Tolling for Clean Air

Causal Impacts of Stockholm's Congestion Tax on Air Quality

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Abstract

This study investigates the causal impact of Stockholm's congestion tax on urban air quality over the extended period of 2000 to 2023, focusing on the annual highest concentration levels of key pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), fine particulate matter ($PM_{2.5}$), and coarse particulate matter (PM_{10}).

The study employs the Difference-in-Differences (DiD) approach, leveraging Stockholm as the treated city and Malmö, a comparable Swedish city that did not implement a congestion charge, as the control. The analysis controls meteorological conditions, city-center traffic flow, and demographic and socio-economic factors, to isolate the causal effect of the congestion tax. Crucially, robustness checks, including placebo tests, were conducted to assess the validity of the parallel trends assumption that air quality trends would have been similar in both cities absent the intervention.

Relative to the control city, results indicate statistically significant reductions of approximately 21.9% for PM_{10} and 29.5% for CO. Placebo tests supported the parallel trends assumption for these pollutants, strengthening the findings. For NO_2, a significant reduction of approximately 29% was estimated, but placebo tests suggested pre-existing trends—warranting caution. $PM_{2.5}$ showed a non-significant negative estimate.

The long-term analysis provides substantial evidence that Stockholm's congestion tax has delivered sustained environmental benefits, particularly in reducing PM_{10} and CO peaks. This reinforces its potential as a double dividend policy for addressing traffic congestion and emissions.

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1. Introduction

This study investigates the environmental impact of Stockholm's congestion tax on urban air quality from 2000 to 2023, focusing on the following pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), and particulate matter (PM_{10} and $PM_{2.5}$), since they are linked to health and environmental damage. The study exploits Stockholm's introduction of a congestion tax as a natural experiment, utilizing a Difference-in-Differences (DiD) framework with Malmö as a control. This allows for a causal assessment of how road pricing influences pollution levels. In doing so, the thesis connects economic theory, environmental externalities, and real-world policy.

Sweden provides a particularly informative setting because its two largest metropolitan areas chose opposite strategies. Stockholm introduced a seven-month congestion tax trial in 2006, followed by a city-wide referendum that endorsed the scheme; the tax then became permanent in 2007. Malmö, by contrast, has never levied a congestion charge despite having a comparable population size, labour market structure, and a border-adjacent transport network. This natural policy divergence creates a credible counterfactual for causal inference.

Congestion pricing is promoted worldwide as a "double dividend" policy that can both relieve traffic delays and curb tailpipe emissions, but the magnitude and durability of its environmental benefits remain contested. Stockholm is an early pioneer of congestion taxation, therefore this thesis investigates: What is the causal impact of Stockholm's congestion tax on urban air quality, as measured by annual average concentrations of $PM_{2.5}$, PM_{10}, NO_2, and CO?

This question matters because traffic emissions account for a large share of harmful urban air pollutants; these pollutants are strongly linked to respiratory and cardiovascular diseases, and to premature mortality. They also damage the wider environment by causing ground-level ozone formation, acidifying soils, and surface waters through nitrogen deposition, and contributing to climate forcing through particulate and carbon monoxide pathways.

Urban congestion remains a challenge in modern cities, where major urban centers routinely experience rush-hour gridlock as too many vehicles crowd onto limited road networks (The Swedish Public Transport Association, 2011). Over the past decade, congestion has worsened worldwide, imposing significant social, economic, and environmental costs. Recent estimates in Europe indicate that traffic delays annually cost 1 % of the EU's GDP, around €140 billion (European Commission, 2017). In Sweden's three largest city regions (Stockholm, Gothenburg, and Malmö), the social cost of congestion has been estimated at SEK 11.5 billion (The Swedish Public Transport Association, 2011). Moreover, in the United States alone, stop-and-go traffic resulted in over 12.5 billion litres of fuel wasted in 2022 (US Department of Energy, 2024). Beyond the direct economic costs, traffic congestion transforms urban areas into hotspots of emissions, releasing a cocktail of toxic pollutants directly into the breathing zones of pedestrians and residents. Among these pollutants are carbon monoxide (CO), nitrogen dioxide (NO_2), and particulate matter (PM_{10} and $PM_{2.5}$) (Simeonova et al., 2021).

Idling engines emit a disproportionately high amount of these harmful substances compared to vehicles operating under normal driving conditions (steady cruise or light acceleration), as a consequence of inefficient combustion and reduced catalyst efficiency when stationary. Among the primary health and environmental effects of these pollutants are the following. CO diffuses across lung tissue and into the bloodstream, making it difficult for the body's cells to bind to oxygen (World Health Organization [WHO], 2025). Elevated CO levels also extend the atmospheric lifetime of methane by consuming hydroxyl radicals, thereby increasing its radiative forcing (Intergovernmental Panel on Climate Change, 2001). NO_2 inflames the respiratory tract, which causes airway irritation (WHO, 2025). NO_x gases react in the atmosphere to form nitric acid, a key component of acid rain(U.S. Environmental Protection Agency, 2025). Particulate matter (PM_{10}/$PM_{2.5}$) penetrates deep into lung tissue, enters the bloodstream, and is strongly linked to cardio-respiratory diseases and premature mortality (WHO, 2025)

In sum, congested traffic not only delays travelers but also imposes hidden costs on society in the form of polluted air, public health burdens, and environmental damage. These harmful side-effects constitute negative externalities; societal costs not reflected in the private cost of driving. When left unpriced, such externalities result in market failure and excessive congestion. Pigouvian theory argues for correcting this inefficiency through taxation equal to the marginal external cost (A.C. Pigou, 1920). A congestion tax aligns private and social costs by incentivizing behavioral change, such as shifting travel to off-peak times or using public transit, thus reducing both traffic and emissions. This economic rationale underpins congestion pricing as a policy tool to internalize the hidden costs of urban driving.

2. Background

2.1 Congestion tax

2.1.1 Policy origins and the 2006 trial

Stockholm's congestion tax emerged after years of political debate, driven by growing concerns over traffic congestion and air pollution by the mid-2000s. In 2004, the Swedish Parliament passed a law (SFS 2004:629), authorizing a trial-congestion tax, legally defined as a national tax rather than a local toll. This legal distinction was crucial, as only the national government can levy such charges in Sweden. The law enabled charges to be imposed from the third of January to the thirty-first of July 2006, laying the groundwork for a full-scale trial of the system. The trial ran from January to July 2006, during which an electronic cordon around the inner city charged vehicles entering or exiting on weekdays. The fee was time-varying: higher during peak hours, lower off-peak; no charges on evenings, weekends, or holidays. The scheme used automatic number-plate recognition and was supported by both the national government and the National Transportation Agency (Swedish Transport Agency, 2025).

The explicit goals of the Stockholm trial were set by the city and national authorities before the trial began. They aimed to reduce peak-hour traffic by 10–15%, improve traffic flow on key roads, cut pollution (CO_2, NO_x, PM), and enhance the urban environment (Tools of Change, 2014). The trial succeeded beyond expectations in meeting these objectives: inner-city traffic fell by 20–25%, and congestion delays dropped by up to 50% on the city's arterial roads (Tools of Change, 2014). CO_2 emissions declined by 14%. Airborne pollutants inside the cordon fell by 10–14% although NO_x dropped by only 8.5% due to older buses with higher emission factors (Eliasson et al., 2009).

These outcomes demonstrated that a congestion tax could both deliver traffic relief and environmental improvements and lend credibility to the scheme.

2.1.2 Design of the permanent system

When the congestion tax was permanently introduced in August 2007, its core objectives remained the same as in the trial: reducing traffic congestion, improving accessibility, and enhancing environmental quality. The design of the permanent system closely mirrored the successful trial. The cordon remained in place; to prevent excessive costs, a maximum charge of 60 SEK per vehicle per day was set. Charges apply on weekdays (approximately 06:30–18:30), with higher fees during peak hours and no charges at night, on weekends, holidays, or in July (Swedish Transport Agency, 2024). Legally, the congestion charge functions as an automated electronic toll: cameras at fixed control points record license plates, and vehicle owners are billed monthly rather than paying immediately for each trip (Swedish Transport Agency, 2024). Enforcement is handled by the national authorities (Swedish Transport Agency, 2024). Revenue has, de facto, been reserved for investment in the Stockholm region's transport infrastructure, aligning the policy with regional development goals and bolstering public acceptance by demonstrating a clear return in the form of improved roads and transit (Eliasson, 2009). When the tax became permanent, only a limited set of vehicle categories remained exempt. Emergency vehicles and those with diplomatic registration were excluded, as were certain heavy buses exceeding 14 tons gross weight. Motorcycles, trailers, and tractors were also exempt (Swedish Transport Agency, 2024). Military vehicles, registered in a separate military vehicle registry, were not subject to the charge (Swedish Tax Agency, 2025). Additionally, individuals holding a disability parking permit could exempt one or two vehicles, ensuring that drivers with severe mobility impairments or their caregivers could obtain relief upon approval by the authorities (Swedish Tax Agency, 2025). By contrast, ordinary taxis and municipal paratransit vehicles for elderly or disabled passengers lost their exemption to enhance fairness and increase revenues for transport infrastructure by the proposition about the congestion tax (Prop. 2006/07:109).

