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Worldwide, one of the most important causes of mortality is air pollution. To solve this problem, national, regional, and local governments have implemented policies to reduce on-road and industrial emissions. In this regard, in 2012, Barcelona city council and Transports Metropolitans de Barcelona (TMB), started the implementation of the Nova Xarxa de Bus (NXB) to redefine the bus network following the criteria of connectivity, efficiency, and rationality. This policy was implemented in seven phases from the years 2012 to 2018. In this context, this paper analyses the impact of this policy on the air quality of the city of Barcelona using a dataset from 2008 to 2016. Using a difference-in-difference approach we show that the implementation of these new routes increased air quality in Barcelona. Additionally, we show that pollution decreased in each of the four phases implemented in the period analysed, and especially in the air quality station near the main roads. From our results, we can infer that an optimal bus route design can improve air quality in urban areas.

Keywords: Air quality, Public transport, Traffic congestion, Bus route assignment**.**

JEL Codes: L91, Q53, R41, R49

UNIVERSITAT DE BARCELONA

Observatori d'anàlisi i avaluació de polítiques públiques

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Worldwide, one of the most important causes of mortality is air pollution. To solve this problem, national, regional, and local governments have implemented policies to reduce on-road and industrial emissions. In this regard, in 2012, Barcelona city council and Transports Metropolitans de Barcelona (TMB), started the implementation of the Nova Xarxa de Bus (NXB) to redefine the bus network following the criteria of connectivity, efficiency, and rationality. This policy was implemented in seven phases from the years 2012 to 2018. In this context, this paper analyses the impact of this policy on the air quality of the city of Barcelona using a dataset from 2008 to 2016. Using a difference-in-difference approach we show that the implementation of these new routes increased air quality in Barcelona. Additionally, we show that pollution decreased in each of the four phases implemented in the period analysed, and especially in the air quality station near the main roads. From our results, we can infer that an optimal bus route design can improve air quality in urban areas.

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Introduction

One of the most important causes of mortality in the world is air pollution. Each year, seven million deaths are associated with it, three due to ambient air pollution (WHO, 2014). On-road traffic can be considered the main contributor to air pollution in urban areas (Holman 1999, Raaschou-Nielsen et al. 2010) and its contribution on EU total CO_2 emissions is over 20% (EEA, 2020); to tackle this problems, the European Union has implemented various policies. In this context, the Ambient Air Quality Directive, along with Directive 2004/107/EC, currently provides the reference framework, in the EU, to control air pollution. Additionally, the EU also wants to reduce the GHG emissions from transport about 20% in comparison to 2008 at 2030 (European Commission, 2014). Consequently, European city councils have also implemented policies to improve air quality. In 2003 London introduced a congestion charge to enter the city center, while in 2006 Stockholm implemented its congestion charge, making it permanent in 2007. In Paris, license plate-based restrictions were brought into force in 2015. Further, we can find similar policies to cope with air pollution worldwide: in Latin American cities such as Mexico, Santiago de Chile, and Bogotá; or in Asian cities such as Beijing or Tianjin (Zhang et al. 2017). In Barcelona, the city council has introduced several policies to facilitate the use of public and alternative transport modes, like bicycles, to reduce the use of cars in the city. In general, what these policies have in common is to encourage private car-users to use public transport as a means to reduce congestion and air pollution. Specifically, they seek to reduce the use of private cars by making them more difficult to use in the city. In this regard, the analysis of how better public transportation methods can also decrease air pollution might be of interest. Instead of focusing on making the use of private cars difficult, or increasing the provision of public transport to address air pollution, an efficient public transport network can also reduce it. Also, it is important to remark that encouraging the promotion of public transport can reduce dependence on fossil fuels by reducing the use of private vehicles.

As noted, most measures aim to make it more difficult to use private vehicles, and the congestion charge is the most common. Beevers and Carslaw (2005) analysed the impact of London's congestion charge on vehicle emissions and found that the policy was successful in decreasing pollution within the city center (-12% for NO_X and -11.9% for PM_{10}) but had mixed results in the inner ring road where NO_x increased by 1.5% and PM_{10} decreased by 1.4%. Additionally, Kelly et al. (2011) show that reductions in NO_X and PM_{10} due to the congestion charge were about 20%. On the other hand, Atkinson et al. (2009) did not find any effect on pollution due to the implementation of the charge in the long term. Other policies have also been implemented in the UK to cope with air pollution, such as the Air Quality Management Areas (AQMA) and the Low Emission Zones (LEZ). In this regard, Gehrsitz and Taleb (2019) analysed the effects of these AQMAs on air quality throughout the UK. Following a differences-in-differences method, the authors show that this policy did not reduce the number of days exceeding the NO_2 limits. On the contrary, the LEZ reduced the average concentrations of NO_2 to about 0.12μg m^3; while the reduction of PM_{10} was between 0.03μg/m^3 and 0.5μg/m^3 (Beevers et al. 2016). LEZ have also been implemented in German cities. Morfeld et al. (2014) analysed LEZ areas that restricted car entry to the Euro 1 standard. The authors found that this policy reduced NO_X by less than 4% and PM_{10} by less than 1%. In the case of Munich, Fensterer et al. (2014) show that this policy reduced PM_{10} concentrations by 13% in traffic monitoring sites and 4.5% in urban monitoring sites. In Naples, Polichetti (2017) analysed the travel restriction that started in 2010. This policy is based on time slots and alternate days where cars are restricted to travel in the city. The author shows that the time slot policy did not improve air quality. His result is similar to that found by Ruprecht and Invernizzi (2009) for the case of Milan.

