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Barcelona Superblocks – can effective urban planning of low emission zones reduce traffic and pollution levels in cities?

Author

Yannick Haf

(580238)

Supervisor

Prof. Dr. Elbert Dijkgraaf

Second assessor

Prof. Dr. Frank van Oort

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Abstract

Low emission zones are areas of limited traffic which have been implemented in various cities around the world in an effort to reduce congestion and pollution levels. The municipality of Barcelona has constructed multiple Low emission zones in the city according to the Superblock (Superislas/Superilles) program, an extensive green urban design plan whose effectiveness is analysed in this paper. As reducing vehicle emissions contributes substantially to improving citizen's health, it is important to study whether the constructed Superblocks actually help curb traffic and pollution. To my knowledge, Superblock effectiveness using city-wide data has not yet been assessed and there has not yet been an attempt to measure what the reduction of traffic and pollution levels caused by the Low emission zones might be. Using a series of dummy variables which capture the end date of construction of each block, this paper sets out to find the change in traffic and pollution caused by each Superblock. The results indicate that Superblocks might have both increasing and decreasing effects depending on certain characteristics, their location and whether they are close to public amenities such as schools. It is important to further analyse exactly which of these attributes determine whether a Superblock has a potentially detrimental or beneficial effect, since this research strongly helps our understanding of how Low emission zones can be used as a helpful tool to reduce congestion or pollution.

1. Introduction

1.1. Green Urban Design Planning

Ever since cars have become affordable to the mainstream consumer, cities have accommodated this by building supporting infrastructure, such as roads, parking spaces and highways. Modern and progressive cities however have been trying to limit the use of cars in an effort to lower traffic accidents, reduce heat island effects or to decrease pollution levels. There have been different approaches to limiting traffic and pollution, such as implementing congestion charges (drivers are charged to enter city centres), controlling parking availabilities (curtailing parking spaces) or setting up limited traffic zones (where cars cannot enter into a predetermined perimeter). According to a meta-analysis conducted by Kuss and Nicholas (2022), limiting traffic in certain city areas can reduce city-centre cars by around 10%-20%. Some cities, such as Barcelona, are implementing car-free zones within the city centre and creating public spaces which in the past were occupied by high volumes of traffic. These reclaimed zones are referred to as Superblocks, or Superilles/Superislas.

1.2. Superblocks Program Barcelona

The idea behind the Superblock program in Barcelona is simple: The city has a comprehensive plan of grouping together neighbouring city blocks, marking them as reduced-velocity or car-free zones and placing public amenities within them, such as benches, picnic tables or playgrounds. Traffic is restricted within these areas, while the bulk of it is diverted around the Superblocks. The main goal of this urban planning initiative is to improve the quality of life for residents in the block by lowering pollution and noise levels, improving traffic safety and by encouraging social activity. Barcelona has historically scored very low on European air quality standards: The EU limit value (as is also recommended by the World Health Organization) for NO2 is $40\mu g/m^3$ of annual mean emissions for example; a value that the city of Barcelona has exceeded between 1996-2011 (Cuevas et al., 2014). These high levels of pollution motivated the city to come up with a plan on combating air pollution, which lead to the Barcelona Air Quality Improvement Plan (PMQAB)[1]. The comprehensive plan includes different actions which are all aimed at improving the city's air quality, including also the Superblock program.

2. Literature Review

The fact that pollution is detrimental to health is widely accepted yet the effectiveness of different measures and policies put into place to tackle this are not explored very thoroughly. The question whether low emission zones (LEZs) actually reduce pollution in cities is a rather difficult one to which there is no clear answer. Holman, Harrison and Querol (2015) analysed

[1] http://hdl.handle.net/11703/83944

whether the implementation of LEZs actually improved urban air quality in five EU countries (Italy, Germany, Denmark, UK and the Netherlands), with mixed results. In their study, they found that there were some subtle reductions in pollution levels of PM10, PM2.5 and NO2, yet due to a multitude of confounding factors, daily meteorological variations and an unclear distinction from the effects of other policies that were put into place, causal interference was doubtful. Boogaard et al. (2012) focused on a sample of Dutch cities, including other locations as controls and compared emissions before and after the establishment of LEZs. Even though traffic levels seemed to be substantially lower once the zones were established, the actual reduction in traffic-related pollutants was insignificant.

The concept of a Superblock is not new. Many cities around the world have already implemented their own versions of the block, such as in London, Singapore or Stockholm (Wang et al., 2017) or in Milan, Rome and Paris (Ku et al., 2020), each city with their own specific adaptation of the concept. In the context of Barcelona, the LEZ scheme was developed by Salvador Rueda, the former director of the Urban Ecology Agency of Barcelona, the so-called UEAB (Agencia de Ecologia Urbana de Barcelona). Superblocks can be seen as a basic unit for reorganizing the city, with an improvement of quality and liveability for residents of a Superblock and a reduction of the total number of private vehicles at the heart of the design. A block usually consists of around 400m x 400m of space where cut-through traffic (the type of traffic that simply passes through an area without starting or stopping within that area) is limited or even prohibited (Rueda, 2014). Between 2015 and 2020 for example, the city of Barcelona has transformed 33km of street and 3.9ha of squares into car-free zones in the Eixample district alone, adding 33.4ha of pedestrian space for residents. The city also estimates that any local resident is a maximum of 200m from an implemented Superblock (Ayuntamiento de Barcelona, 2022). This allows easy access for all residents of the district to the designated car-free zones.

To the best of my knowledge, only measurements of traffic flows, noise intensities and pollution levels have been conducted by the city of Barcelona within or around the blocks, yet there is no direct empirical analysis of the effect of urban transformation by Superblocks on city-wide pollution and traffic levels. Studies have been conducted on the health effects of local block residents, such as with Mueller et al. (2020): The researchers estimated the number of lives saved due to the implementation of Superblocks, using what policymakers estimated the pollution reductions to be. By taking into consideration the ex-ante estimated increases in physical activity, drops in air pollution (NO2), reductions in road traffic noises and mitigation of the heat island effect, which were then scaled by their relative risk on human health, the effect on lives saved was calculated. Mueller et al. believe that around 667 premature deaths a year could be prevented if all planned 503 Superblocks were to be built. The study however solely focusses on residents within a Superblock and does not include the entire city of Barcelona.

Another approach in determining whether Superblocks have a positive effect on pollution levels was conducted by Rodriguez-Rey et al. (2022), where traffic flows and pollution patterns are simulated based on different LEZ scenarios. The authors conclude that if traffic demand stays the same, implementing isolated Superblock areas of reduced traffic has no effect on overall emissions. Only local changes of pollutant concentrations take place because cars are being re-routed, creating new pockets of bottlenecks. This re-routing of traffic is an important criticism of the Superblocks program; even though traffic might be reduced within the designated perimeters, vehicles could simply be directed around the Superblocks and thus cause congestion in other parts of the city. This would then lead to the same or possibly even higher pollution levels in different places around the low emission zones and would speak against their effectiveness. This is due to the fact that while road capacity would be decreased, traffic demand might remain unchanged, leading to a higher number of traffic jams and with it an increase of pollution. For this reason, city-wide traffic levels and pollution measurements will be analysed in this paper.

The goal of this paper is to explore whether there is a link between the construction of Superblocks and a reduction in traffic levels and with it pollution levels. Does the implementation of Superblocks lower pollution and traffic levels? This paper sets out to answer whether LEZs in Barcelona actually achieve what they were designed to do – to reduce congestion. Unlike the previously conducted studies on the Superblock program in Barcelona, this paper contributes to the literature of LEZ effectiveness by drawing directly on traffic and pollution data of the city of Barcelona. Many previously performed studies analyse the potential effects of ex-ante estimated reductions of pollution or traffic and their subsequent effect on factors such as human health – this paper sets out to actually measure what the ex-post pollution and traffic reductions caused by the implementation of Superblocks might be.

3. Methodology

3.1. Regression and estimation method

In order to measure the effect that the construction of Superblocks has on city-level pollution and traffic the following regressions will be used:

$$Traffic_t = \beta_0 + \beta_1 SB_1 +_{\dots} + \beta_n SB_n + \beta_{n+1} Timetrend_t + Controls_t + \varepsilon_i$$

and

$$Traffic_t = \beta_0 + \beta_1 Superblocks + \beta_2 Timetrend_t + Controls_t + \varepsilon_i$$

A similar specification exists for pollution levels:

$$Pollution_t = \beta_0 + \beta_1 SB_1 +_{\dots} + \beta_n SB_n + \beta_{n+1} Timetrend_t + Controls_t + \varepsilon_i$$

and

$$Pollution_t = \beta_0 + \beta_1 Superblocks + \beta_2 Timetrend_t + Controls_t + \varepsilon_i$$

Where $Pollution$ is the measured average pollution level for different pollutants in the city during a given period of time (a list of polluters can be found below), $Traffic$ are the levels of traffic for different times in the city and SB_m is a dummy for each Superblock constructed in Barcelona, which takes on the value 1 once the block is fully functional (once construction finishes) and 0 otherwise. The different Superblocks (SB) are numbered for convenience (SB1, SB2, …, SBn), the index “m” represents the order in which the blocks where numbered. They are simply numbered in the order in which they appear on a list received by the city of Barcelona, they are in no specific order. An abbreviated version of the received list of the blocks and their assigned abbreviation can be found in the appendix section. Furthermore, a variable which increases by one unit every time a Superblock is built was added to a separate regression, denoted by $Superblocks$. This variable serves as a count for the number of blocks in the city. $Timetrend$ is a continuous trend variable that increases by one unit monthly. The trend is added in order to control for unobservable effects that might influence the general direction the dependent variable of interest might move to, such as a general shift of the population away from cars, for instance due to lifestyle changes or increased environmental awareness, which might otherwise erroneously be captured by the effects of the blocks. The importance of using time-varying factors is also highlighted in LEZ studies such as work done by Boogaard et al. (2012) and Davis (2008). $Controls_t$ is a set of covariates. Population, income and infrastructure variables are usually included in the LEZ-analysis literature, as with Bernardo, Fageda and Flores-Fillol (2021), Börjesson et al. (2012) and Santos et al. (2019). The population variable used in this study is the number of inhabitants of Barcelona, as a measure of income the income per capita of Barcelona's residents is used and lastly the number of parking spaces in the city will serve as an infrastructure control. The error term is denoted by ε.

3.2. Data

3.2.1. Pollution

The Spanish government provides historic data on 9 different pollutants which are captured by different measuring stations throughout the country. The city of Barcelona has numerous measuring stations that record pollutant levels, depending on the chemical of interest. The data is taken from up to 7 different measuring stations located throughout Barcelona, hourly for every day from 2001, 2003 or 2004 until 2020, depending on the pollutant[2] (the available data is recorded from 2003-2020 for CO, from 2004-2020 for O3 and from 2001-2020 for SO2 and NO2). According to different national health agencies, such as the Centres for Disease Control and

[2] https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/calidad-del-aire/evaluacion-datos/datos/Datos_2001_2019.aspx

Prevention[3] (CDC) in the United States or the European Environment Agency[4] (EEA), so-called "criteria" pollutants exist, which are the ones most stringently monitored during air quality analyses, since it is crucial to regulate them for the sake of human and environmental health. Of these criteria pollutants, the city of Barcelona has detailed data on nitrogen dioxide (NO2), carbon monoxide (CO), ground-level ozone (O3) and sulphur dioxide (SO2). The aforementioned pollutants may be produced by a variety of different sources, yet a main reason for their existence in cities are due to the presence of cars, especially diesel-engine vehicles (Reşitoğlu, Altinişik, & Keskin, 2015). Even Ozone can be caused by ground-level vehicle pollution ("Cars, Trucks, Buses and Air Pollution", 2008). All of the mentioned pollutants are measured in µg/m^3, apart from CO which is measured and recorded in mg/m^3. To get measurements for the city as a whole, and not simply recordings from certain neighbourhoods where stations are located, the average hourly recordings for all stations were computed. This means that every hour the recordings for each station in the city were averaged to produce a value for an average pollution level of the whole city. Summary statistics, a visual distribution of the data over time and a boxplot showing outliers are included below.

Variable	Observations	Mean	Std. Dev.	Min	Max
CO	41,394	0.32	0.12	0.15	2.05
O3	42,006	57.04	18.55	6.1	150.08
SO2	42,006	2.5	0.65	1.17	12
NO2	42,006	24.44	11.83	3.71	96.79

Figure 1: Descriptive statistics for the pollutants included in the analysis.

[3] https://www.cdc.gov/air/pollutants.htm
[4] https://www.eea.europa.eu/themes/air/air-pollution-sources-1

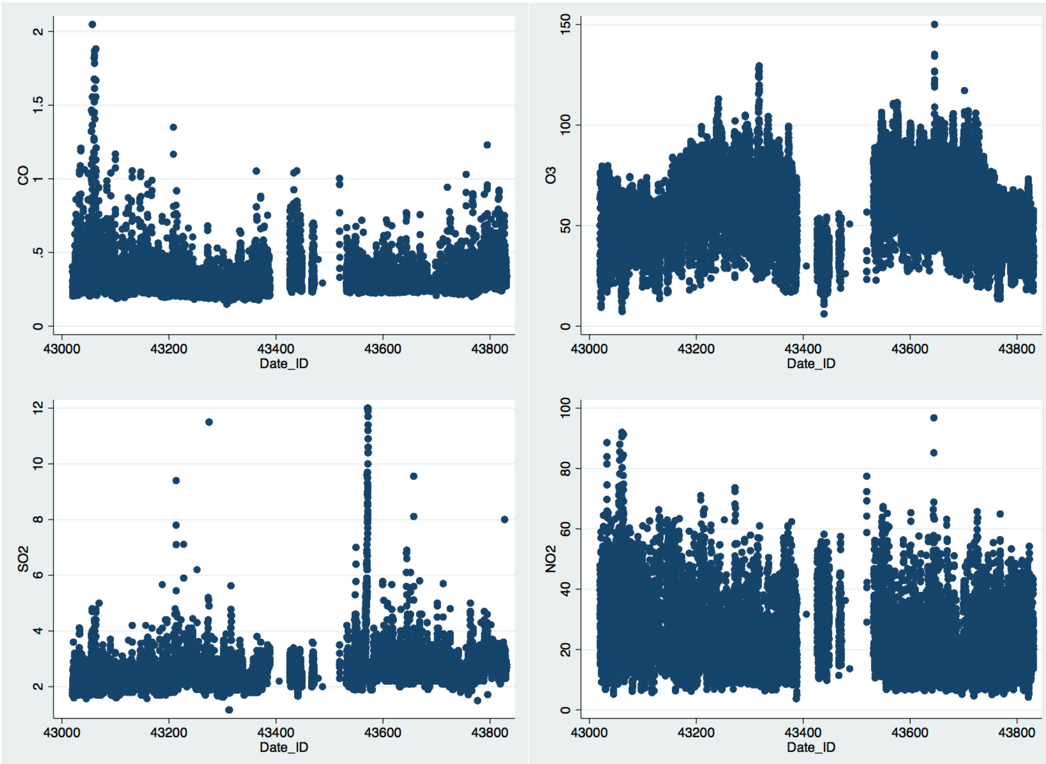

Figure 2: From top left to bottom right: Levels of CO, O3, SO2 and NO2 as a function of time (from the 11th of October 2017 to the 31st of December 2019.