2.1.3 Evolution of the Congestion tax (2007-Present)

Since its permanent introduction in 2007, Stockholm's congestion tax has evolved to reflect a deeper understanding of the policy and changing conditions. In 2016, the congestion tax rates increased for the first time since its inception, with peak-hour charges roughly doubling.[1] At the same time, the geographic scope was extended slightly to include the Essingeleden bypass when the congestion tax was restructured in 2014 (Betänkande 2013/14:SkU24). The 2016 reform aimed to generate additional revenue for major infrastructure projects. In 2020, a more nuanced seasonal and daily charging system was introduced. Stockholm began distinguishing between high-season and low-season traffic periods: in spring and autumn, the maximum daily charge rose to 135 SEK, whereas it remained at 105 SEK during quieter months (Swedish Transport Agency, 2024). These adjustments reflected a data-driven approach, maintaining effectiveness in the face of growth and seasonal variation. The congestion tax has consistently pursued three goals: reducing congestion, improving air quality, and funding transport infrastructure (Prop. 2006/07:109). Initially, green (alternative-fuel) vehicles were exempt to promote cleaner technology, but this exemption ended in 2012 once such vehicles exceeded 5 percent of total traffic. In (Prop. 2011/12:175), the government declared that the incentive had fulfilled its purpose of jump-starting the green car market but had begun to undermine congestion management and fairness. Foreign-registered vehicles were added in 2014 as technical limitations were resolved (Hultkrantz and Xing, 2012).

Throughout these developments, the fundamental goals have remained intact, and the policy has been viewed as largely successful. Traffic levels in the inner city have sustained a 20 percent reduction despite continued city growth (Tools of Change, 2014).

[1] New fees were up from 20 SEK to 30–35 SEK per passage, depending on time and a max of 105 per day.

2.2 Malmö as a counterfactual

Stockholm is Sweden's demographic giant, with a metropolitan population of approximately 1.65 million, around four times that of Malmö's 339,000 (Statistics Sweden, 2025). Yet despite this size difference, the cities share similar urban density: Malmö's core has ~4,200 inhabitants per km², slightly higher than Stockholm's ~3,800/km² (Statistics Sweden). These dense populations are supported by extensive public-transport networks, which is reflected in relatively low car-ownership rates. Stockholm's car ownership is about 357 cars per 1,000 residents (Stockholm Environmental Barometer, 2024), and Malmö's about 346 per 1,000 (Malmö Environmental Barometer, 2024), both well below the national average (426 per 1,000) (Regionfakta, 2025). Despite the acknowledgment of Stockholm's four-to-one population advantage, Malmö's comparable urban density and transit-oriented design make it a valid counterfactual in the DiD framework, with broadly similar traffic and pollution dynamics on a per-area basis.

A key reason to select Malmö as a control is that it has never implemented a congestion tax, whereas Stockholm has (Swedish Transport Administration, 2025). Aside from this policy difference, the two cities operate under the same national regulatory and economic framework. Each boasts an affluent, developed economy, with median annual incomes of approximately 394,000 SEK in Stockholm, and 314,000 SEK in Malmö (Ekonomifakta, 2023). Both are subject to identical nationwide fuel pricing, vehicle standards, fuel taxes and emissions regulations (EU vehicle standards). This common policy environment means drivers in both cities face similar fuel costs and vehicle technologies, eliminating confounding factors related to fuel availability or fleet composition. Likewise, vehicle emission standards, biofuel availability, and traffic laws apply uniformly across Sweden, ensuring that any differences in air quality outcomes can be more credibly attributed to the presence or absence of the congestion tax rather than to other underlying policy disparities.

Geographically, both are low-altitude coastal cities, Stockholm by the Baltic Sea and Malmö by the Oresund Strait. Stockholm's climate is humid continental bordering on oceanic, while Malmö's is fully oceanic. Both experience four seasons, with relatively mild winters and moderate summers, important controls in air-quality analyses. By including weather variables (temperature, wind speed, and precipitation) in our regression, we account for these influences. Data availability in Malmö is on par with Stockholm: both are designated EU air-quality zones and maintain advanced monitoring networks for key pollutants (PM_{10}, $PM_{2.5}$, NO_2, CO). These similarities make Malmö a credible and practical control unit for a difference-in-differences analysis. Nonetheless, Malmö's integration into the bi-national Oresund region means it can be exposed to shocks—driven by Copenhagen's economy, fuel taxes, or transport policies—that are harder to observe. If such shocks coincided with the 2007 congestion-tax period, they could undermine the parallel-trends assumption, so we address this concern later through placebo tests and additional sensitivity checks.

3. Literature Review

3.1 Evidence from Europe on Congestion Pricing and Air Quality

A growing body of international research has investigated whether congestion-charging schemes yield cleaner air in cities. Lessons from other major urban areas provide essential context and benchmarks for the Stockholm case. In London, which introduced a congestion charge in 2003, studies have generally found reductions in traffic emissions and modest improvements in air quality. Beevers and Carslaw (2005) estimated that the London scheme resulted in a 15.9% reduction in NO_x and PM_{10} emissions, as well as a 20% reduction in CO emissions within the charged zone. Another prominent example is Milan, which implemented the Ecopass congestion-charge scheme in 2008 explicitly aimed at reducing pollution. Rotaris et al. (2010) estimated that Ecopass reduced vehicles entering the cordon by about 12.3% and cut traffic-related PM_{10} emissions inside the zone by roughly 20% in its first year, with NO_x declining by 11% and CO_2 by 14%. However, Milan still struggled at times to meet EU daily PM_{10} standards, reflecting both the severity of its pollution problem and the Ecopass scheme's inability to bring coarse-particle levels fully into regulatory compliance.

Taken together, the international evidence indicates that congestion charging reduces traffic volumes and, consequently, urban emissions. However, the magnitude of these air-quality improvements varies markedly among cities, reflecting differences in baseline pollution levels, fleet composition, meteorological conditions, and scheme design. This heterogeneity highlights the importance of city-specific causal assessments to separate the policy's effect from contemporaneous trends and to attribute any observed air-quality gains accurately to congestion pricing.

3.2 Evidence from Stockholm on Congestion Pricing and Air Quality

Stockholm's congestion tax is one of the first such congestion-pricing schemes in Scandinavia and has been studied as a leading example of its kind. The policy's stated goals were to reduce traffic congestion, improve accessibility, and enhance the urban environment. Extensive ex-post evaluations followed the 2006 trial, providing early evidence on environmental outcomes. Johansson et al. (2009) analyzed the trial's impact on emissions and air pollution using measured traffic changes and dispersion modelling. They found that the congestion tax reduced traffic volumes inside the toll cordon by roughly 15%, which in turn cut NO_x emissions by about 8.5% and PM_{10} emissions by 13% within the taxed area. The report also estimated that this reduction in pollution exposure would prevent around 27 premature deaths per year in Greater Stockholm (Johansson, Burman and Forsberg, 2009). This evidence demonstrated that congestion pricing can yield public health benefits via cleaner air, bolstering the policy's rationale beyond mere congestion relief.

A gap exists in empirical research tracking air-quality indicators—NO_2, $PM_{2.5}$, PM_{10}, and CO—over the full course of the congestion tax's implementation, since few studies have quantitatively evaluated Stockholm's air quality beyond its initial years. Most of the existing literature, such as the 2006–2007 evaluation, focused on short-run effects. This gap is significant because long-term changes in vehicle technology, background pollution trends, and possible traffic adaptations (or induced demand) could alter the net environmental impact of the congestion tax over time.

3.3 Contributions of the Present Study

This thesis adds novel value by building on the existing literature and addressing the gaps identified above. In particular, it offers a more comprehensive and causally robust evaluation of the impact of Stockholm's congestion tax on air quality.

