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Bike-Share Programs and Cleaner Air: Insights from New York City

Balancing urbanization and clean air: a policy dilemma

In an era of rapid urbanization, air quality in cities stands as one of the foremost challenges for policymakers. As our world becomes increasingly urbanized, more and more of the global population is exposed to the detrimental effects of air pollution. The consequences are profound: from an array of health issues to substantial medical costs, reduced cognitive performance, higher crime rates, and diminished overall productivity. And the bigger and more dense cities are, the more exposed their inhabitants are to air pollution (Carozzi and Roth 2023).

However, urban density brings with it a host of benefits, such as agglomeration economies, the creation of larger labour and consumer markets, and smaller per capita carbon footprints. Cities therefore face a dilemma between urbanization and air pollution: how do they maximize the benefits of density while minimizing its associated costs?

The consequences of poor air quality are indeed substantial. Epidemiological studies have estimated that excessive air pollution leads to between 100,000 and 200,000 excess deaths each year in the United States (Burnett et al. 2018), and generates considerable medical costs. For instance, the impact of low air quality on asthma crises alone is estimated to cost up to $135 million per year in emergency room visits (Anenberg et al. 2018; Qin, Zahran, and Malilay 2021).

Furthermore, research has shown that air pollution has negative effects on non-medical outcomes, including lower cognitive performance, increased crime rates, reduced labour supply and productivity, and diminished decision-making abilities, all of which negatively affect overall output (Aguilar-Gomez et al. 2022; Klingen and van Ommeren 2021).

The conclusions from this extensive body of research are unambiguous, highlighting the substantial potential gains associated with cleaner air in cities. Policymakers have taken notice, and in recent decades, cities around the world have implemented an array of policies aimed at curbing emissions of air pollutants.

Can cycling policies improve air quality?

With road transportation accounting for up to 40% of air pollution emissions in urban areas (EEA 2021), a significant share of these policies targets individual motor vehicles. These policies can be broadly categorized into two types: those that increase the cost of driving vehicles using polluting fuels, and those that decrease the cost of using alternative, less polluting modes of transportation.

The first type of policies includes low-emissions zones (restricting the entry of vehicles into the city based on emission levels), congestion pricing (where vehicles pay to enter densely populated urban areas), and road closures (reducing road supply, increasing travel times, and making driving a less attractive option). The second approach is about enhancing the attractiveness of sustainable modes of transport, which includes the development of public transport, bike-to-work schemes, and cycling and pedestrian infrastructure.

While the impact of the first set of measures on air pollution has been extensively studied, showing, in general, positive effects on air quality when the cost of driving is increased, policies aimed at encouraging the use of less-polluting modes of transport have received less attention. In particular, the potential of cycling policies and infrastructure to improve air quality has not yet been empirically tested, despite their high theoretical potential.

Cycling enables medium-distance trips with moderate physical effort, and in high-congestion circumstances, it can sometimes be faster than private vehicles, all while emitting virtually no pollution. In a recent study, Leroutier and Quirion (2022) demonstrated that up to 40% of all car trips in the Paris metropolitan area could realistically be shifted to e-bikes. Consequently, incentivizing cycling might induce mode substitution away from polluting vehicles towards cycling, reducing air pollution emissions. However, this hypothesis has not yet been rigorously tested using observational data and methods that ensure which part of the measured change can be attributed to the cycling policy. Indeed, it is not straightforward to disentangle the causes of air pollution reduction and be certain they are not due to other factors such as improvements in fuel efficiency, for example.

Econometric techniques, such as difference-in-differences, help us overcome these challenges and uncover the causal links between a policy intervention and its impacts. I present this method and its results in the next two sections, before turning my attention to the economic magnitude of the effects detected, and how they translate into real-world benefits.

What is bike-share?