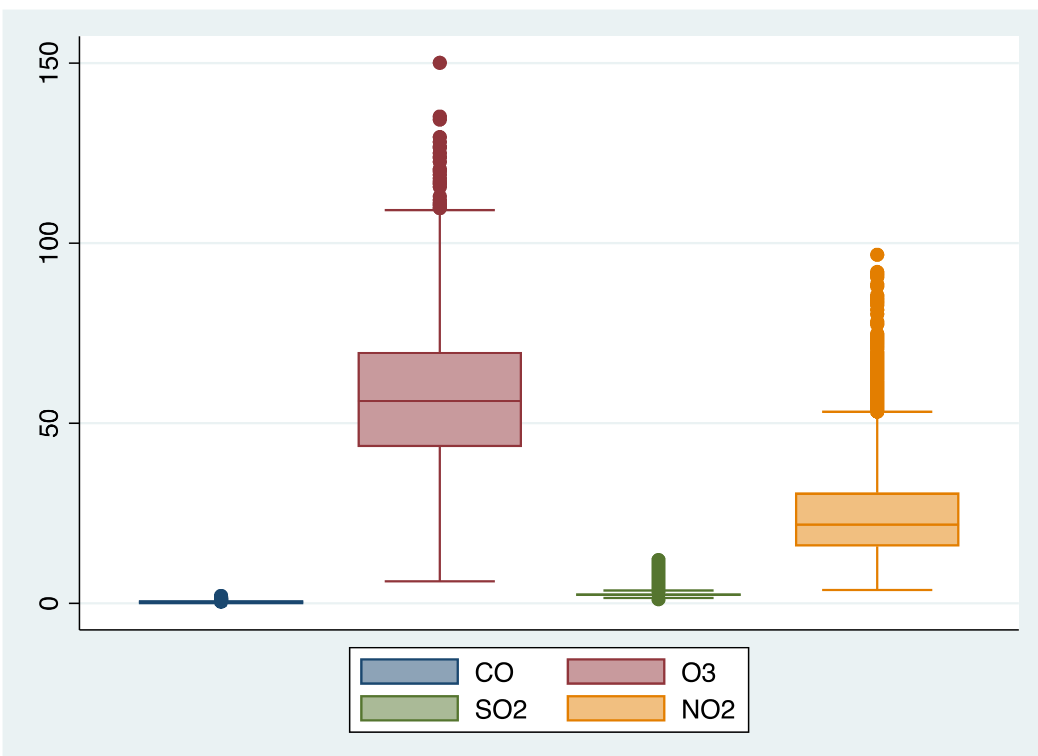

Figure 3: Boxplot of the traffic level data points and its outliers beyond the 5th and 95th percentiles.

3.2.2. Traffic

Traffic data is obtained from the web mapping service Google Maps and compiled by the website "Traffic Index"[5]. Traffic index calculates the total city traffic by using Google Maps' colouring system. Every 20 minutes, an image containing the traffic data reported by Google Maps is saved to the system. This image colour-codes all the streets of Barcelona depending on the traffic intensity. The percentage of coverage for each colour is then weighted and a total traffic intensity is calculated. There are four traffic colours which are green (P_0) orange (P_1), red (P_2) and dark red (P_3), the sum of the colour coverage will always equal 100 ($P_0 + P_1 + P_2 + P_3 = 100$). The formula for calculating the Traffic Congestion Index (TCI) is the following:

$$TCI = (0 \times P_0) + (1 \times P_1) + (2 \times P_2) + (3 \times P_3)$$

The minimum value of TCI is 0, which means no traffic at all, the maximum value of TCI is 300, which means absolute congestion. The data is available starting on the 11th of October 2017, with three hourly reported traffic levels (every 20 minutes a new snapshot of traffic is reported). Congestion is measured for the city as a whole. The terms TCI, $Traffic$ or "traffic levels" will be used interchangeably throughout this paper. For the analysis, daily windows of rush hour will be used, which was chosen to be from 7AM to 9AM in the mornings and 5PM to 7PM in the evenings, according to data gathered by the location technology company TomTom[6]. This means that every day there are 12 total traffic recordings taken into account for the regression, every 20 minutes during the two 2-hour windows (for example daily at 7:02, 7:22, 7:42, 8:02, 8:22 and 8:42 o'clock, and the same in the evening).

5 http://trafficindex.org/barcelona/

6 https://www.tomtom.com/en_gb/traffic-index/barcelona-traffic/

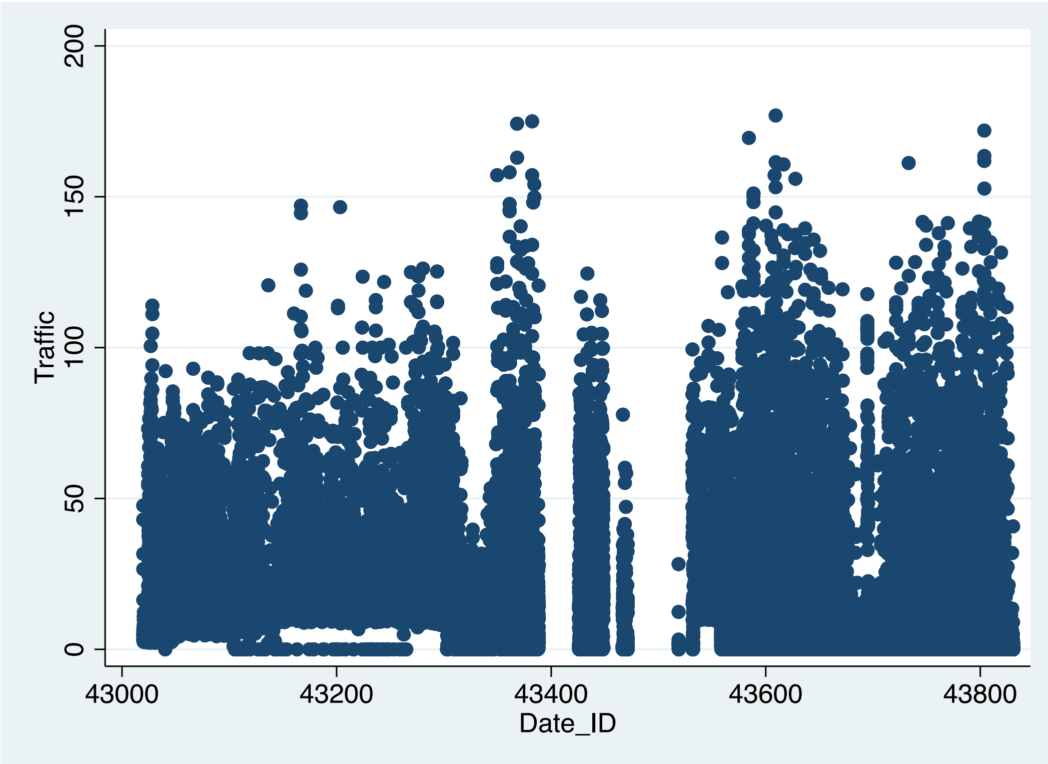

Figure 4: Traffic levels in the city of Barcelona starting from the 1.10.17 to the 31.12.19.

Variable	Observations	Mean	Std. Dev.	Min	Max
Traffic	42,000	15.35	20.23	0	176.93

Figure 5: Descriptive statistics for traffic data.

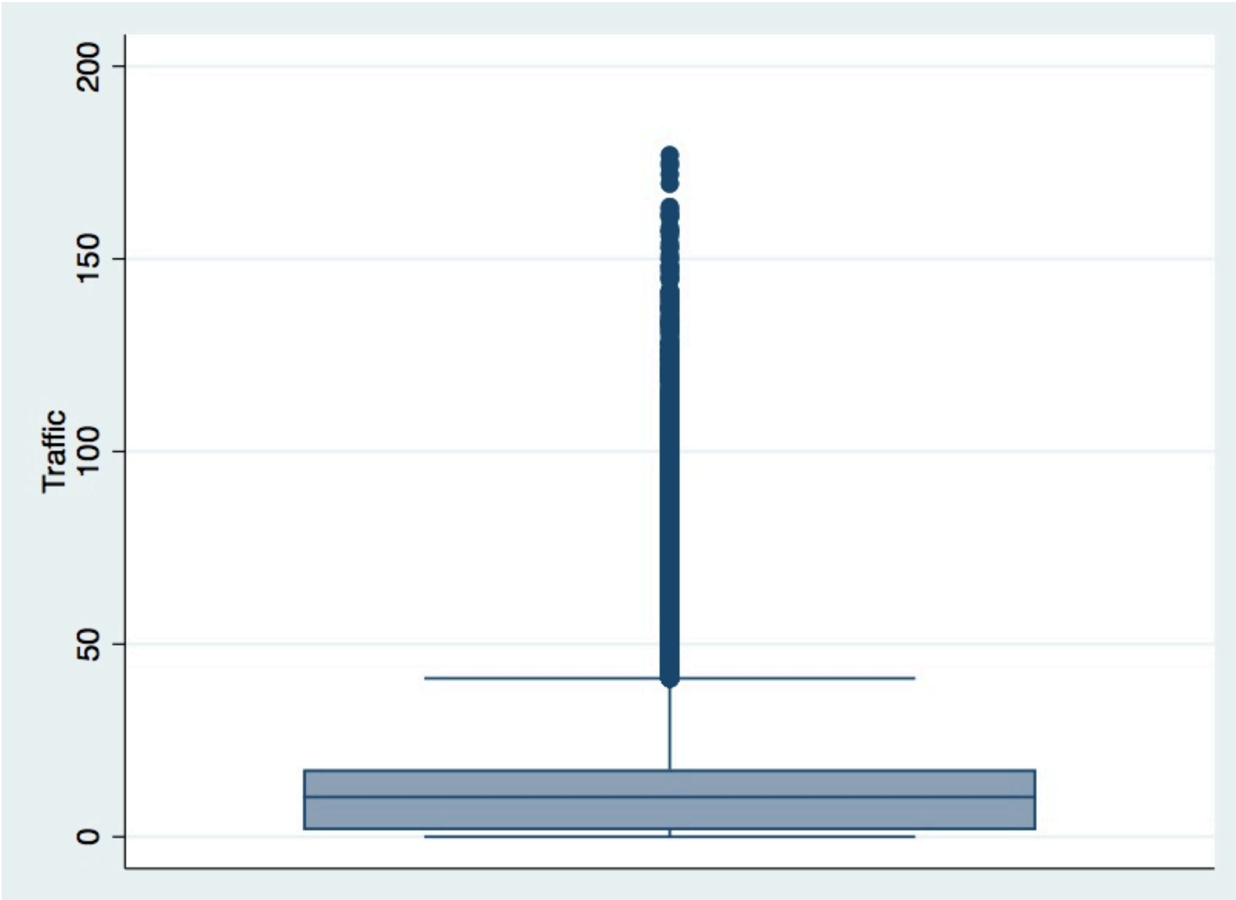

Figure 6: Boxplot of the traffic level data points and its outliers beyond the 5th and 95th percentiles.

3.2.3. Superblocks

A list of the built Superblocks during the 2017-2020 period was provided by the town council of Barcelona (Ayuntamiento de Barcelona). There are 5 major Superblock areas in the city of Barcelona, three of which have data on construction beginning and end dates and there are a total of 18 “variations” in the blocks throughout the analysed timespan. The other two blocks have information on the year (and not the exact day) of the end of construction, which will be assumed to be different dates (for the initial analysis the dates were chosen to be the 1st of July) and a sensitivity check will be performed thereafter to test these different dates. The Superblock in Sant Antoni for example began its construction in February of 2017 and various extensions of the car-free zone were added in different phases in the following two years. These extensions allow for changes and variations in the quantity of Superblocks to be exploited by looking at how additional blocks and their extensions change traffic levels during certain daily timeframes. The end dates of construction of the blocks were then gathered from the official Superblock program website of the government[7] and the so-called "web de obras"[8], an overview of public construction work being done throughout the city. The 5 major LEZs built in this time frame were the Superilla Horta, Superilla Sant Gervasi, Superilla Sant Antoni, Superilla Poblenou and Ejes Verdes Sant Martí (green axes Saint Martin). They were built and extended between the mentioned dates and for the analysis the construction end dates are used, since the interest of this paper is determining the effect a Superblock has on traffic and pollution once it is fully operational. There are three different "types" of construction that were performed on the blocks, "Basic", "Tactical" or "Structural", depending on how extensive construction works were and which amenities were added. The type is also included in the data. These different types of construction show the intensity of performed construction works, ranging from simple changes (basic, such as adding a sign for a 10km/h speed zone) to medium ones (tactic, such as changing the direction of traffic flow on a road) to rather heavy construction (structural, such as widening pedestrian walkways and/or narrowing roads).

As mentioned above, two separate approaches of including Superblocks in the regression are used. The first is treating every Superblock extension (so regardless of the type of construction) as an additional dummy, which then takes on the value 0 before implementation and 1 thereafter. As an example, the Superblock in the area of Poblenou would then take on the value 1 when it is first constructed ($Poblenou1 = 1$), another dummy, $Poblenou2$, then takes on the value 1 as soon as a 10km/h sign is added to the Superblock area. This will be helpful in understanding the size of the effect of the LEZs. Furthermore, a dummy will be included that adds up all the changes (and increases by one unit every time there are any additions to any Superblocks in Barcelona), which would measure the total effect of the blocks. The disadvantage of this specification is that one has to assume the Superblocks are all of equal size, which is not the case in reality. Data on the exact size of all of the Superblocks was also not found. Lastly, the

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[7] https://ajuntament.barcelona.cat/superilles/ca

[8] http://w20.bcn.cat/web_obres_map/obras_es.aspx#x=32902&y=83802&z=5&c=O101&w=963&h=496&i=es&p=29376.747,81749.578&m=IDESTAT:FINALITZADA

date of finalization of construction is used as the date the Superblock dummies take on the value 1, since the research interest of this paper is to find out the effect of the blocks once they are fully operational.