Frist, a long-term analysis spanning from 2000 to 2023—far beyond prior post-trial evaluations—allows us to observe lasting improvements or rebounds in pollution levels over more than a decade. Second, investigating NO_2, PM_{10}, $PM_{2.5}$, and CO together provides a holistic picture of urban air quality and captures differential effects on exhaust-related versus non-exhaust particulates. Third, employing a difference-in-differences framework with Malmö (no congestion charge) as a control account for confounding factors—such as national emissions trends, vehicle technology improvements, and weather patterns—and isolates the congestion tax's causal impact. Finally, controlling meteorological conditions (temperature, wind speed, precipitation) and traffic variables ensures that observed pollution changes are attributed correctly to the tax rather than to weather fluctuations or broader trends.

By combining a long temporal scale, multiple pollutants, a credible counterfactual, and rigorous controls, this study fills a critical gap in the literature. It not only deepens our understanding of Stockholm's case but also offers policy-relevant insights for other cities considering congestion pricing, indicating whether and to what extent congestion charges deliver sustained environmental benefits.

4. Method

4.1 Methodology and Econometric Model

This study adopts a difference-in-differences (DiD) identification strategy to estimate the causal impact of Stockholm's congestion tax on air quality. The DiD approach compares pollution trends in Stockholm—where the tax was introduced—with those in Malmö, a city without such a charge. The congestion tax was first piloted in 2006 and was made permanent in 2007. Malmö thus provides a counterfactual for how air quality would have evolved absent the tax. By differencing out common time trends and persistent city-specific factors, the DiD framework isolates the policy's effect on air pollution.

In the DiD framework, we define key dummy variables as follows:

• **$Treat_i$**: a treatment indicator equal to 1 for observations in Stockholm (treated city) and 0 for Malmö (control city).
• **$Post_t$**: a time indicator equal to 1 for observations from 2006 onward (post-policy period) and 0 for years before 2006 (pre-policy period).
• **DiD_{it}** = $Treat_i \times Post_t$, the difference-in-differences interaction term equal to 1 only for Stockholm in the post-2006 period and 0 otherwise; this captures the treatment effect.

Using these variables, we specify an econometric model to quantify the policy's impact. The dependent variable, $\ln(Y_{it})$, is the natural log of the annual average concentration of pollutant Y in city $_i$ and year $_t$. Taking logs allows the coefficients to be interpreted as approximate percentage changes and mitigates skewness in the concentration data. The baseline regression can be written as:

$$\ln(Y_{it}) = \alpha + \beta_1 Treat_i + \beta_2 Post_t + \beta_3 (Treat_i \times Post_t) + X_{it}'\delta + \epsilon_{it}$$

$\ln(Y_{it})$ equals the natural logarithmic outcome of the pollutant.
α is a constant term.
β_1 captures permanent differences between Stockholm and Malmö.
β_2 absorbs shocks or changes common to both cities in a given year.
β_3 is the DiD estimator of the congestion tax's effect on air quality. A positive β_3 indicates that Stockholm's post-2006 pollution levels (relative to its prior trend and relative to Malmö) increased; a negative β_3 implies that congestion pricing improved air quality by reducing pollution in Stockholm compared to the control. In other words, β_3 measures the difference-in-differences: the change in log

pollution in the treated city minus the change in the control city, netting out overall time trends and city-specific effects.

$\mathbf{X_{it}'\delta}$ is a vector of control variables (see Section 5.2.2), included to account for other determinants of air quality that might confound the policy effect.

$\boldsymbol{\varepsilon_{it}}$ is the error term.

Parallel-Trends Assumption and Robustness

A necessary assumption for DiD validity is that, in the absence of the congestion tax, Stockholm's air quality would have evolved in parallel with Malmö's (Colombia University, n.d). Pre-existing differences between the cities must be fixed, and their pollution trends similar before 2006. We verify this visually by examining pre-treatment trends. Because visual checks alone are not sufficient, we also perform placebo-year tests—introducing fictitious "treatments" before 2006—to ensure the DiD estimator shows no significant impact in those years. Additionally, we include city-specific time trends in robustness checks. These combined procedures confirm that the observed post-2006 divergence in Stockholm's air quality is attributable to the congestion tax rather than coincident shocks or omitted variables. Overall, the DiD strategy, together with controls and robustness tests, provides a rigorous framework for identifying the environmental impact of Stockholm's congestion-pricing policy.

4.2 Data Description

This analysis is based on a panel dataset of annual observations for Stockholm and Malmö, spanning from 200-2023 to ensure a substantial window for comparison. The raw data were collected from official sources (see Table 1); data cleaning and compilation were performed in Microsoft Excel, and the statistical analysis was conducted in Stata. In this section, we describe the data sources, variable construction, and key descriptive statistics.

4.2.1 Outcome Variables

The outcome measures are the concentrations of four air pollutants: fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), nitrogen dioxide (NO_2), and carbon monoxide (CO). For each pollutant, we obtained Air pollution data from the official environmental barometers of Stockholm and Malmö (Miljöbarometern). The outcome variables are annual city-level concentrations of $PM_{2.5}$, PM_{10}, NO_2, and CO. For Stockholm, the Miljöbarometern portal reports pollutant levels at multiple monitoring stations. We selected the "highest-of-stations" series, which represents the maximum annual concentration among all city monitors. To be comparable to Stockholm's "highest-of-stations" measure, we took the yearly maximum value across the available Malmö sites for each pollutant. All pollutant values span 2000–2023 and are expressed in µg/m³ (mg/m³ for CO). For descriptive tables and trend plots, we report these pollutant concentrations in their original units. However, in the regression analysis, the outcome variables will be given at the top of each column, and the concentrations will be log-transformed to stabilize variance and allow us to interpret the coefficients as semi-elasticities.

4.2.2 Control Variables

We include a set of control covariates measured at the city-year level, drawn from official sources:

Firstly, annual average temperature, precipitation, and wind speed were retrieved from the Swedish Meteorological and Hydrological Institute (SMHI) and each city's Miljöbarometern portal. These variables were included to account for meteorological influences on pollutant concentrations. Temperature affects reaction rates of secondary pollutants, precipitation removes particles through wet deposition, and wind speed governs the dispersion and dilution of emissions, ensuring that our estimated effect of the congestion tax is not confounded by weather-driven air-quality fluctuations.

Secondly, annual average daily traffic in the city center as proxies for vehicular activity and its emissions. For Stockholm we use the "inner-city average flow" and for Malmö the "city-centre average flow" as reported from each city's Miljöbarometern portal. Controlling traffic flow captures changes in emissions due to variations in vehicle volume and prevents these shifts from biasing the estimate of the policy's effect on air quality.

Thirdly, population density and average disposable income per capita from Statistics Sweden (SCB) were included to account for urban growth or differences in city size that might correlate with pollution levels. Higher income and economic growth can be associated with more traffic since it enables households and businesses to increase vehicle ownership and travel demand—more private trips, commercial deliveries, and freight movements. Controlling income and economic expansion ensures that changes in air pollution attributed to the congestion tax are not confounded by these underlying traffic-volume drivers.

Finally, the annual fuel price index (gasoline price per litre, in SEK) from Drivkraft Sweden (formerly the Swedish Petroleum Institute) serves as an explanatory variable to capture the effect of fuel cost on driving demand and thus emissions. Including fuel prices helps control external factors (like global oil price changes or tax changes on fuel) that might lead to simultaneous changes in air quality (through altered traffic volume) unrelated to the congestion tax.

Table 1: *Data Source Table*

Data category	Variable measured	City	Source
$PM_{2.5}$	Annual highest observed $PM_{2.5}$ concentration (µg/m³)	Stockholm Malmö	Miljöbarometern – Stockholms stad Miljöbarometern – Malmö stad
PM_{10}	Annual highest observed PM_{10} concentration (µg/m³)	Stockholm Malmö	Miljöbarometern – Stockholms stad Miljöbarometern – Malmö stad
NO_2	Annual highest observed PM_{10} concentration (µg/m³)	Stockholm Malmö	Miljöbarometern – Stockholms stad Miljöbarometern – Malmö stad
CO	Annual highest observed PM_{10} concentration (mg/m³)	Stockholm Malmö	Miljöbarometern – Stockholms stad Miljöbarometern – Malmö stad
Traffic flow	Inner-city average flow (Innerstadssnittet) City-center average flow (Centrala snittet)	Stockholm Malmö	Miljöbarometern – Stockholms stad Miljöbarometern – Malmö stad
Wind speed	Annual mean wind speed (m/s)	Stockholm Malmö	Swedish Meteorological and Hydrological Institute (SMHI) Miljöbarometern – Malmö stad
Temperature	Annual mean temperature (°C)	Stockholm Malmö	Miljöbarometern – Stockholms stad Miljöbarometern – Malmö stad
Precipitation	Annual total precipitation (mm)	Stockholm Malmö	Miljöbarometern – Stockholms stad Miljöbarometern – Malmö stad
Average income	Average annual income (SEK) for population aged 20+ years	Sweden	Statistics Sweden (Statistiska centralbyrån)
Population density	Population density (persons/km²)	Sweden	Statistics Sweden (Statistiska centralbyrån)
Fuel Prices	National average fuel price (SEK per litre)	Sweden	Drivkraft Sverige

Source*: Authors own compilation*

4.3 Data Processing and Analysis

All raw datasets were exported and collated into a master spreadsheet alongside the control series, and underwent cleaning and consistency checks in Microsoft Excel to be merged into a panel by city and year in Microsoft Excel. The constructed panel includes, for each city year: the four logged pollutant outcomes, the Meteorological averages, traffic and fuel variables, and demographic-, and socio-economic variables as described and comprises 48 observations (24 years for Stockholm and Malmö each).