Bike-sharing systems consist of a pool of public bicycles that can be rented for short periods of time within a city. While their origins date back to the 1970s and Amsterdam's *White Bikes*, modern computerised bike-share systems were pioneered in France at the start of the 20th century (1998 in Rennes, 2005 in Lyon and 2007 in Paris). Most of the first bike-share systems are based on a network of fixed docking stations, where bicycles can be picked up and returned, but many schemes are free-floating, where bicycles may be parked anywhere within a pre-defined service area. Bike-share systems have become a ubiquitous sight in cities around the globe: recent estimates by (Meddin et al. 2022) put the number of active schemes at over two thousand worldwide. Importantly, these systems are popular and growing: the North American Bikeshare and Scootershare Association reported 80 million trips taken on bike-share systems in North America in 2022, up from 60 million in 2019.

Cycling in New York City

With its wide avenues and unpredictable taxi drivers, New York City is not known to be a cycling-friendly city. Despite this image, the city has been massively investing in cycling infrastructure in the past decade. The focus of this paper, New York City's Citi Bike bike-share system, was opened in May 2013. Originally covering the south of Manhattan and nearby parts of Brooklyn, it was gradually expanded to entirely cover the island of Manhattan and serve substantial areas of Brooklyn, the Bronx and Queens. The system started with 332 stations and an average of 22 thousand daily trips in 2013; these numbers increased to 780 stations and 56 thousand average daily trips in 2019. In parallel, the network of cycle paths has been greatly developed, with 290 kilometres of protected cycle paths built since 2014. These measures appear to have increased the number of people cycling: yearly mobility surveys from New York City's Department of Transportation show that 500 thousand people reported cycling regularly in 2010, versus 800 in 2019. *Figure 1* shows a bike-share station in operation in New York City.

Figure 1: A bike-share station in New York City, with docks, bicycles, and a payment booth.

How to measure the impact of bike-share on air quality?

There are several challenges associated with estimating the causal effect of cycling on air quality. First, the intervention needs to be clearly defined in time and space. The New York City bike-share program, which relies on a network of fixed stations, offers an ideal scenario for this kind of analysis. The locations of these stations define the areas of the city accessible by bike-share. Importantly, this network has expanded over time since its initial launch in 2013. The successive roll-out allows me to precisely identify, for each year, the geographical areas of the city that were impacted by the bike-share program. I identify these areas by utilizing detailed records of every bike-share trip since the system's inception in 2013.

Each bike-share trip reports the origin and destination stations, enabling me to pinpoint the station pairs that exchanged at least one bicycle in a given year. I then compute, for each pair of origin-destination stations identified, the optimal route a car would have taken to complete the same trip (see *Figure 2*). The underlying idea is that if air pollution concentrations decreased, it must have occurred in areas where fewer cars were likely driven – that is, on the routes that cars would have taken to complete trips now made by bike-share.