3.2.4. Population

In order to measure the population of Barcelona during the analysed period, the Institute of Statistics of Catalonia estimate the so-called seasonal population[9]. The seasonal population measures the number of people in a municipality on a quarterly average, where people that live, work, study or spend some period of time (such as a vacation or weekends) are included in the estimates. Both staying at their own residences and those staying in other establishments (such as in friends' houses or hotels) are taken into account. The unit of measurement is the so-called annual full-time equivalent people (ETCA), which stems from the Catalan "persones equivalents a temps complet annual". If a person spends a single day in Barcelona, this would be 1/365 ETCA, a person spending a week on vacation in the city would count as approximately 0.02 ETCA. This variable seeks to capture the inflow of non-residents and the outflow of residents. The frequency is quarterly from 2017-2019.

3.2.5. Household Income

Disposable household income per capita in the city of Barcelona[10]. The data is available in a yearly frequency and is measured in Euros/year.

3.2.6. Parking

As is common in the literature, a proxy for the quality of vehicle infrastructure is added as a control. The data is taken from the Municipality of Barcelona and supplies the number of public

[9] https://www.idescat.cat/pub/?id=epe&n=9523&geo=mun:080193#Plegable=geo
[10] https://opendata-ajuntament.barcelona.cat/data/en/dataset/renda-disponible-llars-bcn

parking spaces available to the residents of the city[11]. The variable is measured in the number of yearly parking spaces.

Descriptive statistics for the three variables Population, Household Income and Parking can be found below.

Variable	Observation	Mean	Std. Dev.	Min	Max
Population	9	1,758,398	75,794	1,653,848	1,833,089
Income	3	20,512	504	19,781	20,994
Parking	3	694,373	4,787	682,539	697,286

Figure 7: Descriptive statistics for the variables Population, Income and Parking.

3.2.7. Period

The period being analysed will be from the 11th of October 2017 to the 1st of January 2020. The starting date marks the beginning of traffic level recordings that were available to me and the end date is when Barcelona implemented a type of city-wide low emission zone in January 2020—an area of 95 square kilometres where vehicles without a certain environmental classification are prohibited from entering. This environmental policy coupled with the start of the COVID-19 pandemic (and with it the implementation of nation-wide lockdowns in Spain in March of 2020) might likely bias any estimates, which is why the 31st of December 2019 was chosen as the end date.

4. Results

4.1.1. Individual Superblocks and summed up Superblocks

In a first step, the Superblock dummies were regressed on traffic levels. All 18 variations (and the corresponding end dates of construction) were used in the regression, although on four separate

11 https://ajuntament.barcelona.cat/estadistica/castella/Estadistiques_per_temes/Transport_i_mobilitat/Mobilitat/Circulacio/Aparcaments_i_guals/v101.htm

occasions various dummies had to be summed up in order to avoid issues with multicollinearity. This problem might arise due to the fact that multiple extensions were carried out at the same day, for instance in the area of Poblenou, where on the 30^{th} of March 2018 three streets were simultaneously incorporated into the same Superblock. The controls for a time trend, population, income and parking spots were also added. The two different specifications are presented in each column, one including all the individual blocks and the other including the summed up blocks. In addition, as shown in the data section, there are some outliers present in the data and so a regression for each specification using an untrimmed and "trimmed" (where any outliers for traffic beyond the 5^{th} and 95^{th} percentiles were omitted) dataset was run. Out of the 6978 observations, 858 were left out of the analysis after the trimming was performed. Lastly, only rush hour times as defined in the methodology section are considered. Column (1) shows all individual Superblocks, column (2) shows individual Superblocks with the trimmed dataset, column (3) shows the summed up Superblocks and column (4) displays the summed up Superblocks again without outliers. The output can be found below.

	Traffic			
	(1)	(2)	(3)	(4)
Variables				
SB1	-1.560	8.380**		
	(-0.36)	(3.23)		
SB2	12.18**	10.46**		
	(3.15)	(4.19)		
SB3 + SB4 + SB5	-4.563**	-1.277**		
	(-6.39)	(-2.89)		
SB6	0.461	-3.370		
	(0.09)	(-1.09)		
SB7	-2.663	-9.230**		
	(-0.50)	(-2.88)		
SB8	-9.220*	-8.624**		
	(-2.44)	(-3.78)		
SB9	-0.522	-1.292		
	(-0.27)	(-1.15)		
SB10 + SB11 + SB12	-7.691**	-3.849**		
	(-9.71)	(-8.07)		
SB13 + SB14	11.61**	10.98**		
	(6.13)	(9.49)		
SB15	-6.708*	-2.092		
	(-2.08)	(-1.09)		
SB16 + SB17	-4.421**	-1.999**		
	(-5.47)	(-4.02)		
SB18	26.42**	17.79**		
	(6.07)	(7.06)		
Superblocks			-1.035**	-0.411**
			(-6.94)	(-4.45)
Month	1.099**	-0.634**	2.035**	0.390*
	(3.00)	(-2.83)	(7.82)	(2.38)
Population	0.00004**	0.000008	0.00009**	0.00003**
	(5.90)	(1.62)	(18.94)	(12.42)
Income	-0.0215**	-0.00411*	-0.0217**	-0.00855**
	(-7.93)	(-2.34)	(-10.32)	(-6.38)
Parking	0.000186	0.000274**	-0.000591**	-0.000144*
	(1.51)	(3.53)	(-6.52)	(-2.55)
Observations	6978	6120	6978	6120
Adjusted R^2	0.09355	0.13724	0.06512	0.10255

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 1: Superblocks are regressed on traffic. The table reports the coefficients obtained from regressing the Superblock variables on traffic levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM). Column (1) displays the individual Superblocks and controls such as a time trend, population size, household disposable income and parking spots in the city. Column (2) displays the same variables but any outliers for traffic outside of the 5th and 95th percentiles are omitted. Column (3) shows the results for the summed up Superblock variable and column (4) again uses a trimmed dataset, this time with the summed up Superblocks.

In the first column, one can see that SB3 + SB4 + SB5, SB8, SB10 + SB11 + SB12, SB15 and SB16 + SB17 are all significant and negative, which means that they actually seem to reduce traffic levels. SB2, SB13 + SB14 and SB18 on the other hand seem to have a significant and positive effect. Speaking to the magnitude of the effect, since the average TCI in the studied timeframe is about 15.35, the negative effect of the change in traffic as expressed as a percentage of average TCI is between -28.8% and -60.07% (which are the values of SB16 + SB17 and SB8 respectively), which are the minimum and maximum values for traffic reductions. The change in the increase in traffic which the Superblocks might bring about ranges between 75.64% and 172.13% (SB13 + SB14 and SB18 respectively), which are quite substantial. The time trend seems to be significant and positive, meaning that there was actually an increasing and positive time trend for traffic in the city of Barcelona. A greater population (which in the first column is significant and positive) is related to a higher traffic level, which could be explained by the fact that a rise in the number of people in the city coupled with an unchanged individual demand means more people travelling by car. A greater income seems to have a significantly negative effect on citywide traffic levels. The number of parking spaces in the city does not seem to affect the TCI.

The second column displaying the individual Superblocks using trimmed data shows a different pattern: SB3 + SB4 + SB5, SB7, SB8, SB10 + SB11 + SB12 and SB16 + SB17 seem to have a negative and significant effect on the change in traffic while SB1, SB2, SB13 + SB14 and SB18 are positive and significant. Superblock 1 now becomes significantly positive while others either cease to be significant or remain the same arithmetic sign, albeit with a change in magnitude. The change in traffic now reaches from between -8.32% and -60.14% (SB3 + SB4 + SB5 and SB7 respectively) for the negative Superblocks and between 54.60% and 115.91% (SB1 and SB18 respectively) for the positive ones. With both the trimmed and untrimmed datasets the significantly positive Superblocks seem to have a greater individual effect on the change in TCI than the significantly negative ones. Here the time trend seems to be decreasing, in contrast to the analysis performed with an untrimmed dataset, suggesting less traffic over time. This might be an indication of traffic outliers taking on more extreme maximum values as time increases. Population is no longer significant, income still follows a negative trend and the amount of parking spaces in Barcelona now correlate positively with the amount of traffic.

Columns (3) and (4) might share some insight on the effect of the LEZs as a whole, since single Superblocks have varying effects on traffic in the city. Looking at column (3), the summed up Superblocks seem to significantly decrease traffic. Both trimmed (4) and untrimmed (3) datasets produce the same outcome in terms of the direction of effects: Superblocks, income, and parking all correlate negatively with the TCI while the time trend and population seem to be related to an increase in traffic. Judging by the results above, it seems that individual Superblocks might correlate either with a positive, negative or provoke no change at all in traffic and pollution levels. If this is the case, it is important to take a look at all the blocks together that either increase or decrease these levels, this analysis is done in section 4.1.2. for all dependent variables.

Next, the Superblocks are regressed on different polluters, the results can be found in the tables below. The first table reports the results for the pollutant CO. As with the traffic analysis, Column (1) presents the results of the individual blocks being regressed on carbon monoxide, column (2) displays the same specification but with any outliers outside of the 5^{th} and 95^{th} percentiles removed. Columns (3) and (4) summarize the findings for all Superblocks with an untrimmed and trimmed dataset respectively.

	CO			
	(1)	(2)	(3)	(4)
Variables				
SB1	0.102***	0.0783***		
	(4.62)	(6.24)		
SB2	0.0494**	0.0122		
	(2.50)	(1.15)		
SB3 + SB4 + SB5	-0.0106***	-0.0111***		
	(-2.90)	(-5.43)		
SB6	-0.000485	0.0140		
	(-0.02)	(1.02)		
SB7	-0.0796***	-0.0676***		
	(-2.92)	(-4.43)		
SB8	-0.0257	-0.0244**		
	(-1.33)	(-2.41)		
SB9	-0.00777	-0.0197***		
	(-0.79)	(-3.77)		
SB10 + SB11 + SB12	-0.0132***	-0.00306		
	(-3.25)	(-1.44)		
SB13 + SB14	0.0406***	0.0433***		
	(4.20)	(8.36)		
SB15	0.00730	-0.00538		
	(0.44)	(-0.63)		
SB16 + SB17	-0.00900**	-0.0127***		
	(-2.18)	(-5.71)		
SB18	0.161***	0.0502***		
	(7.25)	(4.33)		
Superblocks			-0.000641	-0.000481
			(-0.85)	(-1.15)
Month	-0.00218	-0.000301	0.00267**	0.00161**
	(-1.16)	(-0.29)	(2.02)	(2.17)
Population	0.00000013***	1.47e-08	0.0000003***	0.0000002***
	(3.28)	(0.70)	(11.66)	(12.33)
Income	-0.00005***	-0.000015*	-0.000046***	-0.0000224***
	(-3.36)	(-1.93)	(-4.28)	(-3.75)
Parking	-0.00000423***	7.00e-08	-0.00000728***	-0.00000195***
	(-6.75)	(0.20)	(-15.80)	(-7.33)
Observations	6978	6134	6978	6134
Adjusted R^2	0.09351	0.06551	0.07569	0.03371

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Superblocks are regressed on CO levels. The table reports the coefficients obtained from regressing the Superblock variables on traffic levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM). Columns (1) and (2) represent the individual Superblocks regressed on the pollutant with an untrimmed and trimmed dataset respectively while columns (3) and (4) show the results for the summed up Superblocks with an untrimmed and trimmed dataset.

The first column suggests that SB3 + SB4 + SB5, SB7, SB10 + SB11 + SB12 and SB16 + SB17 all contribute to a negative change in pollution levels of CO. Positive and significant blocks are SB1, SB2, SB13 + SB14 and SB18. In order to compare the magnitudes of the changes in pollution levels, the obtained results are expressed as percentages of the average pollution in the city of Barcelona from 2003-2019 for CO (which is when the recordings start), which was around 0.484mg/m^3. The greatest significantly negative change is caused by SB7, the construction of which correlates with a change of -16.45% in CO levels, while the greatest positive change in pollution levels comes from SB18 and is around 33.28%. The time trend is not significant, yet population seems to correlate positively while income and parking correlate negatively with CO pollution levels.

Regarding column (2), where the individual blocks are regressed on the trimmed CO dataset, SB3 + SB4 + SB5, SB7, SB8, SB9 and SB16 + SB17 seem to be significant and negative, while SB1, SB13 + SB14 and SB18 seem to be positive. The magnitude of the effects on pollution range between values of -2.29% and -13.97% and 8.95% and 16.18%. Regarding the other covariates, only income seems to be significant and correlates negatively with pollution levels. Columns (3) and (4) both show that the Superblocks as a whole seem to be uncorrelated with CO levels while month and population are significant and positive and income and parking seem to correlate negatively with pollution. A possible reason that the summed up Superblocks variable is insignificant might again be due to individual effects cancelling each other out, which is why section 4.1.2 will analyse the Superblocks grouped by type: pollution-increasing, pollution-decreasing or insignificant. This analysis will be conducted for each pollutant.

Next, the same analysis is performed for the pollutant O3. Again columns (1) and (2) show the individual Superblocks (untrimmed and trimmed respectively) regressed on the pollutant while columns (3) and (4) display the summed up Superblocks value, untrimmed and trimmed respectively:

	O3			
	(1)	(2)	(3)	(4)
Variables				
SB1	-9.535***	-1.230		
	(-3.34)	(-0.45)		
SB2	-6.855***	-6.946***		
	(-2.69)	(-2.66)		
SB3 + SB4 + SB5	4.616***	3.204***		
	(9.81)	(7.65)		
SB6	-10.79***	-14.40***		
	(-3.28)	(-4.39)		
SB7	-0.742	-0.0981		
	(-0.21)	(-0.03)		
SB8	11.03***	8.573***		
	(4.43)	(3.82)		
SB9	-6.501***	-4.522***		
	(-5.13)	(-3.99)		
SB10 + SB11 + SB12	-1.283**	-1.187**		
	(-2.46)	(-2.45)		
SB13 + SB14	-11.40***	-9.034***		
	(-9.13)	(-8.08)		
SB15	-5.299**	-4.626**		
	(-2.49)	(-2.40)		
SB16 + SB17	2.739***	3.083***		
	(5.14)	(6.52)		
SB18	0.925	-16.38***		
	(0.32)	(-4.97)		
Superblocks			-0.657***	-0.480***
			(-6.45)	(-5.10)
Month	-0.600**	-0.493**	-1.547***	-1.120***
	(-2.49)	(-2.26)	(-8.72)	(-6.66)
Population	-0.0000042	0.000004	-0.00006***	-0.000036***
	(-0.84)	(0.82)	(-19.61)	(-12.66)
Income	0.0419***	0.0313***	0.0400***	0.0268***
	(23.42)	(16.95)	(27.88)	(19.18)
Parking	-0.0004***	-0.0002**	0.0009***	0.0008***
	(-4.91)	(-2.48)	(15.10)	(14.59)
Observations	6978	6052	6978	6052
Adjusted R^2	0.26898	0.20933	0.19343	0.13697

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Superblocks are regressed on O3 levels. The table reports the coefficients obtained from regressing the Superblock variables on traffic levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM). Columns (1) and (2) represent the individual Superblocks regressed on the pollutant with an untrimmed and trimmed dataset respectively while columns (3) and (4) show the results for the summed up Superblocks with an untrimmed and trimmed dataset.