In Stata, we ran panel regressions on the log of pollutant concentrations, controlling for the aforementioned variables. We note that the pollutants are modeled in log form for estimation but shown in unlogged form in all descriptive tables and pre-trend graphs. Summary statistics and pre-trend plots are computed directly from the merged dataset (in untransformed units), whereas all regression estimates use the log-transformed pollutant levels.

4.4 Descriptive Statistics and Diagnostics

We present summary statistics to illustrate the data's characteristics and the comparability of the treatment (Stockholm) and control (Malmö) cities. Table 2: *Summary Statistics* reports the mean and standard deviation of each key variable by city and by period ("pre" 2000–2005 vs. "post" 2006–2023). Because the congestion tax was piloted in 2006 and became permanent in 2007, we define 2006–2023 as the post-policy period for both cities. Presenting statistics by city and period highlights how key variables in Stockholm change relative to Malmö before and after the intervention. This disaggregated approach is preferable to pooled summaries because it reveals shifts in both level and variability that could otherwise be masked. By breaking pre-2006 and post-2006 figures, readers can readily assess the data's stability and detect any structural changes coinciding with the congestion tax.

Table 2: *Summary Statistics*

City	Period	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	NO_2 (µg/m³)	CO (mg/m³)	Traffic (daily)	Income (kSEK)	Pop.den	Temp (°C)	Precip (mm)	Wind (m/s)
Stockholm	**Pre**	15.25	43.00	47.33	0.833	559,000	240.2	4049,55	7.93	538.5	3.73
	(2000–05)	(1.66)	(2.97)	(1.97)	(0.175)	(15,518)	(12.6)	(39,09)	(0.34)	(50.6)	(0.30)
	Post	8.27	27.83	38.33	0.378	430,778	351.5	4830,1	8.23	549.4	3.36
	(2006–23)	(2.55)	(6.38)	(9.00)	(0.065)	(34,376)	(59.0)	(379,84)	(0.77)	(97.5)	(0.40)
Malmö	**Pre**	11.85	18.05	20.83	0.675	233,350	181.4	1708,92	9.37	562.8	3.73
	(2000–05)	(2.04)	(2.01)	(1.33)	(0.076)	(15,241)	(10.6)	(27,75)	(0.35)	(78.5)	(0.09)
	Post	10.26	18.17	27.28	0.339	186,805	266.3	2046,65	9.92	614.7	3.78
	(2006–23)	(1.84)	(2.63)	(5.12)	(0.113)	(12,492)	(47.1)	(166,40)	(0.73)	(123.7)	(0.11)

Source: *Authors own compilation*

4.4.1 Pre-Policy Comparison

Prior to 2006, Stockholm's annual $PM_{2.5}$ and PM_{10} concentrations averaged 15.25 µg/m³ and 43.00 µg/m³, respectively, compared with Malmö's 11.85 µg/m³ and 18.05 µg/m³. Stockholm's NO_2 (47.33 µg/m³) and CO (0.833 mg/m³) levels also exceeded Malmö's (20.83 µg/m³ and 0.675 mg/m³, respectively). These baseline differences reflect Stockholm's larger traffic volume, larger urban core, and more complex street-canyon microenvironments that trap pollutants. Control variables also differed: Stockholm's average daily traffic flow was about 559,000 vehicles, more than twice Malmö's 233,350, and Stockholm's population density (4,049 p/km²) was roughly two-and-a-half times Malmö's (1,709 p/km²).

However, pre-policy meteorological conditions were broadly comparable: both cities experienced mean temperatures around 8 – 9 °C, precipitation between 538 – 563 mm, and wind speeds near 3.7 m/s.

4.4.2 Post-Policy Comparison

After the congestion tax's introduction, Stockholm's pollutant levels declined markedly post-2006. $PM_{2.5}$ concentrations nearly fell by half, from 15.25 µg/m³ to 8.27 µg/m³. PM_{10} fell from 43.00 µg/m³ to 27.83 µg/m³. NO_2 from 47.33 µg/m³ to 38.33 µg/m³, and CO dropped from 0.833 mg/m³ to 0.378 mg/m³.

In contrast, Malmö's $PM_{2.5}$ fell more modestly from 11.85 µg/m³ to 10.26 µg/m³, and PM_{10} remained roughly unchanged (18.05 µg/m³ to 18.17 µg/m³). Malmö's NO_2 however, rose from 20.83 µg/m³ to 27.28 µg/m³—likely reflecting region-wide traffic and economic growth rather than a local policy change. CO declined from 0.675 mg/m³ to 0.339 mg/m³. These divergent post-tax trends suggest that Stockholm experienced sharper pollutant reductions than Malmö, consistent with a potential congestion tax effect.

Control variables also shifted. Stockholm's traffic flow declined from a pre-mean of 559,000 to 430,778 daily vehicles (−23 %), whereas Malmö's fell from 233,350 to 186,805 (−20 %). Both cities therefore saw comparable relative decreases in traffic volume, implying that any additional air-quality gains in Stockholm may be attributable to the tax rather than broader reductions in driving.

Additionally, both cities experienced rising fuel prices (14.53 SEK/liter vs. 9.85), warmer mean temperatures, and increased precipitation, all factors affecting pollutant dispersion and deposition. Income growth was more pronounced in Stockholm (351.5 thousand SEK up from 240.2 thousand SEK) than in Malmö (266.3 thousand SEK vs. 181.4 thousand SEK), suggesting stronger economic expansion in Stockholm which could otherwise elevate pollution if not controlled for.

4.4.3 Interpreting Pre/Post Patterns

Taken together, the descriptive statistics reveal three key patterns: Post-policy concentrations of $PM_{2.5}$ and PM_{10} fell more steeply in Stockholm than in Malmö.

Both cities experienced lower traffic volumes, but Stockholm saw a larger absolute drop, nearly 128,000 vehicles per day, which aligns with the expected effect of a congestion charge.

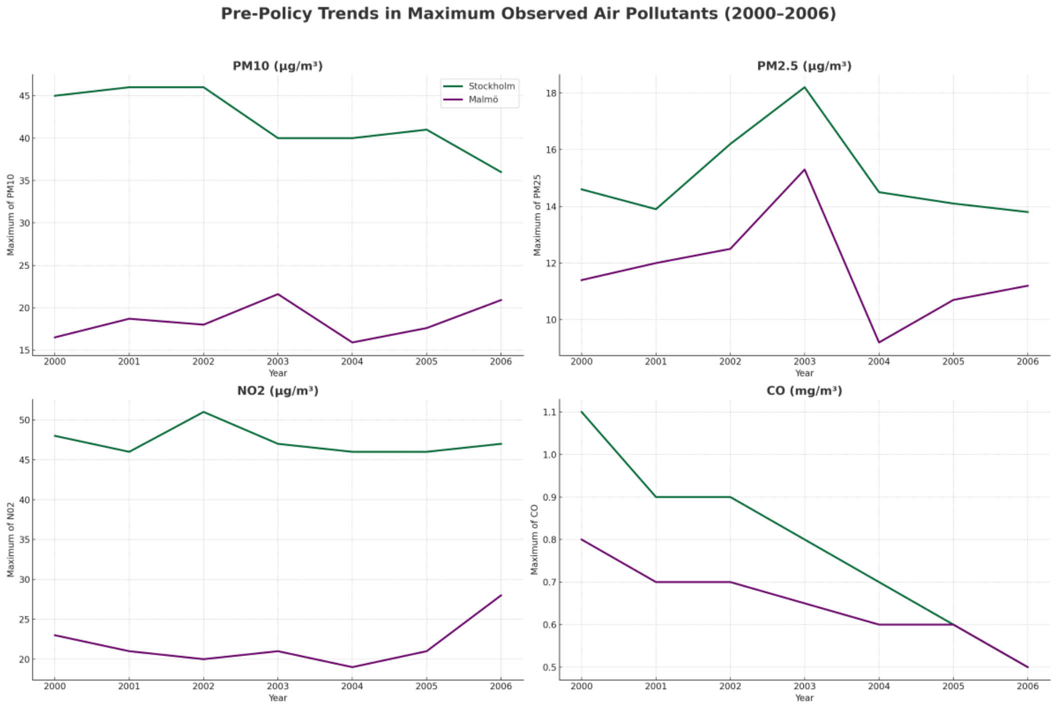
Meteorological and economic factors changed similarly in both cities (rising incomes, higher fuel prices, slightly warmer temperatures, and increased precipitation), making it unlikely that these factors alone explain Stockholm's greater pollution decline.