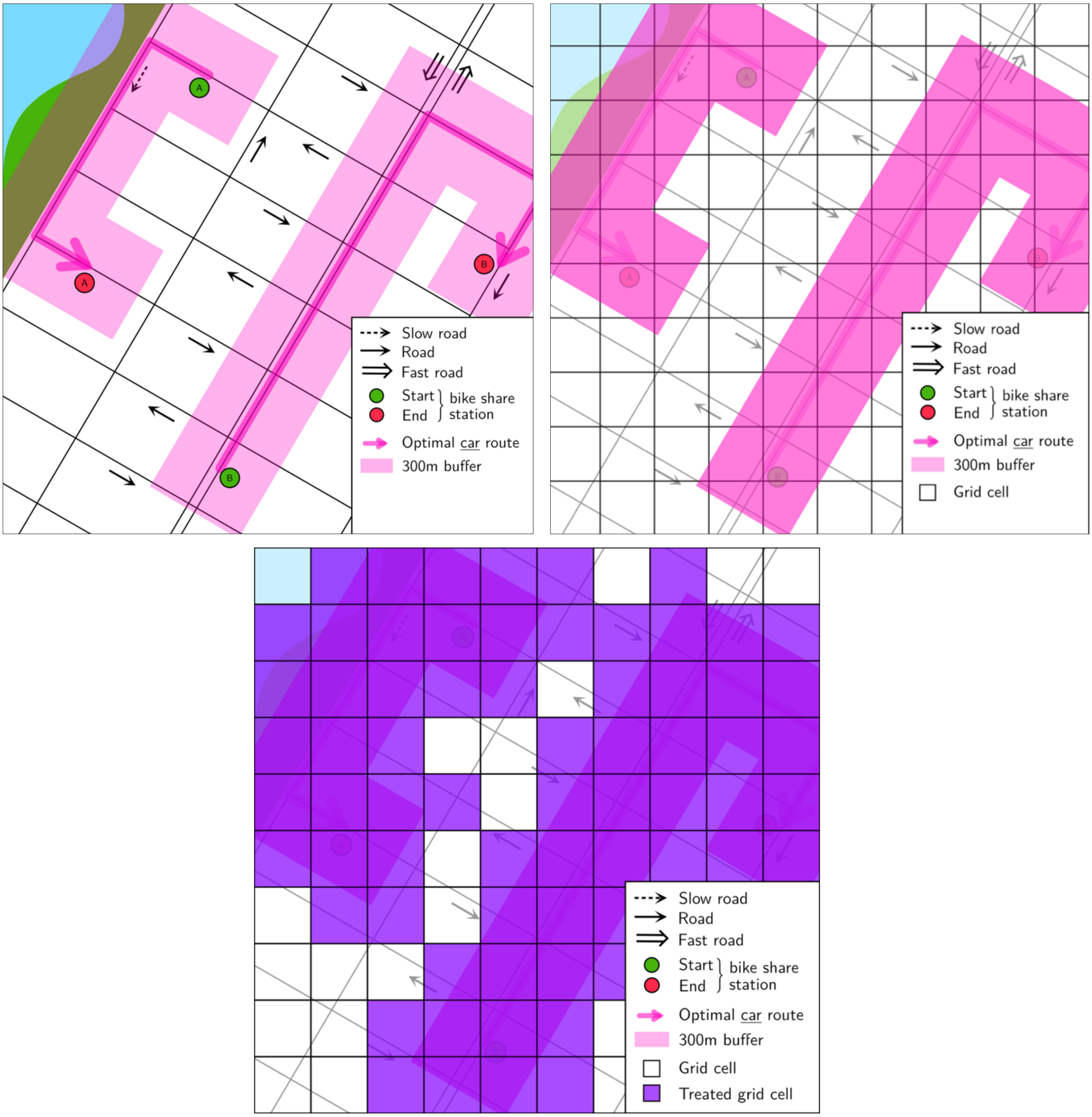

Figure 2: Treatment construction illustration: bike-share trips and car routes.

Notes: In this illustration with toy data, there are two bike-share trips (A and B) taken between two pairs of stations (start station in green and arrival station in red). The pink arrows represent the optimal car route between the pair of start and end station would the bike-share trip have been done by car. The pink area represents the area where air pollution is expected to be affected by the car trip. The unit of observation of the analysis is the 300-by-300-metre cell given by the air pollution data set. After computing the hypothetical optimal car routes between pairs of bike-share station, the spatial extent of the area of influence of car routes is transferred to the grid cells: the cells that overlap the affected area are considered treated.

The second challenge in our analysis is to find a measure of air quality with good temporal and geographic coverage and high spatial resolution. Inadequate resolution would hinder my ability to measure the localized effects of air pollution, which can vary significantly over short distances for certain pollutants. To overcome this challenge, I combine the geographic impact of bike-share data with high-resolution air pollution maps that have been available since 2009 through the New York City Community Air Survey.

These air pollution maps report the yearly concentrations of six air pollutants for over nine thousand cells, each measuring 300m by 300m, effectively covering the entire city. Thanks to their high spatial resolution, I can assign each cell of the air quality maps with a measure of bike-share activity for a given year. This enables me to identify the cells where we would expect car traffic to have decreased due to the presence of bike-share (see *Figure 3*).

