
Within R^2	0.015	0.002	0.003

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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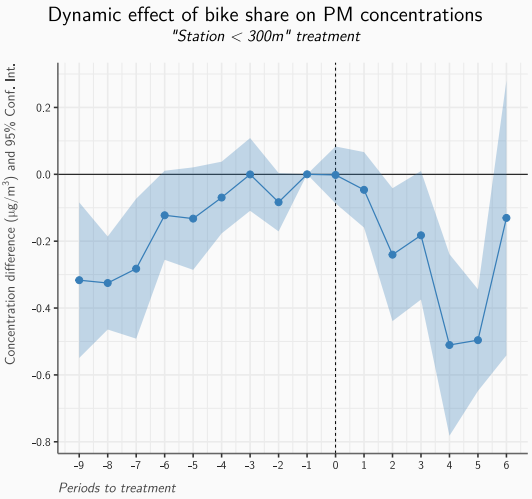
PM 2.5 · Stations



	PM		
	(1)	(2)	(3)
Station	-0.1002	-0.0942**	0.0090
	(0.0788)	(0.0419)	(0.0514)
Baseline controls	✓	✓	✓
Cell FE	✓	✓	✓
Year FE	✓	✓	✓
Year-Community district FE		✓	
Year-Borough FE			✓
Mean concentration pre-treat.	9.441	9.441	9.441
% mean concentration pre-treat.	-1.061	-0.997	0.095
Observations	90,898	90,898	90,898
R^2	0.979	0.992	0.983
Within R^2	0.022	0.007	0.014

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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ATT · Nitric Oxide

	NO			
	(1)	(2)	(3)	(4)
Trips (10K)	-0.0839***		-0.0860***	
	(0.0115)		(0.0114)	
Trips (IHS)		-0.2758***		-0.2947***
		(0.0850)		(0.0845)
Baseline controls			✓	✓
Cell FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Mean concentration pre-treat.	20.322	20.322	20.353	20.353
% mean concentration pre-treat.	-0.413	-1.357	-0.423	-1.448
Observations	91,710	91,710	90,898	90,898
R^2	0.927	0.909	0.929	0.911
Within R^2	0.257	0.077	0.279	0.097

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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ATT · Nitric Dioxide

	NO2			
	(1)	(2)	(3)	(4)
Trips (10K)	-0.0253***		-0.0263***	
	(0.0034)		(0.0033)	
Trips (IHS)		-0.1119***		-0.1218***
		(0.0256)		(0.0254)
Baseline controls			✓	✓
Cell FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Mean concentration pre-treat.	19.950	19.950	20.007	20.007
% mean concentration pre-treat.	-0.127	-0.561	-0.131	-0.609
Observations	91,710	91,710	90,898	90,898
R^2	0.981	0.979	0.982	0.980
Within R^2	0.188	0.103	0.231	0.147

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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ATT · Black Carbon

	BC			
	(1)	(2)	(3)	(4)
Trips (10K)	-0.0010***		-0.0010***	
	(0.0002)		(0.0002)	
Trips (IHS)		-0.0032***		-0.0035***
		(0.0012)		(0.0012)
Baseline controls			✓	✓
Cell FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Mean concentration pre-treat.	1.015	1.015	1.017	1.017
% mean concentration pre-treat.	-0.097	-0.316	-0.100	-0.342
Observations	91,710	91,710	90,898	90,898
R^2	0.958	0.957	0.958	0.957
Within R^2	0.046	0.014	0.052	0.019

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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ATT · PM 2.5

	PM			
	(1)	(2)	(3)	(4)
Trips (10K)	-0.0031***		-0.0033***	
	(0.0011)		(0.0011)	
Trips (IHS)		-0.0036		-0.0057
		(0.0067)		(0.0067)
Baseline controls			✓	✓
Cell FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Mean concentration pre-treat.	9.433	9.433	9.441	9.441
% mean concentration pre-treat.	-0.033	-0.038	-0.035	-0.060
Observations	91,710	91,710	90,898	90,898
R^2	0.979	0.978	0.979	0.979
Within R^2	0.033	0.001	0.055	0.020

Clustered (Community district) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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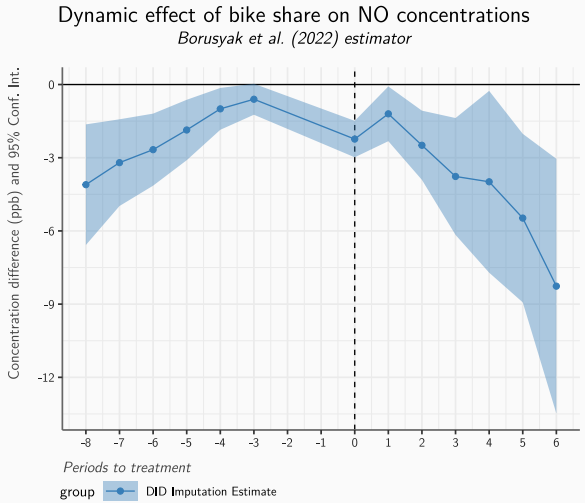
NO · Borusyak, Jaravel & Spiess estimator