These descriptive differences support the plausibility of a congestion-tax effect on Stockholm's air quality. However, they cannot rule out all confounders such as vehicle-fleet turnover or cross-border influences from Copenhagen. Therefore, we apply a difference-in-differences regression, controlling year-to-year meteorology, fuel costs, population changes, and other covariates, to formally test whether the tax drove the observed divergence in air pollution trends.

4.4.4 Pre-trends Plot

In addition to the Summary Statistics table, we employ visual diagnostics. A pre-trends plot (Graph 1) displays the time series of the maximum annual concentrations in Stockholm and Malmö over the years 2000–2006 for each pollutant. This plot allows us to visually assess the parallel trends assumption: the pollution levels in Stockholm (green line) and Malmö (red line) moved roughly in sync, consistent with the requirement for a valid DiD identification.

Figure 1: *Pre- trends Plot*



Source: *Stockholm's and Malmö's own Miljöbarometern portal*

Assessing Parallel-Trend Patterns

Across all four pollutants, the year-to-year movements in Stockholm and Malmö exhibit remarkably similar shapes and inflection points prior to 2006.

In the PM_{10} panel, Stockholm's and Malmö's curves climb together in the early years, reach a shared high point, and then both dip sharply around the same time. They bounce back slightly in the middle of the period as Stockholm drops again in the final year. For $PM_{2.5}$, both cities rose together toward a shared peak in 2003. Immediately thereafter, each city's $PM_{2.5}$ dropped sharply in 2004 and Malmö rebounded slightly in the following year. In the NO_2 panel, both cities' curves start high and keep relatively the same trajectories throughout the pre-period. Stockholm slightly peaked in 2002 while Malmö ascended in the last year. For CO, the two lines exhibit a smooth, continuous downward slope from 2000 to 2006 with a monotonic decline in 2002. Each year's decline in Stockholm is matched by a nearly identical decline in Malmö, confirming that CO concentrations were driven by common factors pre-2006 in both cities.

Taken together, these parallel trajectories bolster confidence that the DiD design's parallel-trends assumption holds. Consequently, when we observe a subsequent break in Stockholm's post-2006 pollution path (relative to Malmö), we can more credibly attribute that change to the congestion tax rather than to spurious pre-existing trends.

5. Results

5.1 Difference-in-Differences Estimates

Table 3 presents estimated coefficients from ordinary least squares (OLS) regressions of the natural logarithm of each pollutant concentration (PM_{10}, $PM_{2.5}$, NO_2, CO) on: a treatment indicator (1 for Stockholm, 0 for Malmö): a post-policy indicator (years > 2006 = 1, or otherwise): their interaction term (DID): and a set of control covariates including temperature, precipitation, wind speed, income, population density, unleaded fuel price (BF95), diesel price, and traffic flow. All models use 48 city-year observations (24 for Stockholm, 24 for Malmö).

Table 3: *Difference-in-Differences Estimates*

Coeff.	**LogPM10**	**LogPM25**	**LogNO2**	**LogCO**
Treated	3.039***	1.879*	-.139	.92
	(.828)	(1.065)	(.774)	(1.322)
Post	.143**	.1	.591***	-.224**
	(.063)	(.081)	(.057)	(.101)
Treated*Post	-.247**	-.185	-.343***	-.35**
	(.106)	(.135)	(.095)	(.169)
Temperature	.034	-.019	-.024	-.037
	(0.23)	(.03)	(.021)	(.037)
Precipitation	0	0	0	0
	(0)	(0)	(0)	(0)
Windspeed	-.101	-.058	.044	-.229**
	(.065)	(.083)	(0.58)	(.104)
Income	-.001	-.002	-.005***	-.005***
	(.001)	(.001)	(.001)	(.002)
Inhabitants/km²	-.001***	-.001**	0	0
	(0)	(0)	(0)	(0)
BF95	.121**	.086	.072	-.27***
(unleaded)(SEK/L)	(.053)	(.068)	(.048)	(.085)
Diesel.price(SEK/L)	-.075**	-.04	-.043	.167***
	(.034)	(.044)	(.031)	(.055)
Trafficflows	0	0	0	0
	(0)	(0)	(0)	(0)
Constant	4.105***	3.94***	2.85	3.243***
	(.684)	(.872)	(.614)	(1.092)

****p<01, ** p<05, *p<1*

Note on Interpreting Coefficients in a Log-Lin Model

In our regressions, each pollutant outcome Yit was transformed as ln(Yit) while all control variables remained in their original units. Logging the dependent variable permits a semi-elasticity interpretation: a one-unit change in a covariate implies that Yit is multiplied by exp(β). Consequently, the percentage change in Y is given by:

$$\exp(\beta) - 1, \text{ where } \beta \text{ denotes the estimated coefficient}$$

Transforming Y to its natural logarithm ensures that the effect of a binary continuous covariate's effect can be interpreted directly as a percent change in the unlogged pollutant level, thereby facilitating clearer policy implications.

5.1.1 Baseline (Treated) Differences

Before 2006 Stockholm's PM_{10} (3.039 ($p < 0.01$)) peaks were roughly 20 times greater than Malmö's, as well was $PM_{2.5}$ levels about 5.5 times higher in Stockholm (1.879 ($p < 0.1$)). For NO_2 and CO, the coefficients show no statistical significance, indicating no pre-2006 difference in NO_2 and CO peaks between the two cities.

5.1.2 Common Time (Post) Effect

PM_{10} exhibited a statistically significant coefficient of 0.143 ($p < 0.05$), indicating that both Stockholm and Malmö experienced a 15.4 % rise in PM_{10} peaks after 2006, a change likely driven by nationwide or regional influences unrelated to the congestion tax.

In contrast, the coefficient for $PM_{2.5}$ was not statistically significant, suggesting no common shift in $PM_{2.5}$ concentrations across the two cities over the same period.

NO_2 showed a highly significant coefficient of 0.591 ($p < 0.01$), which corresponds to an approximately 80.6 % increase in NO_2 peaks in both cities after 2006, again pointing to broader economic or regulatory conditions as the primary drivers.

Finally, the CO coefficient of –0.224 ($p < 0.05$) indicates a 20 % decline in CO peaks in both Stockholm and Malmö, a decrease most plausibly attributable to general improvements in vehicle technology and fuel composition rather than to the implementation of congestion pricing.

5.1.3 Policy Effect (DID interaction)

The difference-in-differences estimates reveal that the congestion tax had a significant impact on Stockholm's pollution levels relative to Malmö. Specifically, the PM_{10} coefficient of –0.247 ($p < 0.05$) indicates that Stockholm experienced an additional 0.247 log-point decline in PM_{10} peaks after 2006, equivalent to an approximate 21.9 % reduction attributable to the tax. $PM_{2.5}$ also shows a negative coefficient of –0.185, corresponding to a 16.9 % reduction that cannot be confidently ascribed to the policy since this effect fails to reach statistical significance ($p > 0.10$). NO_2 levels in Stockholm fell by an extra 0.343 log points relative to Malmö ($p < 0.01$), amounting to roughly a 29 % greater decrease in NO_2 peaks post-implementation. Finally, CO concentrations dropped by 0.350 log points in Stockholm versus Malmö ($p < 0.05$), signifying an approximately 29.5 % reduction in CO that can be credited to the congestion charge.