Column (1) suggests that SB1, SB2, SB6, SB9, SB10 + SB11 + SB12, SB13 + SB14 and SB15 correlate negatively, while SB3 + SB4 + SB5, SB8 and SB16 + SB17 correlate positively with ozone levels. The time trend and parking are negative and significant while income, unlike during the previous analyses, is positive and significant. Again the values can be expressed as percentages of total average pollution levels: O3 levels from 2004-2019 were on average 52.49µg/m^3. This implies that the changes in O3 levels range from -10.09% to -21.72% (SB15 and SB13 + SB14 respectively) and from 5.22% to 21.01% (SB16 + SB17 and SB8 respectively).

Column (2) displays a similar pattern, where the only changes are SB1, which ceases to be significant and SB18, which is now significant and negative – and which also displays the greatest negative change in O3 levels of either analysis, of around -31.21%. The values of each block only differ slightly from untrimmed to trimmed data. In both columns (1) and (2) the time trend and parking seem to correlate negatively with pollution levels while income is significantly positive.

The Superblock variables in columns (3) and (4) both have similar reducing effects on O3 levels, with -1.25% and -0.91% respectively. In both cases month and population are significantly negative while income and parking are significantly positive.

Again the same analysis is performed with the individual blocks and the summed up blocks regressed on SO2, with an untrimmed (columns 1 and 3) and trimmed (columns 2 and 4) dataset.

	SO2			
	(1)	(2)	(3)	(4)
Variables				
SB1	-0.00503	0.0686		
	(-0.05)	(1.37)		
SB2	-0.713***	-0.677***		
	(-8.62)	(-14.96)		
SB3 + SB4 + SB5	0.0357**	0.00596		
	(2.34)	(0.70)		
SB6	0.399***	0.383***		
	(3.74)	(6.62)		
SB7	0.120	0.120*		
	(1.05)	(1.96)		
SB8	-0.0808	0.0771*		
	(-1.00)	(1.74)		
SB9	-0.206***	-0.137***		
	(-5.03)	(-6.02)		
SB10 + SB11 + SB12	0.0120	0.0376***		
	(0.71)	(4.07)		
SB13 + SB14	-0.00888	-0.0351		
	(-0.22)	(-1.55)		
SB15	0.195***	0.119***		
	(2.83)	(3.17)		
SB16 + SB17	-0.0705***	-0.0305***		
	(-4.08)	(-3.09)		
SB18	0.327***	0.161***		
	(3.52)	(2.68)		
Superblocks			-0.00512	0.00330*
			(-1.61)	(1.84)
Month	0.0230***	0.0258***	0.0143***	0.0179***
	(2.95)	(5.93)	(2.58)	(5.74)
Population	0.000001***	0.00000052***	0.0000009***	0.0000004***
	(5.97)	(5.71)	(8.93)	(7.35)
Income	0.00037***	0.000027	0.00026***	-0.00005**
	(6.36)	(0.83)	(5.78)	(-2.01)
Parking	-0.00002***	-0.00001***	-0.00000343*	-0.00000314***
	(-7.08)	(-6.61)	(-1.78)	(-2.84)
Observations	6978	6415	6978	6415
Adjusted R^2	0.15117	0.24547	0.12831	0.20649

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Superblocks are regressed on SO2 levels. The table reports the coefficients obtained from regressing the Superblock variables on traffic levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM). Columns (1) and (2) represent the individual Superblocks regressed on the pollutant with an untrimmed and trimmed dataset respectively while columns (3) and (4) show the results for the summed up Superblocks with an untrimmed and trimmed dataset.

Column (1) shows that SB2, SB9 and SB16 + SB17 seem to be significant and negative and that SB3 + SB4 + SB5, SB6, SB15 and SB18 seem to be significant and positive. To grasp the magnitude of these effects the values are again expressed as percentages of total average pollution levels, which were 4.95μg/m^3 from 2001-2019. The regression output yields changes in SO2 levels which range from -1.42% to -14.40% (SB16 + SB17 and SB2 respectively) and from 0.72% to 8.06% (SB3 + SB4 + SB5 and SB6 respectively). Month, population and income seem to all be significant and positive while parking is significant and negative.

There are changes in the regression output once the trimmed dataset is used in column (2). SB3 + SB4 + SB5 is now no longer significant, while SB7, SB8 and SB10 + SB11 + SB12 are now significant and positive. The other blocks might have experienced a change in the size of the effect yet no changes in the direction (positive or negative) of the effect. The same blocks as in column (1) produce the greatest/smallest changes in SO2 levels, the values are now -0.62% and -13.67% and 0.76% and 7.73%. Income is no longer significant whereas month and population remain significantly positive and parking significantly negative.

Column (3) shows no significant increase or decrease in pollution levels due to the presence of the Superblocks. All the covariates however are significant: month, population and income correlate positively while parking seems to correlate negatively with sulphur dioxide. The trimmed dataset in column (4) produces similar results regarding the controls in column (3), yet now the summed up Superblock variable is significant and positive, with an increase of 0.07% of total average pollution levels.

Lastly, the analysis is also carried out for the remaining pollutant NO2, again with the individual blocks using an untrimmed (column 1) and trimmed (column 2) dataset and the summed up blocks with untrimmed (column 3) and trimmed (column 4) data.

	NO2			
	(1)	(2)	(3)	(4)
Variables				
SB1	9.868***	5.938***		
	(4.92)	(3.48)		
SB2	4.969***	2.736**		
	(2.77)	(1.97)		
SB3 + SB4 + SB5	-0.429	-0.717***		
	(-1.30)	(-2.64)		
SB6	0.327	3.533*		
	(0.14)	(1.94)		
SB7	-5.570**	-4.472**		
	(-2.25)	(-2.16)		
SB8	-4.170**	-5.191***		
	(-2.38)	(-3.66)		
SB9	-0.214	-1.164		
	(-0.24)	(-1.62)		
SB10 + SB11 + SB12	-0.724**	-0.437		
	(-1.97)	(-1.52)		
SB13 + SB14	6.829***	6.962***		
	(7.77)	(9.83)		
SB15	-1.204	0.247		
	(-0.80)	(0.20)		
SB16 + SB17	-0.124	-0.612**		
	(-0.33)	(-2.00)		
SB18	9.770***	3.123**		
	(4.85)	(2.00)		
Superblocks			0.0285	0.126**
			(0.41)	(2.25)
Month	-0.901***	-0.473***	-0.0714	0.0247
	(-5.31)	(-3.44)	(-0.60)	(0.25)
Population	0.0000041	0.000005*	0.0000244***	0.000025***
	(1.17)	(1.70)	(11.76)	(14.64)
Income	-0.00230*	-0.00478***	-0.00410***	-0.00612***
	(-1.82)	(-4.74)	(-4.22)	(-7.83)
Parking	-0.000188***	7.95e-08	-0.000562***	-0.000330***
	(-3.31)	(0.00)	(-13.44)	(-9.35)
Observations	6978	6193	6978	6193
Adjusted R^2	0.12960	0.11398	0.11200	0.08967

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Superblocks are regressed on NO2 levels. The table reports the coefficients obtained from regressing the Superblock variables on traffic levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM). Columns (1) and (2) represent the individual Superblocks regressed on the pollutant with an untrimmed and trimmed dataset respectively while columns (3) and (4) show the results for the summed up Superblocks with an untrimmed and trimmed dataset.

Column (1) shows that SB7, SB8 and SB10 + SB11 + SB12 all are significant and negative while SB1, SB2, SB13 + SB14 and SB18 are significant and positive. Again these changes in pollution levels are expressed as percentages of total average pollution levels, which for NO2 was 27.0065µg/m^3 from 2001-2019. The values are minimum and maximum decreases of -2.68% and -20.62% (SB7 and SB10 + SB11 + SB12 respectively) and minimum and maximum increases of 18.40% and 36.54% (SB2 and SB1 respectively). Month, income and parking all seem to be negative and significant, while population is not significant.

A similar pattern arises when looking at the "trimmed" results in column (2), here the most significant changes are SB3 + SB4 + SB5 and SB16 + SB17, which are now significant and negative, SB6, which is now significant and positive and SB10 + SB11 + SB12, which is now no longer significant. The significance of the covariates has changed slightly too, where population has now become significant and parking has lost its significance.

Columns (3) and (4) only show a notable difference regarding the Superblocks variable: Superblocks correlate positively with pollution levels in column (4), having an effect of an increase of around 0.47% of average pollution levels (whereas in column (3) the LEZ variable was insignificant). In both cases the time trend is insignificant, Population is positive and significant and Income and Parking both have negative and significant effects on NO2.

In order to compare the results of the effects on the changes in traffic levels and pollution levels, an overview of the effects was added below. One can now see the effects of the individual blocks on each dependent variable, for this analysis the rush hour times were used and the trimmed dataset was analysed.

Variables	(1) Traffic	(2) CO	(3) O3	(4) SO2	(5) NO2
SB1	8.380***	0.0783***	-1.230	0.0686	5.938***
	(3.23)	(6.24)	(-0.45)	(1.37)	(3.48)
SB2	10.46***	0.0122	-6.946***	-0.677***	2.736**
	(4.19)	(1.15)	(-2.66)	(-14.96)	(1.97)
SB3 + SB4 + SB5	-1.277***	-0.0111***	3.204***	0.00596	-0.717***
	(-2.89)	(-5.43)	(7.65)	(0.70)	(-2.64)
SB6	-3.370	0.0140	-14.40***	0.383***	3.533*
	(-1.09)	(1.02)	(-4.39)	(6.62)	(1.94)
SB7	-9.230***	-0.0676***	-0.0981	0.120*	-4.472**
	(-2.88)	(-4.43)	(-0.03)	(1.96)	(-2.16)
SB8	-8.624***	-0.0244**	8.573***	0.0771*	-5.191***
	(-3.78)	(-2.41)	(3.82)	(1.74)	(-3.66)
SB9	-1.292	-0.0197***	-4.522***	-0.137***	-1.164
	(-1.15)	(-3.77)	(-3.99)	(-6.02)	(-1.62)
SB10 + SB11 + SB12	-3.849***	-0.00306	-1.187**	0.0376***	-0.437
	(-8.07)	(-1.44)	(-2.45)	(4.07)	(-1.52)
SB13 + SB14	10.98***	0.0433***	-9.034***	-0.0351	6.962***
	(9.49)	(8.36)	(-8.08)	(-1.55)	(9.83)
SB15	-2.092	-0.00538	-4.626**	0.119***	0.247
	(-1.09)	(-0.63)	(-2.40)	(3.17)	(0.20)
SB16 + SB17	-1.999***	-0.0127***	3.083***	-0.0305***	-0.612**
	(-4.02)	(-5.71)	(6.52)	(-3.09)	(-2.00)
SB18	17.79***	0.0502***	-16.38***	0.161***	3.123**
	(7.06)	(4.33)	(-4.97)	(2.68)	(2.00)
Month	-0.634***	-0.000301	-0.493**	0.0258***	-0.473***
	(-2.83)	(-0.29)	(-2.26)	(5.93)	(-3.44)
Population	0.00000750	1.47e-08	0.000004	0.000000516***	0.00000481*
	(1.62)	(0.70)	(0.82)	(5.71)	(1.70)
Income	-0.00411**	-0.0000148*	0.0313***	0.0000266	-0.00478***
	(-2.34)	(-1.93)	(16.95)	(0.83)	(-4.74)
Parking	0.000274***	7.00e-08	-0.000185**	-0.00000968***	7.95e-08
	(3.53)	(0.20)	(-2.48)	(-6.61)	(0.00)
Constant	-110.5*	0.520*	-434.1***	7.251***	116.4***
	(-1.83)	(1.87)	(-7.48)	(6.25)	(3.14)
Observations	6120	6134	6052	6415	6193
Adjusted R^2	0.13724	0.06551	0.20933	0.24547	0.11398

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: An overview of the effects of the different Superblocks. The table reports the coefficients obtained from regressing the Superblock variables on traffic and pollution levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM) using a trimmed dataset.

For traffic, the following individual blocks are significant and negative: SB3 + SB4 + SB5, SB7, SB8, SB10 + SB11 + SB12 and SB16 + SB17. Superblocks with a positive effect include SB1, SB2, SB13 + SB14 and SB18. The LEZs with a pollution-reducing effect for CO include SB3 + SB4 + SB5, SB7, SB8, SB9, SB16 + SB17 and those with an increasing effect are SB1, SB13 + SB14 and SB18. For O3, SB2, SB6, SB9, SB10 + SB11 + SB12, SB13 + SB14, SB15 and SB18 lower pollution levels while SB3 + SB4 + SB5, SB8 and SB16 + SB17 increase them. For SO2 the pollution-decreasing Superblocks are SB2, SB9 and SB16 + SB17 and the increasing ones are SB6, SB7, SB8, SB10 + SB11 + SB12, SB15 and SB18. Lastly, the blocks that might have a negative effect on NO2 are SB3 + SB4 + SB5, SB7, SB8, SB16 + SB17 and the ones that might have a positive effect are SB1, SB2, SB6, SB13 + SB14 and SB18. Another table was added below to ease the comparison. Green cells are Superblocks that decrease pollution or traffic levels, red cells are those that increase them and values of 0 denote effects that are not significant.

Variables	Traffic	CO	O3	SO2	NO2
SB1	8.38	0.0783	0	0	5.938
SB2	10.46	0	-6.946	-0.677	2.736
SB3 + SB4 + SB5	-1.277	-0.0111	3.204	0	-0.717
SB6	0	0	-14.4	0.383	3.533
SB7	-9.23	-0.0676	0	0.12	-4.472
SB8	-8.624	-0.0244	8.573	0.0771	-5.191
SB9	0	-0.0197	-4.522	-0.137	0
SB10 + SB11 + SB12	-3.849	0	-1.187	0.0376	0
SB13 + SB14	10.98	0.0433	-9.034	0	6.962
SB15	0	0	-4.626	0.119	0
SB16 + SB17	-1.999	-0.0127	3.083	-0.0305	-0.612
SB18	17.79	0.0502	-16.38	0.161	3.123

Table 7: An overview of the effects of the different Superblocks. The table reports the coefficients obtained from regressing the Superblock variables on traffic and pollution levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM) using a trimmed dataset. This table colour-codes the results from table 6 in a way were traffic/pollution-decreasing blocks are highlighted in green, blocks with an increasing effect are red and the zeros show insignificant Superblocks.

4.1.2. Grouped Superblocks

For an overview of the Superblocks and the magnitude of their different effects on the changes in pollution levels, table 8 was added below. The table summarizes the first column of every regression of the individual blocks on the different polluters, which are the coefficients obtained from regressing the Superblock variables on traffic levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM). These coefficients are then expressed as percentages of total average pollution.