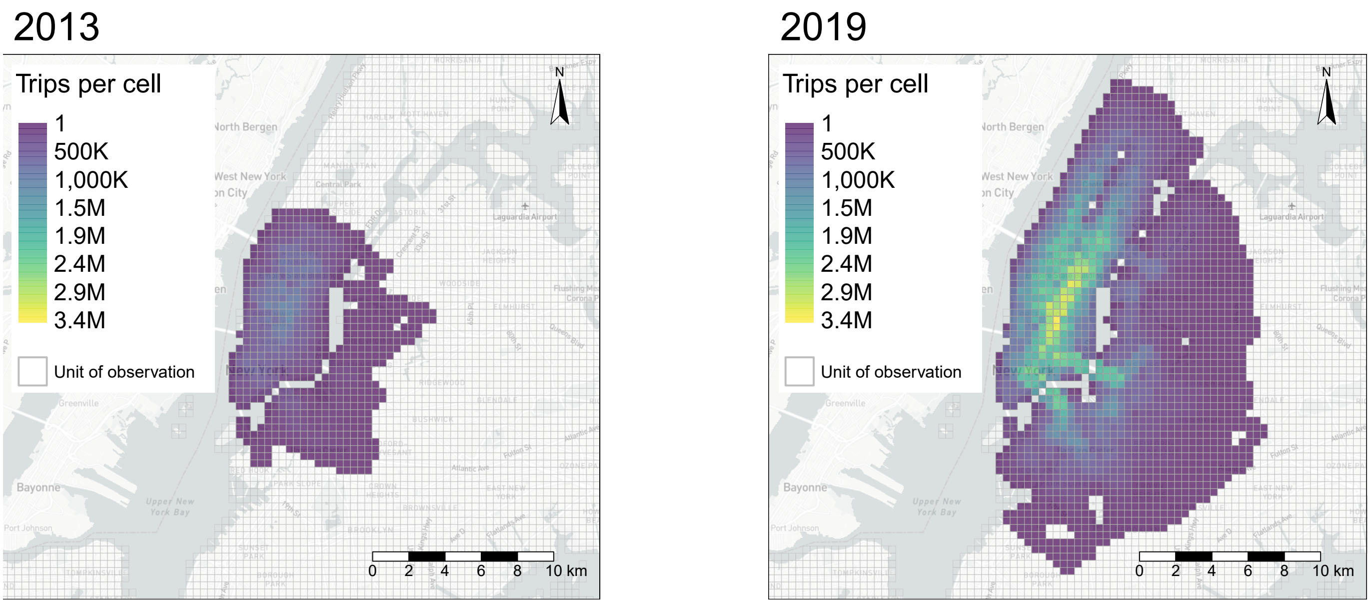

Figure 3: Spatial extent of treatment and imputed trips per cell at bike-share implementation and last study period.

In order to evaluate the causal impact of a policy like the New York City bike-share scheme, difference-in-differences models have classically been used. In a nutshell, difference-in-differences defines a treatment group (i.e., individuals or areas subject to the policy) and a control group (outside the reach of the policy), and compares these groups before and after the onset of the intervention. By doing so, difference-in-differences removes any time trend in the outcome variable common to both groups, and isolates the effect of the intervention on the treated group.

In this study, I conduct a difference-in-differences analysis with staggered timing using a balanced panel of 300m by 300m cells as the units of observation. The outcome variable is the concentration of a given air pollutant in a given year, and the treatment variable is defined as whether the cell is crossed by a hypothetical car route between a pair of bike-share stations that exchanged at least one bicycle in a given year. Essentially, this strategy compares air pollution concentrations in cells where car traffic is most likely affected by bike-share with cells that are not likely to be impacted, both before and after the deployment and expansion of the bike-share program. In addition, I also control for socio-demographic characteristics and the length of bike paths in each cell, which can have an impact on mode choices and bike-share usage.

Did bike-share reduce air pollution concentrations? What is the magnitude of the change?

The results indicate that the concentrations of nitric oxide, a common marker of vehicular traffic, and black carbon, which is associated with diesel engines, decreased by 13% and 3% respectively compared to pre-bike-share mean concentrations in areas where fewer cars were expected to be driven after the implementation of the bike-share program.

As previously mentioned, air pollution has been linked to a host of health issues and increased mortality. To gain a sense of the economic magnitude of these effects and how they translate into real-world benefits, I combine the results from the econometric analysis with health data and the costs of medical outcomes to perform a back-of-the-envelope monetary valuation. This allows me to estimate the value of the improvements in air quality attributable to the bike-share program in monetary terms.