5.1.4 Control Variables

Neither temperature nor precipitation coefficients reached significance, indicating no systematic bias from seasonal conditions. Wind speed entered the CO model with a coefficient of –0.229 ($p < 0.05$), implying a 20.4 % decrease in CO peaks for each 1 m/s increase in wind speed, consistent with enhanced atmospheric dispersion. Higher income levels were associated with cleaner air: a 1 kSEK rise in mean income corresponded to 0.5 % reductions in both NO_2 and CO (-0.005, $p < 0.01$), likely reflecting cleaner vehicle ownership or reduced driving. Denser population areas also saw modest gains, an additional person per km^2 was linked to 0.1 % declines in PM_{10} and $PM_{2.5}$ peaks (–0.001, $p < 0.01$ and $p < 0.05$ respectively), suggesting greater transit use in denser areas. Fuel-price effects further differentiated pollutant profiles: a higher unleaded petrol price raised PM_{10} by 11.4 % (0.121, $p < 0.05$) but reduced CO by 23.6 % (–0.270, $p < 0.01$), whereas each SEK-per-liter increase in diesel price cut PM_{10} by 7.2 % (–0.075, $p < 0.05$) and raised CO by 15.4 % (0.167, $p < 0.01$), reflecting different emission characteristics of gasoline versus diesel engines. Finally, average daily traffic flows exerted no significant additional influence on any pollutant once these controls were included.

5.2 Placebo test: Fake Treatment Year 2004

To test the validity of the parallel-trends assumption in our difference-in-differences (DiD) framework, we conducted a placebo test by assigning 2004—a false treatment year—two years before Stockholm's pilot congestion tax. We estimated the DiD model as before but replaced the true post-treatment indicator with the Post_04 dummy (equal to 1 from 2004 onward) and interacted it with the Treated indicator (Stockholm) to generate the placebo DiD estimator, DID_04.

The logic behind this test is straightforward: if the model attributes a significant treatment effect to a year before the tax's implementation, the identifying assumption of parallel trends may be violated. Table 4 presents the results of this placebo-treatment model.

Table 4: *Fake Treatment Estimates*

Coeff.	**LogPM10**	**LogPM25**	**LogNO2**	**LogCO**
Treated	3.485*** (.791)	2.677*** (.933)	1.562 (1.181)	-.799 (1.298)
Post_04	-.007 (.074)	-.134 (.087)	.323*** (.11)	-.105 (.121)
Treated*Post	-.139 (0.93)	-.028 (.109)	-.35** (.138)	-.155 (.152)
Temperature	.047* (0.24)	-.004 (.029)	.01 (.036)	-.052 (.04)
Precipitation	0 (0)	0 (0)	0 (0)	0 (0)
Windspeed	-.076 (.07)	-.028 (.083)	.046 (.104)	-.183 (.115)
Income	0 (.001)	-.001 (0)	-.004** (.002)	-.004** (.002)
Inhabitants/km²	-.001*** (0)	-.001*** (0)	0 (0)	0 (0)
BF95 (SEK/L)	.195*** (.056)	.188*** (.066)	.204** (.084)	-.3*** (.092)
Diesel.price (SEK/L)	-.121*** (.037)	-.104** (.043)	-.125** (.055)	.185*** (.06)
Trafficflows	0 (0)	0 (0)	0 (0)	0 (0)
Constant	3.854*** (.638)	3.848*** (.752)	2.992*** (.952)	2.052* (1.046)

**** p<.01, ** p<.05, * p<.1*

Among the four logged pollutant outcomes, only log NO_2 exhibits a statistically significant placebo effect: the DID_04 coefficient for the 2004 placebo year is –0.35 ($p = 0.16$). This indicates that, even before the congestion tax was introduced, Stockholm's NO_2 levels were declining faster than Malmö's, thus violating the parallel-trends assumption for NO_2. In contrast, the placebo estimates for PM_{10}, $PM_{2.5}$, and CO are small and statistically insignificant, suggesting no differential pre-trends for those pollutants.

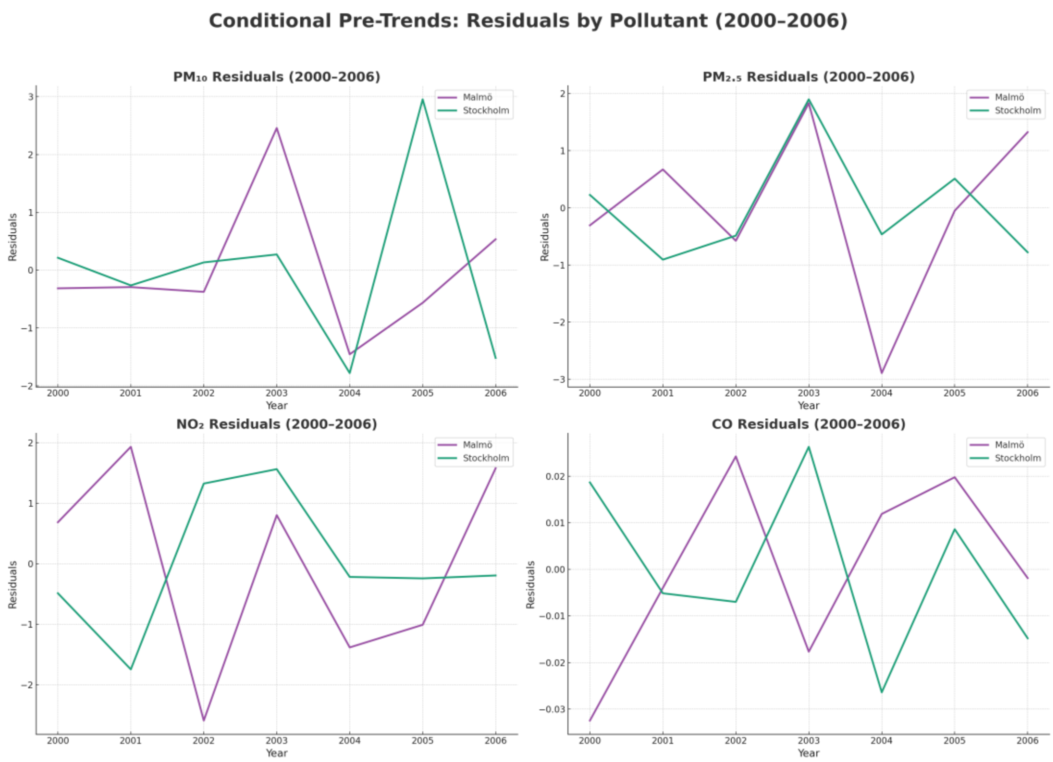
These findings bolster our confidence in the main results for PM_{10}, $PM_{2.5}$, and CO but counsel caution when interpreting the NO_2 treatment effect, since part of the post-2006 divergence may reflect pre-existing trends rather than the tax itself.

5.3 Robustness Check: Conditional Pre-Trends Based on Covariate-Adjusted Residuals

To further assess the parallel-trends assumption in our difference-in-differences analysis, we conducted a robustness check by plotting conditional pre-trends for each pollutant. Specifically, we regressed each pollutant (PM_{10}, $PM_{2.5}$, NO_2, CO) on our set of control variables using only the pre-policy data. We then plotted the annual residuals for Stockholm and Malmö to compare their trajectories visually.

This approach tests whether, after removing variation explained by observable confounders, the two cities still follow similar pollution trends. If Stockholm's and Malmö's residuals track each other closely, it supports the parallel-trends assumption conditional on the included controls.

Figure 2: *Conditional Pre-trends Plot*



The residual plots (Graph 2) display broadly similar trajectories for Stockholm and Malmö across most pollutants. For both PM_{10} and $PM_{2.5}$, Stockholm and Malmö follow comparable yet noisy residual paths, with some divergence in 2003–2005, particularly for PM_{10}, but no persistent directional gap. This indicates that, after controlling observables, the remaining pollutant variation is not systematically different across cities.

NO_2 residuals exhibit moderate fluctuations in both cities, with slightly greater volatility in Malmö, yet no sustained separation emerges. CO residuals are tightly clustered and show minimal divergence throughout the period, offering the strongest evidence of conditional parallel trends. Overall, after adjusting for key confounders, Stockholm and Malmö demonstrate parallel pollution trajectories in the pre-treatment years, especially for CO and $PM_{2.5}$, though PM_{10} and NO_2 show some year-to-year variation that warrants cautious interpretation.

6. Discussion

6.1 Discussion of The Results

The DiD estimate indicates a statistically significant reduction in PM_{10} concentrations attributable to the congestion tax. Prior to 2006, Stockholm's PM_{10} levels were substantially higher than Malmö's. Although both cities saw traffic-volume declines post-2006, Stockholm's absolute drop, nearly 128,000 vehicles per day was larger, aligning with the expected effect of a congestion charge. We estimate a 21.9% reduction in PM_{10} in Stockholm relative to Malmö, supporting the policy's goal of lowering particulate emissions in the city center.