Superblock	CO	O3	SO2	NO2
SB1	21.08%	-18.16%	0	36.54%
SB2	10.21%	-13.06%	-14.40%	18.40%
SB3 + SB4 + SB5	-2.19%	8.79%	0.72%	0
SB6	0	-20.56%	8.06%	0
SB7	-16.45%	0	0	-20.62%
SB8	0	21.01%	0	-15.44%
SB9	0	-12.38%	-4.16%	0
SB10 + SB11 + SB12	-2.73%	-2.44%	0	-2.68%
SB13 + SB14	8.39%	-21.72%	0	25.29%
SB15	0	-10.09%	3.94%	0
SB16 + SB17	-1.86%	5.22%	-1.42%	0
SB18	33.28%	0	6.60%	36.18%
Superblocks	0	-1.25%	0	0

Table 8: The coefficients obtained after regressing the individual Superblocks and the summed up Superblocks variable on the different pollutants during rush hour times expressed as percentages of total average pollution levels (which Is measured from 2003-2019 for CO, from 2004-2019 for O3 and from 2001-2019 for SO2 and NO2). The total average pollution levels are 0.484mg/m^3 for CO, 52.49µg/m^3 for O3, 4.95µg/m^3 for SO2 and 27.0065µg/m^3 for NO2. The values were taken from the first column of tables 2-5.

As a note, there is no column featuring the percentage increases/decreases in traffic levels as it is difficult to make statements about the magnitude of the TCI because it is a measure of weighted averages. It is striking that although there might be both increases and decreases in pollution levels caused by the blocks, the summed up Superblock variable either seems to not correlate at all, or in the case of ozone only to correlate very slightly with a reduction in pollution levels. Since it seems that certain Superblocks might cause reductions in pollution levels (or traffic levels) while others might increase them, in a next step the individual blocks are grouped together depending on their effect. For each regression performed in tables 1-5, all the Superblock variables from the respective first columns with the same arithmetic signs are added together in order to produce a new variable. As an example, SB1, SB2, SB13 + SB14 and SB18 are added together in order to produce a "group" variable for pollution-increasing blocks for the analysis of CO levels. The results can be found below.

	(1)	(2)	(3)	(4)	(5)
	(Traffic)	(CO)	(O3)	(SO2)	(NO2)
Variables					
SBnegative	-6.100***	-0.00898***	-4.972***	-0.0277***	-0.823***
	(-14.88)	(-6.52)	(-18.61)	(-4.38)	(-3.09)
SBpositive	9.870***	0.0174***	3.339***	0.0184**	4.059***
	(10.86)	(7.11)	(10.88)	(2.37)	(11.39)
Month	1.307***	-0.0000821	-1.182***	0.0253***	-0.555***
	(5.98)	(-0.10)	(-7.83)	(8.36)	(-6.63)
Population	0.00004***	9.32e-08***	-0.000007**	0.00000043***	0.000015***
	(7.61)	(6.73)	(-2.17)	(7.81)	(7.77)
Income	-0.0226***	-0.000022***	0.0312***	-0.00007***	-0.0055***
	(-10.83)	(-3.81)	(24.01)	(-2.76)	(-7.69)
Parking	0.000379***	-2.73e-08	0.000087	-0.000009***	-0.000068*
	(3.83)	(-0.09)	(1.39)	(-7.18)	(-1.66)
Observations	6978	6134	6052	6415	6193
Adjusted R^2	0.09060	0.05066	0.18992	0.21042	0.10805

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Following the analyses conducted in the first columns of tables 1-5, the individual Superblocks that were negative and significant were summed up, represented by the variable SBnegative, while the Superblocks that were positive and significant were summed up, represented by the variable SBpositive.

Table 9 shows that different Superblocks might have different effects on traffic and pollution. All variables (except for Month in the second and Parking in the second and third columns) seem to be significant. Below is a brief overview of the various Superblock-groups causing increases/decreases in traffic and pollution levels and the districts they are located in. Each cell containing blocks essentially represents the negative and positive groups featured in table 9.

Variables	Negative Superblocks	Locations	Positive Superblocks	Locations
Traffic	SB3 + SB4 + SB5 SB8 SB10 + SB11 + SB12 SB15 SB16 + SB17	Poblenou Sant Antoni Horta Sant Antoni Sant Antoni	SB2 SB13 + SB14 SB18	Sant Antoni Sants/Sant Marti Sant Marti
CO	SB3 + SB4 + SB5 SB7 SB10 + SB11 + SB12 SB16 + SB17	Poblenou Sant Antoni Horta Sant Antoni	SB1 SB2 SB13 + SB14 SB18	Sant Antoni Sant Antoni Sants/Sant Marti Sant Marti
O3	SB1 SB2 SB6 SB10 + SB11 + SB12 SB13 + SB14 SB15	Sant Antoni Sant Antoni Sant Antoni Horta Sants/Sant Marti Sant Antoni	SB3 + SB4 + SB5 SB8 SB16 + SB17	Poblenou Sant Antoni Sant Antoni
SO2	SB2 SB9 SB16 + SB17	Sant Antoni Sant Antoni Sant Antoni	SB3 + SB4 + SB5 SB6 SB15 SB18	Poblenou Sant Antoni Sant Antoni Sant Marti
NO2	SB7 SB8 SB10 + SB11 + SB12	Sant Antoni Sant Antoni Horta	SB1 SB2 SB13 + SB14 SB18	Sant Antoni Sant Antoni Sants/Sant Marti Sant Marti

Figure 8: For each dependent variable, the Superblocks that increase or decrease traffic and pollution and their locations are featured. The cells containing the blocks essentially represent the groups SBnegative and SBpositive in table 9.

All the Superblocks of the Horta district (SB10 + SB11 + SB12) seem to decrease traffic and pollution levels (of all pollutants except for SO2), they never cause a positive change. SB7, which is located in the Sant Antoni district, also never seems to increase traffic or pollution, as it seems to correlate with a negative change in CO and NO2 levels. SB18 (Sant Marti district) seems to have an increasing effect in all cases but with the pollutant O3. There are some shared characteristics yet also some differences between these three Superblock sections. The LEZ in the Horta neighbourhood, which is comprised of SB10, SB11 and SB12, occupies an area of around 79,452m^2. The majority of the LEZ is made up of so-called “vias veïnales”, which are streets where pedestrians are prioritized and cars adhere to a speed limit of 10km/h. The only type of traffic on a via veïnal is usually only vehicles driven by residents that live on the streets and the vehicles used for the delivery of goods to local businesses. Another street type exists in the Horta LEZ, which is the “via local”: These are one-way streets with a limit of 30km/h. According to estimates of the municipality[12], some 2,000-5,000 vehicles a day used to pass through this LEZ in order to get to the “Ronda de Dalt”, the B20 highway which follows the perimeter of the city. This through traffic is now directed around the Superblock. Lastly, of the three Superblocks mentioned, the Horta Superblock is furthest away from a school (more than 500m). SB7 in Sant Antoni, which also never seems to increase traffic or pollution, is characterized by a bicycle lane, vias veïnales with 10km/h speed limits and is around 200m away from a school. The LEZ area is around 6,145m^2 in size[13]. The last Superblock section, SB18 in Sant Marti, seems to mostly correlate with an increase of traffic and pollution. The block is characterized by a bicycle zone, a via veïnal with a 10km/h speed limit and is located very close to a school (around 150m). The size of this section is around 3,720m^2 and there are also different public amenities, such as a playground for children and benches facing trees and greenery[14]. Based on these traits it is difficult to exactly pinpoint why some Superblocks increase or decrease traffic levels, yet the proximity to schools and size of the blocks might offer a possible explanation. If a Superblock severely inhibits parents’ ability to drop off or pick up their children from school, then especially during rush hour times there might be an agglomeration of vehicles located around the blocks trying to get close to the school. This would further reinforce the hypothesis that Superblocks might cause bottlenecks in different areas of the city if they are not strategically placed, especially if they make it difficult to reach busy areas such as local schools. Furthermore, it seems that SB18 is the smallest of the three analysed Superblocks in terms of square metres. It might be more beneficial to implement bigger LEZs as for instance suggested by Morfeld, Groneberg and Spallek (2014), who analysed LEZs in Germany; if LEZs are big enough so that they can operate together and symbiotically, then this might alleviate the bottleneck effect. Further research could be done in order to discern whether LEZs built close to public facilities or services actually increase traffic and pollution levels relative to those built further away and whether larger unified Superblocks have greater reducing effects than smaller ones.

[12] https://ajuntament.barcelona.cat/superilles/es/content/horta
[13] https://ajuntament.barcelona.cat/superilles/ca/content/sant-antoni
[14] https://ajuntament.barcelona.cat/superilles/es/content/poblenou

As a last discussion point, the covariates also do not always follow the same direction for every analysis. The time trend seems to correlate both positively and negatively when looking at traffic (depending on whether a trimmed or untrimmed dataset is used), positive in the case of CO (whenever it is significant), negative in every case of O3, positive in every case of SO2 and mostly negative regarding NO2. Population is less ambiguous, correlating mostly positively with traffic, CO, SO2 and NO2, while negatively with O3. Income seems to correlate negatively with traffic, CO and NO2 levels yet positively with O3 and SO2. Lastly parking seems to correlate negatively with CO, SO2, NO2 and for the most part ambiguously with traffic and O3. The seemingly haphazard direction of effects might be due to the low number of observations.

5. Discussion

5.1. Robustness and Sensitivity Checks

5.1.1. Robust Standard Errors

In order to check for heteroscedasticity, robust standard errors were used instead of regular standard errors. When working with panel data, there might be an issue of heteroscedasticity if there are great changes in outcomes of the dependent variables over time. Since the time window analysed is around 27 months, the danger of heteroscedastic standard errors could be relatively low – a time frame of multiple decades for example might be more prone to this issue, due to for instance great changes in vehicle demand. Nevertheless, the analyses performed in the results section (tables 1-5) were repeated using robust standard errors, producing very similar results with no significant deviations.

5.1.2. Different Time Trends

In a next step, different time trends were added in order to check the robustness of the specification. Firstly, the individual blocks were regressed on the dependent variables and again rush hour times and the untrimmed datasets were used. In addition to the linear month count, a squared term (Monthsqu) and a squared and cubed term (Monthcube) were added. The results can be found below.

	(1)	(2)	(3)	(4)	(5)
Variables	Traffic	CO	O3	SO2	NO2
SB1	3.809	0.140***	-10.14***	0.131	11.25***
	(0.86)	(6.15)	(-3.45)	(1.37)	(5.45)
SB2	12.40***	0.0510***	-6.879***	-0.707***	5.025***
	(3.21)	(2.59)	(-2.70)	(-8.57)	(2.80)
SB3 + SB4 + SB5	-2.237***	0.00571	4.354***	0.0945***	0.168
	(-2.62)	(1.31)	(7.74)	(5.19)	(0.42)
SB6	0.461	-0.000485	-10.79***	0.399***	0.327
	(0.09)	(-0.02)	(-3.28)	(3.75)	(0.14)
SB7	-2.663	-0.0796***	-0.742	0.120	-5.570**
	(-0.50)	(-2.93)	(-0.21)	(1.06)	(-2.25)
SB8	-11.10***	-0.0389**	11.24***	-0.128	-4.654***
	(-2.93)	(-2.01)	(4.49)	(-1.59)	(-2.65)
SB9	-3.390*	-0.0279***	-6.178***	-0.279***	-0.950
	(-1.69)	(-2.73)	(-4.67)	(-6.52)	(-1.02)
SB10 + SB11 + SB12	-8.898***	-0.0216***	-1.147**	-0.0185	-1.034***
	(-10.76)	(-5.13)	(-2.10)	(-1.04)	(-2.69)
SB13 + SB14	8.335***	0.0177*	-11.03***	-0.0916**	5.989***
	(4.16)	(1.73)	(-8.34)	(-2.14)	(6.44)
SB15	-7.272**	0.00335	-5.236**	0.181***	-1.349
	(-2.25)	(0.20)	(-2.46)	(2.63)	(-0.90)
SB16 + SB17	-6.173***	-0.0213***	2.937***	-0.115***	-0.573
	(-7.01)	(-4.74)	(5.05)	(-6.11)	(-1.40)
SB18	28.49***	0.176***	0.691	0.379***	10.30***
	(6.53)	(7.89)	(0.24)	(4.07)	(5.09)
Population	0.000021**	-3.75e-08	-0.00000154	0.0000004*	-0.000002
	(2.38)	(-0.83)	(-0.26)	(1.95)	(-0.47)
Income	-0.0234***	-0.0000597***	0.0422***	0.000322***	-0.00278**
	(-8.55)	(-4.28)	(23.32)	(5.51)	(-2.19)
Parking	0.000925***	0.000000951	-0.000481***	0.00000014	0.00000155
	(4.81)	(0.97)	(-3.78)	(0.03)	(0.02)
Month	-2.611***	-0.0282***	-0.182	-0.0707***	-1.853***
	(-3.15)	(-6.66)	(-0.33)	(-3.99)	(-4.81)
Monthsqu	0.139***	0.000972***	-0.0156	0.00351***	0.0356***
	(4.98)	(6.84)	(-0.85)	(5.89)	(2.75)
Constant	-198.3	0.901	-459.2***	-5.158*	87.89
	(-1.53)	(1.37)	(-5.38)	(-1.87)	(1.46)
Observations	6978	6978	6978	6978	6978
Adjusted R^2	0.09664	0.09944	0.26895	0.15527	0.13042

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Superblocks are regressed on independent variables using different time trends. The table reports the coefficients obtained from regressing the Superblock variables on (1) traffic, (2) CO, (3) O3, (4) SO2 and (5) NO2 levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM) using an untrimmed dataset. A squared monthly time trend was added.

The squared time trend variable seems to be significant in all cases but for column (3), for ozone. Comparing the results of each column to the first columns of tables 1-5 one can see that Month is negative, whereas the squared time trend is positive and significant, meaning that there might be first a decrease followed by a later increase in traffic or pollution levels (excluding O3) as time goes on. A linear combined with a squared time trend might provide a good fit in the cases of traffic, CO, SO2 and NO2.

Regarding the effect of the individual Superblocks on traffic (as column (1) shows), the main changes for traffic are that SB9 is now significant (with a negative effect) and parking is now significantly positive. The other blocks only display slight differences in magnitude of effects. For CO, comparing the results of column (1) in table 2 with the results of column (2) in table 10, SB3 + SB4 + SB5 is no longer significant, SB8 and SB9 are now significant and negative and Population and Parking are not significant anymore. The effects of the LEZs with the added squared term on O3 are very similar to the ones in column (1) of table 3, there are no significant changes except for the aforementioned insignificance of Month, indicating that a linear trend might provide a more accurate fit. Regarding SO2, SB13 + SB14 is now significant and negative and Parking is no longer significant. Lastly, in the case of NO2, Parking is now insignificant.