Note: "On-car-route" treatment definition

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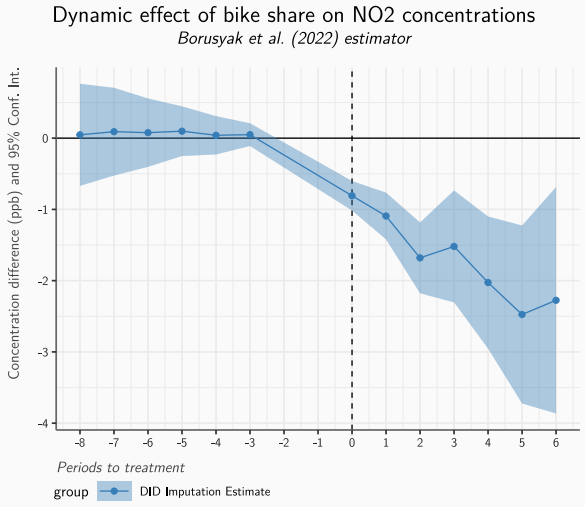
NO2 · Borusyak, Jaravel & Spiess estimator



Note: "On-car-route" treatment definition

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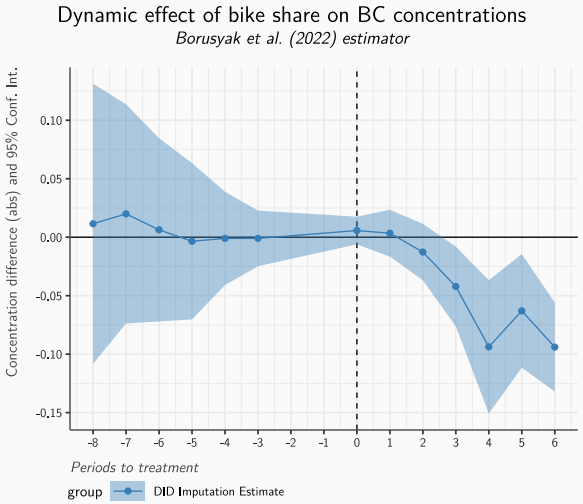
BC · Borusyak, Jaravel & Spiess estimator



Note: "On-car-route" treatment definition

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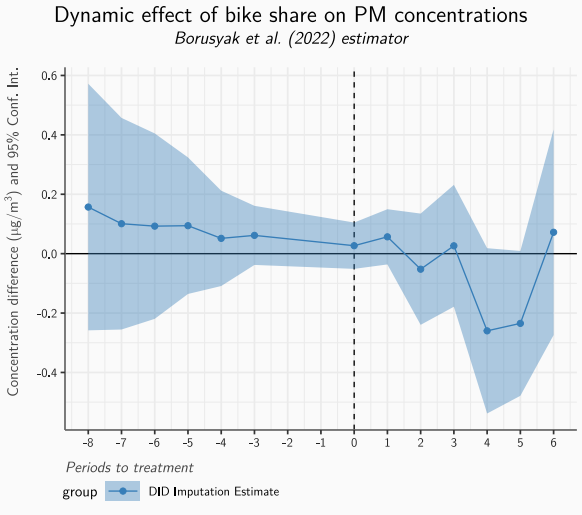
PM · Borusyak, Jaravel & Spiess estimator



Note: "On-car-route" treatment definition

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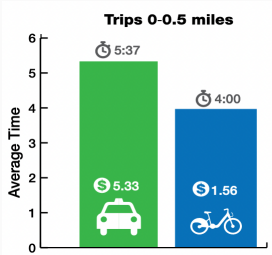
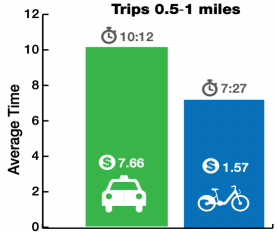
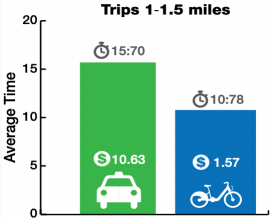
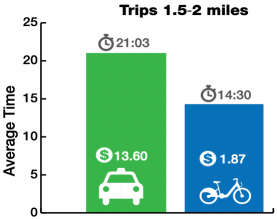
NYC 2019 Mobility Report









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