Carbon monoxide concentrations also declined significantly: our DiD model shows a 29.5% CO reduction in Stockholm versus Malmö. This supports the notion that the tax successfully targeted tailpipe emissions, as CO is a direct product of incomplete combustion, particularly from idling engines in congested traffic. Both cities saw CO peaks decline after 2006, likely due to general improvements in vehicle technology, but Stockholm's reduction was significantly larger. Unlike PM_{10}, the placebo treatment-year test for CO reveals no pre-2006 divergence, bolstering confidence that the tax drove this outcome.

For fine particulate matter ($PM_{2.5}$), the DiD estimate was negative (–0.185) but not statistically significant ($p > 0.10$). This corresponds to an approximate 16.9% reduction, but we cannot be confident this is a true effect of the tax since both cities experienced parallel $PM_{2.5}$ declines after 2006. The lack of statistical significance could reflect various factors, the influence of non-exhaust particulates which may not be reduced by traffic volume alone, or other uncaptured confounding factors. Literature suggests that even with traffic reductions, cities like Milan still struggled to meet stringent PM_{10} standards, indicating the complexity of tackling particulate pollution.

In the NO_2 model, we observe an estimated 29% greater reduction in Stockholm relative to Malmö post-2006. This is a notable environmental benefit, especially considering NO_2's role in inflating the respiratory tract and contributing to acid rain. However, a placebo test with a 2004 treatment year uncovers a significant pre-2006 decline in Stockholm's NO_2 ($DiD_{04} = –0.35$, $p = 0.016$), violating the parallel-trends assumption and cautioning against attributing the entire post-2006 divergence solely to the congestion tax.

Among controls, higher wind speeds correlate with lower CO concentrations, reflecting dilution effects. Rising incomes link to reductions in NO_2 and CO, possibly via cleaner vehicles. Increased population density associated with lower PM_{10} and $PM_{2.5}$, perhaps due to greater transit use. Fuel-price rises have asymmetric effects dampening PM_{10} more than CO, mirroring diesel versus petrol emission profiles. Traffic-flow terms, once other covariates are included, exert no additional detectable influence on peak pollutant levels. Finally, the $Post_t$ coefficient captures shared time trends, such as a general post-2006 drop in CO and modest NO_2 declines in both cities, underscoring the DiD approach's value in isolating the policy's specific environmental impact.

While international studies consistently find that congestion pricing delivers measurable air-quality gains, the magnitude and persistence of these effects vary across contexts. For example, London's 2003 charging zone reduced NO_x and PM_{10} by approximately 16 % and CO by 20 % within its cordon (Beevers & Carslaw, 2005). Milan's Ecopass cut PM_{10} by roughly 20 % and NO_x by 11 % in its first year (Rotaris et al., 2010). Our long-run DiD estimates for Stockholm closely echo and extend the findings from the city's original 2006 congestion trial. Johansson et al. (2009) documented a short-term 13 % reduction in PM_{10} and an 8.5 % drop in NO_x during the trial period. In contrast, we observe a sustained 21.9 % decrease in PM_{10} and a 29.0 % reduction in NO_2 over the full 2006–2023 horizon, confirming that emission gains persist well beyond the pilot phase. Likewise, whereas the trial saw roughly a 6 % fall in CO concentrations, our estimates reveal a more pronounced 29.5 % decline in CO peak levels relative to the Malmö counterfactual. That $PM_{2.5}$ shows only a small, statistically insignificant decline suggests that fine-particle abatement in Stockholm may be constrained by non-tailpipe sources or by regional background levels unaffected by local traffic policies.

Overall, these comparisons demonstrate not only that Stockholm's congestion charge delivers the "double dividend" of traffic relief and cleaner air but also that its environmental benefits amplify over time, underscoring the policy's long-term efficacy in a Nordic urban context.

6.2 Policy Relevance

The results suggest that Stockholm's congestion tax has fulfilled its promise of improving urban air quality, most clearly for CO. This supports congestion pricing as a double-dividend policy, capable of reducing traffic delays and mitigating the substantial health and environmental costs of tailpipe emissions. The sustained reductions observed over more than fifteen years post-trial indicate that these environmental benefits are not merely short-lived but represent lasting improvements.

The policy's success in cutting pollution aligns with its stated objectives, which include both reducing congestion and enhancing the urban environment. These findings are highly relevant for other major urban centers facing similar challenges. The Stockholm example demonstrates that even amid city growth and evolving vehicle fleets, congestion pricing can help maintain lower pollution levels compared with a comparable city lacking such a measure.

6.3 Limitations and Future Improvements

Despite the rigorous approach, the study has limitations. The placebo test raised concerns about the parallel-trends assumption for NO_2, suggesting pre-existing differential trends for this pollutant. Conditional pre-trend plots supported parallel trends for CO and $PM_{2.5}$ but revealed year-to-year variation for PM_{10} and NO_2, indicating the assumption does not hold perfectly for all pollutants. The geographical position of Malmö within the Oresund region also exposes it to potential unobserved shocks from Copenhagen that could conceivably affect its air quality trends and slightly undermine its counterfactual credibility.

To improve the study, Future research could explore the policy's effects using finer temporal scales (daily or hourly data) to capture nuances related to the time-differentiated charging structure and exempt periods. Investigating spatial displacement of traffic and emissions to areas just outside the congestion cordon would provide a more complete picture of the policy's environmental footprint. Further analysis could differentiate between the exhaust and non-exhaust sources to explain why $PM_{2.5}$ did not show a statistically significant reduction and explore the role of regional transport of fine particles. Finally, further investigation should apply methods robust to parallel-trends violations, particularly for NO_2, to obtain a more definitive estimate for that pollutant.

7. Conclusion

This study aimed to estimate the causal impact of Stockholm's congestion tax on urban air quality by analyzing the annual peak concentration levels of CO, NO_2, PM_{10}, and $PM_{2.5}$ over the period 2000-2023. Employing a difference-in-differences (DiD) design with Malmö as a counterfactual and examining this over a long temporal scale and for multiple, the analysis sought to provide a more comprehensive and causally robust evaluation of the policy's environmental effects than previous short-term studies.

The results for PM_{10} and CO are more credible as the parallel trends assumption of the DiD model holds for these pollutants based on the placebo tests. This provides empirical support for Stockholm's congestion tax´s successful contribution to improved urban air quality, with estimated reductions of 21.9% in PM_{10} and 29.5% in CO relative to the control city, reinforcing its potential as a double-dividend policy. However, the findings for $PM_{2.5}$ and NO_2 were less certain. The DiD estimate for $PM_{2.5}$ failed to exhibit statistical significance due to declining pollution levels in both Stockholm and Malmö after 2006. Therefore, we cannot be confident that the observed reduction is a true effect of the tax. As for NO_2, a placebo treatment-year test uncovers pre-tax divergences, Stockholm's NO_2 levels were already falling faster than Malmö's, raising concerns about the parallel-trends assumption and preventing full attribution of the post-2006 NO_2 decline to the congestion tax.

Despite these limitations, the evidence demonstrates that Stockholm's congestion tax has delivered sustained environmental benefits, particularly in reducing PM_{10} and CO peaks. This reinforces its role as a "double dividend" policy. The long-term analysis period strengthens the finding that these environmental benefits can be sustained. Future research could explore more granular data or methods robust to parallel trend violations.

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9. Appendix

The following appendix contains structured tables detailing the congestion tax system in Stockholm. It includes time-based toll charges for both the inner city and Essingeleden, distinctions between high and low season rates, officially exempt days, seasonal definitions, and a overview of the data sources used in the thesis. These tables serve as supplementary reference material to support the analysis presented in the main body of the report.