Next, both a squared and cubed time trend are added, the results of which are displayed in table 11.

	(1)	(2)	(3)	(4)	(5)
Variables	Traffic	CO	O3	SO2	NO2
SB1	10.83**	0.129***	-8.888***	0.175*	11.11***
	(2.38)	(5.54)	(-2.94)	(1.79)	(5.23)
SB2	16.41***	0.0451**	-6.163**	-0.682***	4.950***
	(4.21)	(2.26)	(-2.39)	(-8.17)	(2.73)
SB3 + SB4 + SB5	-2.025**	0.00540	4.392***	0.0958***	0.164
	(-2.38)	(1.24)	(7.80)	(5.26)	(0.41)
SB6	0.461	-0.000485	-10.79***	0.399***	0.327
	(0.09)	(-0.02)	(-3.28)	(3.75)	(0.14)
SB7	-2.663	-0.0796***	-0.742	0.120	-5.570**
	(-0.50)	(-2.93)	(-0.21)	(1.06)	(-2.25)
SB8	-9.539**	-0.0412**	11.52***	-0.119	-4.683***
	(-2.52)	(-2.13)	(4.60)	(-1.46)	(-2.66)
SB9	-4.660**	-0.0260**	-6.405***	-0.287***	-0.926
	(-2.32)	(-2.53)	(-4.82)	(-6.68)	(-0.99)
SB10 + SB11 + SB12	-10.40***	-0.0194***	-1.415**	-0.0279	-1.006**
	(-12.17)	(-4.44)	(-2.50)	(-1.52)	(-2.53)
SB13 + SB14	4.835**	0.0228**	-11.66***	-0.114**	6.055***
	(2.34)	(2.16)	(-8.52)	(-2.57)	(6.30)
SB15	-7.402**	0.00354	-5.259**	0.180***	-1.347
	(-2.30)	(0.22)	(-2.47)	(2.61)	(-0.90)
SB16 + SB17	-4.881***	-0.0232***	3.167***	-0.107***	-0.598
	(-5.43)	(-5.04)	(5.32)	(-5.54)	(-1.43)
SB18	22.16***	0.185***	-0.437	0.340***	10.42***
	(4.98)	(8.12)	(-0.15)	(3.56)	(5.03)
Population	0.00001	-2.02e-08	-0.000004	0.0000003	-0.000002
	(1.03)	(-0.44)	(-0.61)	(1.53)	(-0.40)
Income	-0.0145***	-0.0000728***	0.0438***	0.000378***	-0.00295**
	(-4.76)	(-4.68)	(21.72)	(5.80)	(-2.08)
Parking	0.000308	0.0000019*	-0.000591***	-0.000004	0.000013
	(1.44)	(1.70)	(-4.18)	(-0.82)	(0.13)
Month	2.806**	-0.0361***	0.784	-0.0368	-1.955***
	(2.42)	(-6.08)	(1.02)	(-1.48)	(-3.62)
Monthsqu	-0.456***	0.00185***	-0.122**	-0.000224	0.0468
	(-4.87)	(3.85)	(-1.96)	(-0.11)	(1.07)
Monthcube	0.0149***	-0.0000219*	0.00266*	0.0000935*	-0.000281
	(6.65)	(-1.91)	(1.79)	(1.95)	(-0.27)
Constant	67.64	0.511	-411.8***	-3.491	82.88
	(0.50)	(0.74)	(-4.61)	(-1.21)	(1.32)
Observations	6978	6978	6978	6978	6978
Adjusted R^2	0.10222	0.09978	0.26918	0.15560	0.13030

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Superblocks are regressed on independent variables using different time trends. The table reports the coefficients obtained from regressing the Superblock variables on (1) traffic, (2) CO, (3) O3, (4) SO2 and (5) NO2 levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM) using an untrimmed dataset. A squared and cubed monthly time trend were added.

Columns (1) and (2) of table 11, displaying the Superblocks' effects on traffic and CO levels, seem to have significant linear, squared and cubed time trends. In the case of traffic, the time variables indicate a ceteris paribus overall increasing trend ($Traffic = Month_t - Month_t^2 + Month_t^3$), while the trend for CO might be ceteris paribus net decreasing ($CO = - Month_t + Month_t^2 - Month_t^3$). Regarding O3, the variable Month loses its significance while the other time trends seem to be significant, indicating again that a linear trend might prove to be the best fit. For SO2, only the cubed trend is significant and the specification of NO2 does not seem to require a squared and cubed term to be added since they are both insignificant.

For traffic, SB1 is now significant and positive, SB9 is now significant and negative and Population lost its significance. There are minor changes in the magnitude of effects but no other significant changes such as with the aforementioned variables. The analysis of CO shows that SB3 + SB4 + SB5 is now insignificant, SB8 and SB9 are now significant and negative and Population has lost its significance while Parking is now positive.

It is important to note that the effects of Superblocks SB7, SB10 + SB11 + SB12 and SB18 do not change in the sense that they remain mostly negative or positive throughout the analysis. Since some specifications seem to profit from added time trend terms, yet the size of the effect of LEZs seem to depend on the specification chosen, it is imperative to look at aggregate Superblock effects as to see how the effect as a whole might change. Since grouping the Superblocks into a positive and negative group (those that increase or decrease traffic and pollution levels respectively in the first columns of tables 1-5) seems to be a better fit than the summed up Superblock approach, the same robustness check is performed for the grouped Superblocks variables. Again first a squared time trend is added and then both a squared and cubed term:

	(1)	(2)	(3)	(4)	(5)
Variables	Traffic	CO	O3	SO2	NO2
SBnegative	-6.353***	-0.0125***	-5.056***	-0.142***	-1.294***
	(-14.58)	(-4.94)	(-14.92)	(-8.24)	(-3.68)
SBpositive	8.982***	0.0324***	4.354***	0.0739***	4.952***
	(6.95)	(6.01)	(12.49)	(4.78)	(9.79)
Population	0.0000366***	0.000000161***	-0.0000219***	0.000000663***	0.0000122***
	(6.96)	(6.25)	(-6.27)	(6.17)	(5.21)
Income	-0.0153***	-0.0000634***	0.0483***	0.000326***	-0.00244**
	(-5.77)	(-4.56)	(26.67)	(5.69)	(-2.01)
Parking	-0.000146	-0.00000262***	-0.000584***	-0.00000842**	-0.000261***
	(-0.82)	(-2.97)	(-4.93)	(-2.07)	(-3.26)
Month	4.664***	-0.00969**	2.005***	-0.0255	-0.721*
	(5.73)	(-2.26)	(3.69)	(-1.14)	(-1.89)
Monthsqu	-0.310***	0.000817**	-0.309***	0.00203	-0.0151
	(-4.45)	(2.17)	(-6.53)	(1.16)	(-0.44)
Constant	357.8***	3.185***	-475.4***	0.353	239.6***
	(3.32)	(5.74)	(-6.63)	(0.14)	(4.78)
Observations	6978	6978	6978	6978	6978
Adjusted R^2	0.09337	0.08819	0.25911	0.14417	0.12663

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12: Following the analyses conducted in tables 1-5, the individual Superblocks that were negative and significant were summed up, represented by the variable SBnegative, while the Superblocks that were positive and significant were summed up, represented by the variable SBpositive. Grouped Superblocks are regressed on independent variables using different time trends. The table reports the coefficients obtained from regressing the Superblock variables on (1) traffic, (2) CO, (3) O3, (4) SO2 and (5) NO2 levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM) using an untrimmed dataset. A squared monthly time trend was added.

It seems that for columns (1), (2) and (3), both time trends (linear and squared) seem to be significant, which, after taking into account the direction of the effect, means that Traffic follows a positive, CO levels a negative and Ozone a first increasing and then decreasing time trend (shortly after 3 months). For SO2 and NO2, the squared trend does not seem to increase explanatory power. In all cases, each Superblocks is significant. Parking loses its significance in the first column.

Again both the squared and cubed time trends are added in a next step of the analysis.

	(1)	(2)	(3)	(4)	(5)
Variables	Traffic	CO	O3	SO2	NO2
SBnegative	-6.353***	-0.0125***	-5.056***	-0.142***	-1.294***
	(-14.58)	(-4.94)	(-14.92)	(-8.24)	(-3.68)
SBpositive	8.982***	0.0324***	4.354***	0.0739***	4.952***
	(6.95)	(6.01)	(12.49)	(4.78)	(9.79)
Population	0.0000366***	0.000000161***	-0.0000219***	0.000000663***	0.0000122***
	(6.96)	(6.25)	(-6.27)	(6.17)	(5.21)
Income	-0.0153***	-0.0000634***	0.0483***	0.000326***	-0.00244**
	(-5.77)	(-4.56)	(26.67)	(5.69)	(-2.01)
Parking	-0.000146	-0.00000262***	-0.000584***	-0.00000842**	-0.000261***
	(-0.82)	(-2.97)	(-4.93)	(-2.07)	(-3.26)
Month	4.664***	-0.00969**	2.005***	-0.0255	-0.721*
	(5.73)	(-2.26)	(3.69)	(-1.14)	(-1.89)
Monthsqu	-0.310***	0.000817**	-0.309***	0.00203	-0.0151
	(-4.45)	(2.17)	(-6.53)	(1.16)	(-0.44)
Monthcube	0.00745***	-0.0000196**	0.00677***	-0.0000172	0.000302
	(4.74)	(-2.34)	(6.44)	(-0.47)	(0.40)
Constant	357.8***	3.185***	-475.4***	0.353	239.6***
	(3.32)	(5.74)	(-6.63)	(0.14)	(4.78)
Observations	6978	6978	6978	6978	6978
Adjusted R^2	0.09337	0.08819	0.25911	0.14417	0.12663

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 13: Following the analyses conducted in tables 1-5, the individual Superblocks that were negative and significant were summed up, represented by the variable SBnegative, while the Superblocks that were positive and significant were summed up, represented by the variable SBpositive. Grouped Superblocks are regressed on independent variables using different time trends. The table reports the coefficients obtained from regressing the Superblock variables on (1) traffic, (2) CO, (3) O3, (4) SO2 and (5) NO2 levels during the rush hour times (from 7AM to 9AM and 5PM to 7PM) using an untrimmed dataset. A squared and cubed monthly time trend were added.

As with table 12, for the first three columns all time trend variables seem to be significant. Traffic seems to follow an overall increasing, Carbon monoxide a slightly decreasing and O3 levels again a firstly increasing and after three months a then decreasing time trend ceteris paribus. For the three dependent variables traffic, CO and O3, the cubed time trend seems to best describe reality, although the variable Parking again loses its significance for the analysis of traffic levels as compared to table 9.

In summation, it seems that for the analysis of traffic and CO both a squared and cubed time trend can be added to the linear one for possibly more explanatory power when looking at the Superblocks individually. In other cases, such as for O3, a linear trend seems to deliver the best fit for the model. The best approach for the analysis of the grouped Superblocks might be using a linear, squared and cubed time trend at once for the dependent variables traffic, CO and O3. The specifications for SO2 and NO2 in the grouped Superblock case do not seem to profit from additional time trends apart from the linear one.

5.1.3. Sensitivity Checks

Since some construction end dates had to be randomly chosen, a sensitivity check was performed. For SB13 and SB14, only information on the year of the end of construction was known (which was 2019) and the 1st of July 2019 was chosen as a generic end date. The end dates were selectively changed to the 1st of April, 1st of July and 1st of October and certain permutations were included. The results for the Superblocks being regressed on traffic levels are shown below, rush hour times (from 7AM to 9AM and 5PM to 7PM) and the untrimmed dataset are used. For simplicity's sake, regressions where the end date of construction for SB13 was selected to be the 1st of April and SB14 was selected to be the 1st of October for example, will be referred to as "SB13 April and SB14 October". Column (1) shows SB13 April and SB14 July, column (2) shows SB13 July and SB14 April, column (3) SB13 April and SB14 October, column (4) SB13 October and SB14 April, column (5) SB13 July and SB14 October and lastly column (6) displays SB13 October and SB14 July. Permutations for SB13 April and SB14 April and SB13 October and SB14 October were not included since these versions would not allow for the separation of the single variable "SB13 + SB14" into the two separate variables "SB13" and "SB14".

	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
SB1	-11.49***	-11.49***	-4.043	-4.043	-2.163	-2.163
	(-2.78)	(-2.78)	(-0.87)	(-0.87)	(-0.47)	(-0.47)
SB2	9.070**	9.070**	10.90***	10.90***	12.03***	12.03***
	(2.36)	(2.36)	(2.80)	(2.80)	(3.09)	(3.09)
SB3 + SB4 + SB5	-6.469***	-6.469***	-5.853***	-5.853***	-4.609***	-4.609***
	(-9.24)	(-9.24)	(-7.70)	(-7.70)	(-6.36)	(-6.36)
SB6	0.461	0.461	0.461	0.461	0.461	0.461
	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
SB7	-2.663	-2.663	-2.663	-2.663	-2.663	-2.663
	(-0.50)	(-0.50)	(-0.50)	(-0.50)	(-0.50)	(-0.50)
SB8	-9.884**	-9.884**	0.0423	0.0423	-9.884**	-9.884**
	(-2.37)	(-2.37)	(0.01)	(0.01)	(-2.36)	(-2.36)
SB9	-2.244	-2.244	-1.468	-1.468	-0.566	-0.566
	(-1.16)	(-1.16)	(-0.76)	(-0.76)	(-0.29)	(-0.29)
SB10 + SB11 + SB12	-8.251***	-8.251***	-7.976***	-7.976***	-7.709***	-7.709***
	(-10.41)	(-10.41)	(-10.03)	(-10.03)	(-9.71)	(-9.71)
SB13	-11.76***	16.15***	-10.16***	9.369***	12.76***	10.82***
	(-6.37)	(4.65)	(-5.26)	(3.28)	(3.51)	(3.79)
SB14	16.15***	-11.76***	9.369***	-10.16***	10.82***	12.76***
	(4.65)	(-6.37)	(3.28)	(-5.26)	(3.79)	(3.51)
SB15	-7.186**	-7.186**	-6.904**	-6.904**	-6.730**	-6.730**
	(-2.23)	(-2.23)	(-2.14)	(-2.14)	(-2.08)	(-2.08)
SB16 + SB17	-4.599***	-4.599***	-2.769***	-2.769***	-4.573***	-4.573***
	(-5.31)	(-5.31)	(-3.26)	(-3.26)	(-5.04)	(-5.04)
SB18	27.41***	27.41***	25.65***	25.65***	26.56***	26.56***
	(6.31)	(6.31)	(5.89)	(5.89)	(6.08)	(6.08)
Month	3.011***	3.011***	1.885***	1.885***	1.189***	1.189***
	(10.31)	(10.31)	(4.01)	(4.01)	(2.71)	(2.71)
Population	0.0000816***	0.0000816***	0.0000464***	0.0000464***	0.0000473***	0.0000473***
	(14.26)	(14.26)	(4.47)	(4.47)	(4.36)	(4.36)
Income	-0.0228***	-0.0228***	-0.0179***	-0.0179***	-0.0220***	-0.0220***
	(-8.77)	(-8.77)	(-5.93)	(-5.93)	(-7.30)	(-7.30)
Parking	-0.000373***	-0.000373***	-0.0000496	-0.0000496	0.000161	0.000161
	(-3.16)	(-3.16)	(-0.33)	(-0.33)	(1.16)	(1.16)
Constant	565.2***	565.2***	311.9***	311.9***	248.1**	248.1**
	(6.72)	(6.72)	(2.75)	(2.75)	(2.21)	(2.21)
Observations	6978	6978	6978	6978	6978	6978
Adjusted R^2	0.09684	0.09684	0.09544	0.09544	0.09344	0.09344

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 14: The Superblocks are regressed on traffic during rush hour times (from 7AM to 9AM and 5PM to 7PM) using different end dates of construction for SB13 and SB14. Column (1) shows SB13 April and SB14 July, column (2) shows SB13 July and SB14 April, column (3) SB13 April and SB14 October, column (4) SB13 October and SB14 April, column (5) SB13 July and SB14 October and lastly column (6) displays SB13 October and SB14 July.