Epidemiological research has provided us with concentration-response functions, which are estimates of how health outcomes, such as mortality, react to changes in air pollution concentrations. Using concentration-response functions on mortality, emergency department visits, and hospitalizations from studies by Meng et al. (2021) and Zheng et al. (2015), I find that the decrease in nitric oxide concentrations attributable to the bike-share program saved 33 lives, prevented 1,122 emergency department visits, and reduced hospitalizations by 412 cases in areas where fewer cars were driven due to bike-share.

To translate these numbers into monetary terms, I rely on the Environmental Protection Agency's value of statistical life and data from Blewett et al. (2021) for the average cost of emergency department visits and hospitalizations. When multiplying the number of saved lives, visits, and hospitalizations by their respective costs, I find that the deployment of the bike-share program in New York City since 2013 has saved a total of $327 million thanks to the reduction in nitric oxide concentrations it caused.

Is there concrete evidence the bike-share program reduced motor traffic? Evidence from taxi trip records

An important question arises when considering these findings: does concrete evidence exist that the bike-share program has genuinely reduced car traffic, the primary mechanism hypothesized to explain the decrease in air pollution? Answering this question would considerably strengthen the evidence that bike-share programs lead to an improvement in air quality, and provide policymakers with more precise tools to design effective interventions.

To answer this question, I look to the taxi service in New York City. Taxis share several key characteristics with bike-share, making them prime candidates for substitution: the average trip distance is similar (the majority of both taxi and bike-share trips are less than 3 kilometres), rider demographics are comparable (with a median age of around 35 years old), and the areas where bike-share has been implemented display high taxi usage. The New York City Department of Transportation has collected high-quality data on all taxi trips within its jurisdiction since 2009, enabling a very accurate analysis of taxi trips at a fine geographical scale.

I combine these data with bike-share expansion data to investigate whether bike-share reduced the number of taxi pick-ups in areas where it was implemented. To draw meaningful conclusions, I distinguish between short and long taxi trips, classifying them as less than or more than 5 kilometres, respectively. The rationale here is that short taxi trips are most likely to have been substituted by bike-share, given that more than 80% of bike-share trips are less than 5 kilometres. In contrast, long taxi trips should remain largely unaffected by the implementation of bike-share, as they serve a different purpose.

In an event study analysis, I find that short taxi trips decreased faster than long taxi trips in areas where bike-share was implemented. This result offers suggestive evidence that bike-share induces some substitution away from taxi service, reducing car traffic and providing a plausible mechanism for the reduction in air pollution concentrations.

How to measure the impact of bike-share on air quality?

The policy implications drawn from this study are significant, underscoring the importance of policies that encourage mode substitution from polluting vehicles to sustainable transport options. To maximize the benefits of cycling initiatives, policymakers should focus on designing interventions that realize the potential of cycling to substitute for motor vehicles.

The findings from Leroutier and Quirion (2022), showing that up to 40% of all commuting trips in the Paris metropolitan area could realistically be substituted by e-bikes, demonstrate the high potential of cycling to reduce air pollution. The key is to design interventions that can unlock this potential. In the case of New York City, the fact that bike-share is faster and more cost-effective than taxi service during rush hours in busy neighbourhoods seems to have played a significant role in encouraging taxi passengers to switch to bike-share. Designing policies that ensure that cycling can compete with motor vehicles on trips within cities is the first key step to realise that potential.

Additionally, sustainable modes of transport can gain a competitive edge when polluting alternatives are made less attractive. Policies like road closures, congestion pricing, and urban tolls can enhance the relative appeal of sustainable modes of transport. However, it is important to note that the implementation of these policies may present its own set of challenges, especially concerning the distribution of benefits and costs across different socio-economic groups, as demonstrated by Bou Sleiman (2023).

In conclusion, this study provides crucial insights into the potential of bike-share programs to reduce air pollution in urban areas. The findings not only establish a robust connection between the presence of bike-share programs and lower air pollution levels, but also illustrate the economic and health benefits that stem from these improvements.

By promoting policies and initiatives that encourage mode substitution away from polluting vehicles and towards sustainable transport options, cities can make significant strides towards cleaner, healthier urban environments. These findings offer a compelling case for incorporating cycling infrastructure and bike-share programs into the broader urban planning strategies for sustainable and vibrant cities.

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