Table 5: *Data Source Reference Table*

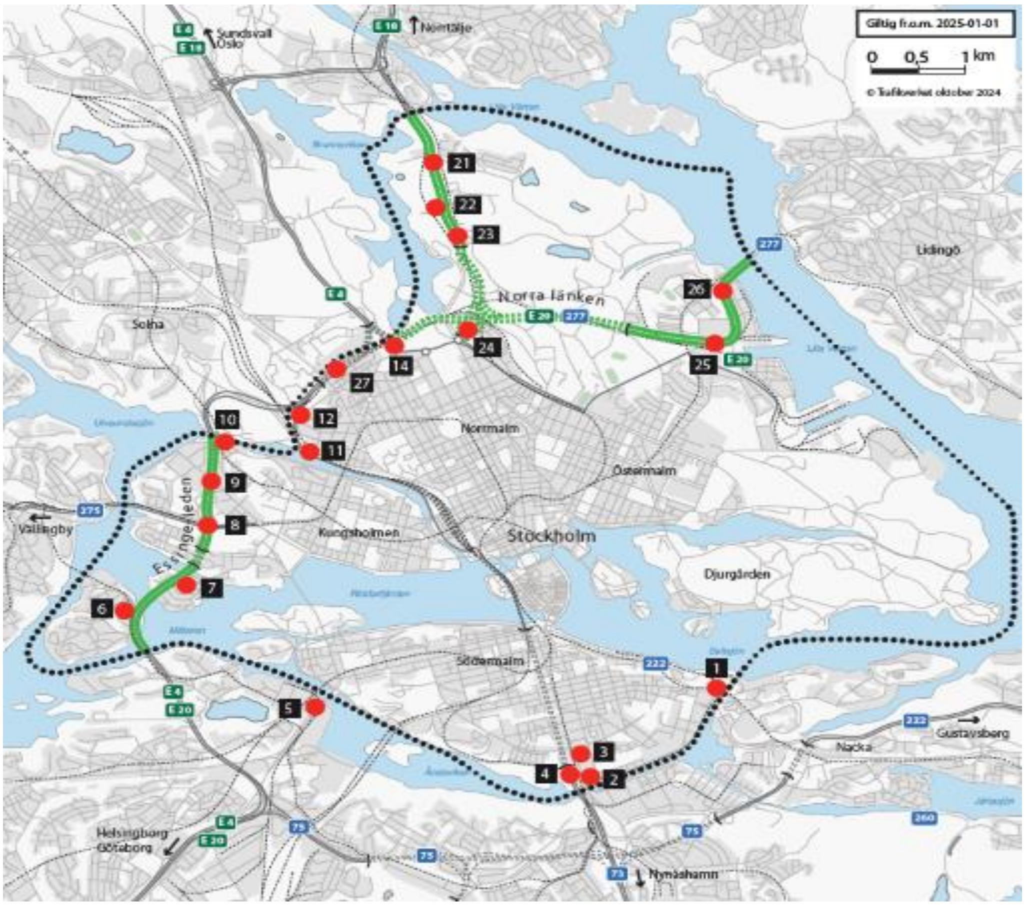
Institution	Description	URL	Access Date
Stockholm Environmental Barometer	Air: Particles – PM2.5 Annual Mean Values	https://miljobarometern.stockholm.se/luft/partiklar/pm2-5-arsmedelvarden/	9 June 2025
Malmö Environmental Barometer	Air: Particle Concentration (PM2.5)	https://miljobarometern.malmo.se/luft/halter-i-utomhusluft/halten-av-partiklar-pm-2-5/	9 June 2025
Stockholm Environmental Barometer	Air: Particles – PM10 Annual Mean Values	https://miljobarometern.stockholm.se/luft/partiklar/pm10-arsmedelvarden/	9 June 2025
Malmö Environmental Barometer	Air: Particle Concentration (PM10)	https://miljobarometern.malmo.se/luft/halter-i-utomhusluft/halten-av-partiklar-pm-10/	9 June 2025
Stockholm Environmental Barometer	Air: Nitrogen Dioxide – Annual Mean Values	https://miljobarometern.stockholm.se/luft/kvavedioxid/kvavedioxid-arsmedelvarden/	9 June 2025
Malmö Environmental Barometer	Air: Nitrogen Dioxide Levels in Outdoor Air	https://miljobarometern.malmo.se/luft/halter-i-utomhusluft/kvavedioxid/	9 June 2025
Stockholm Environmental Barometer	Air: Carbon Monoxide – Annual Mean Values	https://miljobarometern.stockholm.se/luft/kolmonoxid/kolmonoxid-arsmedelvarde/	9 June 2025

Malmö Environmental Barometer	Air: Carbon Monoxide Levels in Outdoor Air	https://miljobarometern.malmo.se/luft/halter-i-utomhusluft/kolmonoxid/	9 June 2025
Stockholm Environmental Barometer	Traffic: Motor Vehicle Flows – Inner City and Regional Centre	https://miljobarometern.stockholm.se/trafik/motorfordon/trafikfloden-innerstaden-och-regioncentrum/	9 June 2025
Malmö Environmental Barometer	Traffic: Car Traffic Volumes – Central Section	https://miljobarometern.malmo.se/trafik/resvanor-och-trafikmatningar/biltrafikmangder/centrala-snittet/	9 June 2025
Swedish Meteorological and Hydrological Institute (SMHI)	Wind (Station 98210)	https://www.smhi.se/data/temperatur-och-vind/vind/wind/98210	9 June 2025
Malmö Environmental Barometer	Climate and Weather Statistics: Wind Strength	https://miljobarometern.malmo.se/klimat/klimat-och-vaderstatistik/vindstyrka/	9 June 2025
Stockholm Environmental Barometer	Climate and Weather Statistics: Mean Temperature	https://miljobarometern.stockholm.se/klimat/klimat-och-vaderstatistik/medeltemperatur/	9 June 2025
Malmö Environmental Barometer	Climate and Weather Statistics: Temperature	https://miljobarometern.malmo.se/klimat/klimat-och-vaderstatistik/temperatur/	9 June 2025
Stockholm Environmental Barometer	Climate and Weather Statistics: Annual Precipitation	https://miljobarometern.stockholm.se/klimat/klimat-och-vaderstatistik/arsnederbord/	9 June 2025
Malmö Environmental Barometer	Climate and Weather Statistics: Precipitation	https://miljobarometern.malmo.se/klimat/klimat-och-vaderstatistik/nederbord/	9 June 2025

Statistics Sweden (SCB)	Household Disposable Income	https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__HE__HE0110__HE0110A/SamForvInk1/	9 June 2025
Statistics Sweden (SCB)	Population, Area and Density	https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BE__BE0101__BE0101C/BefArealTathetKon/	9 June 2025
Drivkraft Sverige	Facts & Statistics: Fuel Prices	https://drivkraftsverige.se/fakta-statistik/priser/	9 June 2025

Source: Authors own accomplishment

Figure 3: *Stockholm Congestion Tax Zone and Toll Points Map*



Source: Swedish Transport Agency, https://www.transportstyrelsen.se/sv/vagtrafik/fordon/skatter-och-avgifter/trangselskatt/trangselskatt-i-stockholm/, accessed 9 June 2025.

Table 6: *Toll Amount by Time – Inner City (High & Low Season)*

Time Interval	Toll Amount (SEK) – High Season	Toll Amount (SEK) – Low Season
06:00–06:29	15	15
06:30–06:59	30	25
07:00–08:29	45	35
08:30–08:59	30	25
09:00–09:29	20	15
09:30–14:59	11	11
15:00–15:29	20	15
15:30–15:59	30	25
16:00–17:29	45	35
17:30–17:59	30	25
18:00–18:29	20	15

Source: Swedish Transport Agency https://www.transportstyrelsen.se/sv/vagtrafik/fordon/skatter-och-avgifter/trangselskatt/trangselskatt-i-stockholm/, accessed 9 June 2025.

Table 7: *Toll Amount by Time – Essingeleden (High & Low Season)*

Time Interval	Toll Amount (SEK) – High Season	Toll Amount (SEK) – Low Season
06:00–06:29	15	15
06:30–06:59	27	22
07:00–08:29	40	30
08:30–08:59	27	22
09:00–09:29	20	15
09:30–14:59	11	11
15:00–15:29	20	15
15:30–15:59	27	22
16:00–17:29	40	30
17:30–17:59	27	22
18:00–18:29	20	15

Source: Swedish Transport Agency, https://www.transportstyrelsen.se/sv/vagtrafik/fordon/skatter-och-avgifter/trangselskatt/trangselskatt-i-stockholm/, accessed 9 June 2025.

Table 8: *Days Exempt from Congestion Tax*

Exempt Day
Saturdays and Sundays
Public holidays
The day before a public holiday, except: • Day before Good Friday • Day before Ascension Day • Day before All Saints' Day • Day before May 1st (if on a weekday except Saturday) • Day before National Day (if on a weekday except Saturday)
July, **except for the first five weekdays** (excluding Saturdays) of the month

Source: Swedish Transport Agency, https://www.transportstyrelsen.se/sv/vagtrafik/fordon/skatter-och-avgifter/trangselskatt/trangselskatt-i-stockholm/, accessed 9 June 2025.

Table 9*: Season Duration Definitions*

Season	**Time Period**
High Season	March 1 – Day before Midsummer Eve, August 15 – November 30
Low Season	All Other Time

Source: Swedish Transport Agency, https://www.transportstyrelsen.se/sv/vagtrafik/fordon/skatter-och-avgifter/trangselskatt/trangselskatt-i-stockholm/, accessed 9 June 2025.

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