The majority of the variables do not change substantially: Even though they might change in value, the direction of their effect (positive or negative) and whether they are significant or not remains the same. When expressing the greatest change in magnitude (which is that of SB2 when comparing the results from columns (1) and (2) to those of (5) and (6), a change in TCI of 2.96) as a percentage of the total average TCI (15.35), one can find a maximum value for change of around 19.28%. Independent variables that do vary substantially depending on which end date is chosen are SB1, SB8, SB13, SB14 and parking. SB1 and SB8 are no longer significant in columns (3), (4), (5) and (6) and in columns (3) and (4) respectively. SB13 and SB14 vary greatly in terms of their sign depending on which dataset is chosen for the analysis. When comparing “SB13 April and SB14 July” to “SB13 July and SB14 April”, and any other permutation where the dates are simply switched, all values for SB13 and SB14 remain the same, the two blocks simply switch values, while the other blocks’ values do not change. Lastly, parking loses its significance in all but in columns (1) and (2).

The sensitivity check is repeated for the pollutant CO, again the same permutations for the end of construction dates for SB13 and SB14 were used as in the previous table.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
SB1	0.0696***	0.0696***	0.104***	0.104***	0.103***	0.103***
	(3.29)	(3.29)	(4.40)	(4.40)	(4.38)	(4.38)
SB2	0.0399**	0.0399**	0.0488**	0.0488**	0.0498**	0.0498**
	(2.02)	(2.02)	(2.45)	(2.45)	(2.50)	(2.50)
SB3 + SB4 + SB5	-0.0159***	-0.0159***	-0.0124***	-0.0124***	-0.0105***	-0.0105***
	(-4.44)	(-4.44)	(-3.18)	(-3.18)	(-2.83)	(-2.83)
SB6	-0.000485	-0.000485	-0.000485	-0.000485	-0.000485	-0.000485
	(-0.02)	(-0.02)	(-0.02)	(-0.02)	(-0.02)	(-0.02)
SB7	-0.0796***	-0.0796***	-0.0796***	-0.0796***	-0.0796***	-0.0796***
	(-2.92)	(-2.92)	(-2.92)	(-2.92)	(-2.92)	(-2.92)
SB8	-0.0241	-0.0241	0.00412	0.00412	-0.0241	-0.0241
	(-1.13)	(-1.13)	(0.25)	(0.25)	(-1.13)	(-1.13)
SB9	-0.0116	-0.0116	-0.00844	-0.00844	-0.00767	-0.00767
	(-1.17)	(-1.17)	(-0.85)	(-0.85)	(-0.78)	(-0.78)
SB10 + SB11 + SB12	-0.0145***	-0.0145***	-0.0134***	-0.0134***	-0.0131***	-0.0131***
	(-3.58)	(-3.58)	(-3.28)	(-3.28)	(-3.24)	(-3.24)
SB13	-0.0232**	0.0525***	-0.0151	0.0447***	0.0379**	0.0425***
	(-2.45)	(2.95)	(-1.53)	(3.06)	(2.04)	(2.91)
SB14	0.0525***	-0.0232**	0.0447***	-0.0151	0.0425***	0.0379**
	(2.95)	(-2.45)	(3.06)	(-1.53)	(2.91)	(2.04)
SB15	0.00583	0.00583	0.00721	0.00721	0.00736	0.00736
	(0.35)	(0.35)	(0.44)	(0.44)	(0.45)	(0.45)
SB16 + SB17	-0.0111**	-0.0111**	-0.00420	-0.00420	-0.00864*	-0.00864*
	(-2.51)	(-2.51)	(-0.97)	(-0.97)	(-1.86)	(-1.86)
SB18	0.165***	0.165***	0.158***	0.158***	0.161***	0.161***
	(7.44)	(7.44)	(7.09)	(7.09)	(7.20)	(7.20)
Month	0.00371**	0.00371**	-0.00179	-0.00179	-0.00239	-0.00239
	(2.48)	(2.48)	(-0.75)	(-0.75)	(-1.07)	(-1.07)
Population	0.0000003***	0.0000003***	9.70e-08*	9.70e-08*	0.00000012**	0.00000012**
	(8.72)	(8.72)	(1.83)	(1.83)	(2.15)	(2.15)
Income	-0.0000603***	-0.0000603***	-0.0000368**	-0.0000368**	-0.0000454***	-0.0000454***
	(-4.54)	(-4.54)	(-2.39)	(-2.39)	(-2.95)	(-2.95)
Parking	-0.00000583***	-0.00000583***	-0.00000433***	-0.00000433***	-0.00000417***	-0.00000417***
	(-9.66)	(-9.66)	(-5.70)	(-5.70)	(-5.87)	(-5.87)
Constant	5.013***	5.013***	3.809***	3.809***	3.833***	3.833***
	(11.64)	(11.64)	(6.57)	(6.57)	(6.67)	(6.67)
Observations	6978	6978	6978	6978	6978	6978
Adjusted R^2	0.09306	0.09306	0.09315	0.09315	0.09339	0.09339

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 15: The Superblocks are regressed on CO levels during rush hour times (from 7AM to 9AM and 5PM to 7PM) using different end dates of construction for SB13 and SB14. Column (1) shows SB13 April and SB14 July, column (2) shows SB13 July and SB14 April, column (3) SB13 April and SB14 October, column (4) SB13 October and SB14 April, column (5) SB13 July and SB14 October and lastly column (6) displays SB13 October and SB14 July.

In this case, SB13, SB14 and SB16 + SB17 have values that are no longer significant in some columns, namely in columns (3) and (4). Superblocks SB1, SB2, SB3 + SB4 + SB5 and SB10 + SB11 + SB12 only have slight variations in magnitude, namely a maximum of around 7.11%, 2.05%, 1.12% and 0.29% of total average pollution levels respectively (as an example, the biggest difference between values for SB1 would be between columns (2) and (3), which would be 0.0344mg/m^3). SB18 has the greatest maximum change in magnitude of around 66.74%, which is quite substantial. Regarding the other covariates, the direction of the effects of Population, Income and Parking remain the same while the time trend is only significant (and positive) in columns (1) and (2).

Again, the sensitivity check is performed for the pollutant O3.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
SB1	0.0685	0.0685	-12.55***	-12.55***	-18.21***	-18.21***
	(0.03)	(0.03)	(-4.14)	(-4.14)	(-6.00)	(-6.00)
SB2	-3.525	-3.525	-7.067***	-7.067***	-8.950***	-8.950***
	(-1.39)	(-1.39)	(-2.77)	(-2.77)	(-3.51)	(-3.51)
SB3 + SB4 + SB5	6.989***	6.989***	5.227***	5.227***	3.955***	3.955***
	(15.17)	(15.17)	(10.52)	(10.52)	(8.31)	(8.31)
SB6	-10.79***	-10.79***	-10.79***	-10.79***	-10.79***	-10.79***
	(-3.29)	(-3.29)	(-3.31)	(-3.31)	(-3.29)	(-3.29)
SB7	-0.742	-0.742	-0.742	-0.742	-0.742	-0.742
	(-0.21)	(-0.21)	(-0.21)	(-0.21)	(-0.21)	(-0.21)
SB8	1.494	1.494	4.221**	4.221**	1.494	1.494
	(0.54)	(0.54)	(1.97)	(1.97)	(0.54)	(0.54)
SB9	-4.862***	-4.862***	-5.630***	-5.630***	-7.131***	-7.131***
	(-3.83)	(-3.83)	(-4.45)	(-4.45)	(-5.65)	(-5.65)
SB10 + SB11 + SB12	-0.730	-0.730	-1.094**	-1.094**	-1.538***	-1.538***
	(-1.40)	(-1.40)	(-2.10)	(-2.10)	(-2.95)	(-2.95)
SB13	13.99***	-2.644	10.68***	-16.98***	5.076**	10.818***
	(11.52)	(-1.16)	(8.46)	(-9.10)	(2.13)	(3.79)
SB14	-2.644	13.99***	-16.98***	10.68***	-22.75***	12.755**
	(-1.16)	(11.52)	(-9.10)	(8.46)	(-12.14)	(3.51)
SB15	-4.787**	-4.787**	-5.332**	-5.332**	-5.622***	-5.622***
	(-2.26)	(-2.26)	(-2.53)	(-2.53)	(-2.65)	(-2.65)
SB16 + SB17	1.715***	1.715***	0.369	0.369	0.555	0.555
	(3.01)	(3.01)	(0.66)	(0.66)	(0.93)	(0.93)
SB18	0.623	0.623	2.706	2.706	3.040	3.040
	(0.22)	(0.22)	(0.95)	(0.95)	(1.06)	(1.06)
Month	-2.649***	-2.649***	-0.470	-0.470	0.689**	0.689**
	(-13.79)	(-13.79)	(-1.53)	(-1.53)	(2.39)	(2.39)
Population	-0.0000353***	-0.0000353***	0.0000179***	0.0000179***	0.0000374***	0.0000374***
	(-9.38)	(-9.38)	(2.64)	(2.64)	(5.25)	(5.25)
Income	0.0421***	0.0421***	0.0330***	0.0330***	0.0350***	0.0350***
	(24.66)	(24.66)	(16.76)	(16.76)	(17.66)	(17.66)
Parking	0.000172**	0.000172**	-0.000369***	-0.000369***	-0.000746***	-0.000746***
	(2.22)	(2.22)	(-3.80)	(-3.80)	(-8.17)	(-8.17)
Constant	-842.5***	-842.5***	-390.0***	-390.0***	-206.8***	-206.8***
	(-15.23)	(-15.23)	(-5.26)	(-5.26)	(-2.80)	(-2.80)
Observations	6978	6978	6978	6978	6978	6978
Adjusted R^2	0.27420	0.27420	0.28260	0.28260	0.27569	0.27569

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 16: The Superblocks are regressed on O3 levels during rush hour times (from 7AM to 9AM and 5PM to 7PM) using different end dates of construction for SB13 and SB14. Column (1) shows SB13 April and SB14 July, column (2) shows SB13 July and SB14 April, column (3) SB13 April and SB14 October, column (4) SB13 October and SB14 April, column (5) SB13 July and SB14 October and lastly column (6) displays SB13 October and SB14 July.

The sensitivity analysis of the chosen end dates produces some quite different results. SB1, SB2, SB8, SB10 + SB11 + SB12, SB13, SB14 and SB16 + SB17 change their significance depending on the dates, SB13 and SB14 not only change their significance but the direction of the effect is also dependent on the chosen specification. The maximum difference in the change in effect, expressed as a percentage of the total average pollution levels, ranges from only slight alterations, as is the case with SB15 (1.59%) to a tremendous difference, as with SB14, with a difference of almost 70% from columns (2) to (5). The variable Month is positive and significant in columns (5) and (6) and negative and significant in columns (1) and (2). Income is positive and significant regardless of the chosen dates while Population and Parking change their signs depending on the selected specification.

The same sensitivity check is performed with the pollutant SO2:

	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
SB1	0.0561 (0.64)	0.0561 (0.64)	0.137 (1.40)	0.137 (1.40)	-0.124 (-1.25)	-0.124 (-1.25)
SB2	-0.674*** (-8.28)	-0.674*** (-8.28)	-0.654*** (-7.94)	-0.654*** (-7.94)	-0.742*** (-8.93)	-0.742*** (-8.93)
SB3 + SB4 + SB5	0.0798*** (5.38)	0.0798*** (5.38)	0.0863*** (5.37)	0.0863*** (5.37)	0.0266* (1.72)	0.0266* (1.72)
SB6	0.399*** (3.78)	0.399*** (3.78)	0.399*** (3.78)	0.399*** (3.78)	0.399*** (3.74)	0.399*** (3.74)
SB7	0.120 (1.06)	0.120 (1.06)	0.120 (1.06)	0.120 (1.06)	0.120 (1.05)	0.120 (1.05)
SB8	-0.211** (-2.39)	-0.211** (-2.39)	-0.0987 (-1.42)	-0.0987 (-1.42)	-0.211** (-2.37)	-0.211** (-2.37)
SB9	-0.154*** (-3.76)	-0.154*** (-3.76)	-0.145*** (-3.55)	-0.145*** (-3.55)	-0.215*** (-5.23)	-0.215*** (-5.23)
SB10 + SB11 + SB12	0.0262 (1.56)	0.0262 (1.56)	0.0292* (1.73)	0.0292* (1.73)	0.00854 (0.50)	0.00854 (0.50)
SB13	0.484*** (12.38)	0.182** (2.47)	0.501*** (12.26)	0.102* (1.68)	0.217*** (2.79)	-0.164*** (-2.69)
SB14	0.182** (2.47)	0.484*** (12.38)	0.102* (1.68)	0.501*** (12.26)	-0.164*** (-2.69)	0.217*** (2.79)
SB15	0.201*** (2.95)	0.201*** (2.95)	0.204*** (2.99)	0.204*** (2.99)	0.191*** (2.77)	0.191*** (2.77)
SB16 + SB17	-0.131*** (-7.17)	-0.131*** (-7.17)	-0.111*** (-6.18)	-0.111*** (-6.18)	-0.100*** (-5.19)	-0.100*** (-5.19)
SB18	0.361*** (3.93)	0.361*** (3.93)	0.342*** (3.71)	0.342*** (3.71)	0.356*** (3.82)	0.356*** (3.82)
Month	-0.000992 (-0.16)	-0.000992 (-0.16)	-0.0132 (-1.32)	-0.0132 (-1.32)	0.0407*** (4.34)	0.0407*** (4.34)
Population	0.00000102*** (8.45)	0.00000102*** (8.45)	0.000000639*** (2.91)	0.000000639*** (2.91)	0.00000153*** (6.59)	0.00000153** (6.59)
Income	0.000127** (2.31)	0.000127** (2.31)	0.000180*** (2.82)	0.000180*** (2.82)	0.000274*** (4.25)	0.000274*** (4.25)
Parking	-0.00000936*** (-3.75)	-0.00000936*** (-3.75)	-0.00000584* (-1.86)	-0.00000584* (-1.86)	-0.0000233*** (-7.85)	-0.0000233** (-7.85)
Constant	4.001** (2.25)	4.001** (2.25)	1.251 (0.52)	1.251 (0.52)	9.707*** (4.04)	9.707*** (4.04)
Observations	6978	6978	6978	6978	6978	6978
Adjusted R^2	0.16985	0.16985	0.16946	0.16946	0.15247	0.15247

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 17: The Superblocks are regressed on SO2 levels during rush hour times (from 7AM to 9AM and 5PM to 7PM) using different end dates of construction for SB13 and SB14. Column (1) shows SB13 April and SB14 July, column (2) shows SB13 July and SB14 April, column (3) SB13 April and SB14 October, column (4) SB13 October and SB14 April, column (5) SB13 July and SB14 October and lastly column (6) displays SB13 October and SB14 July.

The analysis paints a slightly different picture, as the results seem to be more robust than the previously presented pollutants. The variables seem fairly stable, where SB8 and SB10 + SB11 + SB12 are significant only in some of the columns while SB13 and SB14 are the only blocks that change the direction of their effect depending on the chosen dates. The LEZ consisting of SB10 + SB11 + SB12 had a previously insignificant effect on SO2 levels yet is now positive time in columns (3) and (4) – the first time in this paper that this Superblock contributes to an increase in pollution levels. The two blocks SB13 and SB14 also have the greatest maximum difference of change (as expressed again in percentage of total average), which is around 13.43% for either, while other blocks' effects only differ by around 0.4% to 1.8%. Population, Income and Parking all maintain their significance and the direction of their effect throughout the columns while Month only seems to have a positive effect in columns (5) and (6).

Lastly, NO2 is also subjected to the same sensitivity check, the results of which can again be found below.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
SB1	4.114**	4.114**	9.271***	9.271***	10.51***	10.51***
	(2.15)	(2.15)	(4.32)	(4.32)	(4.90)	(4.90)
SB2	3.155*	3.155*	4.476**	4.476**	5.124***	5.124***
	(1.77)	(1.77)	(2.48)	(2.48)	(2.84)	(2.84)
SB3 + SB4 + SB5	-1.557***	-1.557***	-1.041***	-1.041***	-0.380	-0.380
	(-4.80)	(-4.80)	(-2.96)	(-2.96)	(-1.13)	(-1.13)
SB6	0.327	0.327	0.327	0.327	0.327	0.327
	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)
SB7	-5.570**	-5.570**	-5.570**	-5.570**	-5.570**	-5.570**
	(-2.26)	(-2.26)	(-2.26)	(-2.26)	(-2.25)	(-2.25)
SB8	-3.465*	-3.465*	0.980	0.980	-3.465*	-3.465*
	(-1.79)	(-1.79)	(0.64)	(0.64)	(-1.79)	(-1.79)
SB9	-1.153	-1.153	-0.684	-0.684	-0.168	-0.168
	(-1.29)	(-1.29)	(-0.76)	(-0.76)	(-0.19)	(-0.19)
SB10 + SB11 + SB12	-1.036***	-1.036***	-0.858**	-0.858**	-0.705*	-0.705*
	(-2.82)	(-2.82)	(-2.33)	(-2.33)	(-1.92)	(-1.92)
SB13	-6.599***	8.111***	-5.415***	6.622***	5.610***	7.668***
	(-7.71)	(5.04)	(-6.06)	(5.01)	(3.33)	(5.79)
SB14	8.111***	-6.599***	6.622***	-5.415***	7.668***	5.610***
	(5.04)	(-7.71)	(5.01)	(-6.06)	(5.79)	(3.33)
SB15	-1.483	-1.483	-1.280	-1.280	-1.181	-1.181
	(-0.99)	(-0.99)	(-0.86)	(-0.86)	(-0.79)	(-0.79)
SB16 + SB17	-0.159	-0.159	0.889**	0.889**	0.0379	0.0379
	(-0.40)	(-0.40)	(2.26)	(2.26)	(0.09)	(0.09)
SB18	10.32***	10.32***	9.211***	9.211***	9.614***	9.614***
	(5.13)	(5.13)	(4.57)	(4.57)	(4.75)	(4.75)
Month	0.216	0.216	-0.598***	-0.598***	-0.996***	-0.996***
	(1.59)	(1.59)	(-2.74)	(-2.74)	(-4.89)	(-4.89)
Population	0.0000254***	0.0000254***	0.00000181	0.00000181	0.00000101	0.00000101
	(9.58)	(9.58)	(0.38)	(0.38)	(0.20)	(0.20)
Income	-0.00321***	-0.00321***	0.000270	0.000270	-0.00178	-0.00178
	(-2.67)	(-2.67)	(0.19)	(0.19)	(-1.27)	(-1.27)
Parking	-0.000508***	-0.000508***	-0.000285***	-0.000285***	-0.000163**	-0.000163**
	(-9.29)	(-9.29)	(-4.14)	(-4.14)	(-2.52)	(-2.52)
Constant	394.6***	394.6***	216.3***	216.3***	174.9***	174.9***
	(10.12)	(10.12)	(4.12)	(4.12)	(3.35)	(3.35)
Observations	6978	6978	6978	6978	6978	6978
Adjusted R^2	0.13278	0.13278	0.13275	0.13275	0.12956	0.12956

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 18: The Superblocks are regressed on SO2 levels during rush hour times (from 7AM to 9AM and 5PM to 7PM) using different end dates of construction for SB13 and SB14. Column (1) shows SB13 April and SB14 July, column (2) shows SB13 July and SB14 April, column (3) SB13 April and SB14 October, column (4) SB13 October and SB14 April, column (5) SB13 July and SB14 October and lastly column (6) displays SB13 October and SB14 July.

In the table one can see that SB3 + SB4 + SB5, SB8 and SB16 + SB17 are only significant in some of the specifications, the direction of the effect for SB13 and SB14 depends on the chosen dates. Again the maximum difference of change, expressed as percentage of total average, was computed; significant differences, which for the sake of discussion was chosen to be values over 10%, include 23.68% (SB1) and 54.47% (SB13 and SB14). The effect of Month is significant and negative in columns (3), (4), (5) and (6) and in (1) and (2) for Income, while Parking is always negative and significant. Population seems to be significant and positive in the first two columns.

It is difficult to make a generalized statement about all of the different sensitivity checks performed on traffic and pollutants. Depending on the chosen end dates of construction for SB13 and SB14 the results seem to change in terms of significance, direction of effect or magnitude of effect, in some cases very heavily (as with O3) and in other cases rather subtly (such as with SO2). This might indicate that the end dates chosen do in fact heavily influence the stability of the results and with it the explanatory power of the model. Results should be interpreted taking into consideration that two construction end dates were unknown and that these dates are in fact crucial for the model. Especially when it comes to the previously mentioned Superblocks SB7, SB10 + SB11 + SB12 and SB18, whose effects have remained fairly constant throughout the analyses performed; SB7 and SB18 do not change substantially while SB10 + SB11 + SB12 seems to actually increase SO2 levels when the dates are chosen to be a mixture of April and October. If the city of Barcelona were to publish the exact end dates of construction for each Superblock extension this might further strengthen the informative value of the study.

5.2. Discussion

It seems that individual Superblocks can cause both a rise or a fall in traffic and pollution levels. A decrease might be the result of the demand for traffic falling, since individuals now have a more difficult time traveling through the city of Barcelona, obstructed by the LEZs that were put into place. Individuals then either resort to different methods of transportation, such as bicycles or public transport, or choose other alternatives, such as traveling less in general. It could also be that certain traffic bottlenecks, areas of the city that usually had high levels of congestion and that now see less traffic because drivers can no longer travel through them, are now alleviated and traffic is now dispersed to the areas around them. If traffic is now redirected evenly around the Superblock, without creating a new bottleneck, this could lower congestion and pollution citywide. An explanation for why the Superblocks might cause pollution levels to rise in some cases might not only be because more congestion is caused but also due to the fact that vehicles driving at lower speeds might produce more pollution. As analysed for instance by Khreis (2016), engine type, vehicle type, as well as type of gasoline can heavily influence how efficient speed to pollution ratios are (meaning the greatest speed for the lowest level of emissions). Multiple studies show that at a speed of around 50km/h the greatest engine efficiency is reached, and Khreis found an exponential decrease in nitrous oxide emissions for diesel engine vehicles as speeds get closer to the 50km/h mark. If vehicles are forced to slow down to a pace of 10km/h, as is the case in the Poblenou area Superblocks (where SB18 is located), this might explain higher emissions.

Lastly, the reason that throughout the analysis the covariates Population, Parking and Income might seem to have ambiguous effects on traffic and pollution might be because there are only very few observations. More granular data, such as monthly or even weekly data frequency might deliver more stable results and might allow for more thorough interpretations.

6. Limitations

An issue regarding causality might arise when the decision to build Superblocks in certain locations was not random but rather due to factors that might also correlate with pollution levels. This might hold if a city decides to implement the Superblock-program in areas with generally high pollution levels. Even though there is no information available on the city of Barcelona's website as to why specific locations were selected for the construction of Superblocks, it is reasonable to believe that they were chosen for either logistical (ease of building), financial (low cost of construction) or pollution-related (historically high pollution levels, leading to a higher willingness to test urban design tactics in these areas) reasons. Building Superblocks in randomly selected areas in the city would most likely lead to a less-biased experimental outcome yet is rather difficult to implement in practice. For this reason, a causal interpretation of the results might lead to wrong conclusions. There might be a correlation between Superblocks and traffic or pollution, yet for reasons such as selection bias, where LEZ allocation is not done randomly, causality might be doubtful. Furthermore, there might be different confounding factors or omitted variable biases (OVB) that might influence the results and challenge causal interference. Some pollutants are not only produced by vehicles but might also be directly emitted by sources such as construction sites, agricultural activities or fires or can even result from complex chemical reactions of molecules such as sulphur or nitrogen dioxide, which means that the levels of these pollutants might be intercorrelated (EPA, 2021). Since there are various other factors that might contribute to the production of the studied pollutants, it might be helpful to include controls such as number of active industrial power plants in the vicinity, forest fire occurrences or other weather and seasonal variables that might have an effect on pollution, so as to isolate the effect the blocks might have on the dependent variables. In addition, a measure for different vehicle types might provide some further insight into how effective LEZs really are. Part of the decrease in emissions might be due to more efficient cars being used by the population, such as non-diesel engine vehicles or electric cars. If vehicle types or similar proxies were to be included this might significantly reduce some OVB.

In addition, regarding traffic, using the traffic congestion index makes interpreting the magnitude of the Superblocks' effects rather difficult. The index is helpful in understanding traffic coverage as a whole, yet does not give any indication as to which parts of the city are experiencing which type of congestion.

7. Conclusion

The goal of this paper was to explore whether there is a link between the construction of Superblocks and a reduction in traffic and pollution levels. It is an analysis of whether the LEZs in Barcelona actually achieve this reduction and if so, what some successful characteristics of Superblocks might be. In order to research this, a specification was chosen where individual blocks and covariates were regressed on dependent variables such as traffic and different polluters using a dummy approach: As soon as construction was finished on a Superblock the variable takes on the value one. Other approaches include summing up the Superblocks and grouping them into categories of traffic/pollution-increasing and decreasing groups. The results show that these LEZs can have different effects – Superblocks can either correlate with an increase, a decrease or not correlate at all with traffic and pollution levels. The direction of the effect might be dependent on characteristics such as the size, the location or the proximity of Superblocks to public amenities. It might be that for the city of Barcelona as a whole, the effects cancel out, rendering the effect of the LEZs insignificant. There are however several limitations of the data, some assumptions that might be theoretically justifiable but practically unrealistic and the results seem to vary depending on the specification chosen. Only in the case of traffic and ground-level Ozone do the Superblocks as a whole seem to contribute to a lowering of city-wide levels, albeit only slightly. More data is needed to investigate exactly why some Superblocks always increase or decrease traffic and pollution, it is especially interesting to explore which characteristics exactly contribute to a Superblock's success. Lastly, there might also be more confounding factors present such as additional emitting sources or seasonal variations that are unaccounted for.

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9. Appendix

District	SB Code	Between	Section	Type
Sant Antoni	SB1	Borrell - Tamarit	Square	Structural
Sant Antoni	SB2	Floridablanca - Tamarit	c. Borell	Structural
Poblenou	SB3	Granada - Tanger	Cruilla - Granada	Structural
Poblenou	SB4	Pere IV - Pallars	Cruilla - Granada	Structural
Poblenou	SB5	S. Avila - Badajoz	Cruilla - Sancho Avila	Structural
Sant Antoni	SB6	Borrell - Urgell	c. Tamarit	Structural
Sant Antoni	SB7	Viladomat - Borrell	c. Parlament	Tactical
Sant Antoni	SB8	Sepulveda - Floridablanca	c. Borell	Structural
Sant Antoni	SB9	Calabria - Viladomat	c. Tamarit	Structural
Horta	SB10	Tajo - Pça. Eivissa	c. Fulton-Horta	Structural
Horta	SB11	Eduard Toda - Chapí	c. Feliu i Codina	Structural
Horta	SB12	Canigó/ Fabra i Puig	vorera passant a c. Canigó	Structural
Sants	SB13	Tarragona - Bejar	c. Sant Nicolau	Tactical
Sant Marti	SB14	BacdeRoda - Provençals	c. Cristobal de Moura	Structural
Sant Antoni	SB15	Gran Via - Sepulveda	c. Borrell	Basic
Sant Antoni	SB16	Manso - Parlament	c. Borrell	Tactical
Sant Antoni	SB17	Parlament - Campo Sagrado	c. Borrell	Tactical
Sant Marti	SB18	Roc Boronat - Llacuna	c. Almogàvers	Structural

Table 19: Information on the different Superblocks and their location. For each Superblock section, their designated code, the streets between which the block can be found ("Between"), the street on which it is located ("Section") and the construction type can be found. As an example, SB7 is located on Calle Parlament, between the streets Calle Viladomat and Calle Borrell and was a tactical construction.

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