Furthermore, cities worldwide have implemented policies to reduce air pollution. Zhang et al. (2017) examined license-plate driving restrictions in Bogotá. The authors found that a decrease in NO was accompanied by an increase in $PM_{10,}$ NO_x, and $NO_{2.}$ On the other hand, Viard (2015), explored the effects of two different restrictions in Beijing and found that during 'every-other-day restrictions' (when cars are restricted to use one out of two days) reduced pollution by 19%, and 'one-day-per-week restrictions' (when cars are restricted to use one day per week), reduced pollution by 7%. Focusing on the case of Barcelona, Gonçalves et al. (2008) and Baldasano et al. (2010) analysed the speed limitation (80km/h) that the city council applied on congested urban motorways in 2008. Their results show that emissions were reduced by 4% overall, with a decrease of 5.7%, 5.3%, and 3.0% for NO_2, $SO_{2,}$ and $PM_{10,}$ respectively. On the other hand, Bel and Rosell (2013) found the opposite effect. Using difference in differences techniques the authors found that NO_X pollution increased by 1.7-3.2% and PM_{10} by 5.3-5.9%. Moreover, the authors found that the variable speed policy applied in two city access routes in January 2019, and showed that this policy reduced emissions from PM_{10} between 14.5% and 17.3% and between 7.7% and 17.1% for NO_x.

It is important to note that not only policies that focus on reducing the use of private cars can improve air quality. Studies show that better public transport schemes can also reduce air pollution in urban areas. Schiller et al. (2010) conclude that public transportation can be a key factor in reducing the use of private cars and emissions. This result is in line with Dobranskyte-Niskota et al. (2007), Haghshenas and Vaziri (2012), and Jeon et al. (2008) who also show that public transportation decreases pollution. Ambarwati et al. (2016) find that success in public transport use is associated with well-designed urban infrastructure. Therefore, to produce long-term environmental advantages, the authors show that the design of improvements in public transport should be linked to urban development. Taking into account public transportation's specific modes, Li et al. (2019) analysed the impact of the subway expansion in Beijing from 2008 to 2016. Using a difference-in-difference analysis, the authors show that air quality in Beijing was improved by about 2% due to an increase in subway density of about one standard deviation. In the case of buses, Bel and Holst (2018) examined the impact of Mexico city's bus rapid transit (BRT) network. The authors show that the BRT reduced emissions of CO between 5.5-7.2%, NO_x by 4.7-6.5%, and PM_{10} by about 7.3-9.2%. In the case of SO_2, the authors did not find any reduction.

Public transportation and, its expansion, can reduce air pollution in urban areas, but the fact that the redesign of bus routes can also decrease it has not been analysed in depth. Jimenez and Roman (2016) show that it is possible to reduce emissions from pollutants through efficient bus fleet distribution. This effect could be due to the fact that better bus lines attracts new users, or due to a reduction in travel time. In this regard, in Rome, Russo et al. (2022) showed that providing specific bus lanes increased the number of bus users in 26% and reduced travel time in about 18%, among other welfare effects. In this regard, in 2012, Barcelona city council jointly with Transports Metropolitans de Barcelona (TMB)[3], implemented the Nova Xarxa de bus de Barcelona (NXB)[4] intending to redefine the bus network following criteria of connectivity, efficiency, and rationality, among others. The initiative is based on the creation of 28 new bus lines with faster straighter routes that prioritise buses over private cars. From 2012 to 2018, the main objective was to redistribute existing resources (buses) efficiently, by introducing more direct routes, increasing bus lanes, having fewer bus stops, and fewer delays at traffic lights. From 2018 to date the implementation has also included the acquisition of 66 new buses. 43 were destined for the new routes while the others were employed on the traditional routes that remained. This policy was designed to be implemented in seven phases. The first phase started on 1st October 2012 with the inclusion of five new routes. On 18th November 2013, the second phase began, with an additional five routes. The third phase started on 15th September 2014, with the inclusion of four routes. The fourth phase included three new routes that started two years after the third one, on 29th February 2016. The fifth phase started on 13th November 2017 and included four new routes. Finally, the sixth and seventh phases were implemented in 2018, with the sixth starting on 25th June with the addition of three routes and the seventh on 25th November with the inclusion of the last five routes. Today eight routes horizontally cross the city (called H), 17 cross the city in a vertical way (called V), and three routes diagonally cross the city (called D).

[3] Barcelona Metropolitan Transport, in English

[4] In English, New Barcelona Bus Network

Our aim is to analyse the impact of the new route design in Barcelona on air pollution. Using a database of pollutants from 20 air quality stations inside and outside Barcelona city, and periods before and after the various phases of the new route assignment were implemented, to assess its impact on the city's air quality. To analyse this, we rely on difference-in-difference methods, following Bel and Holst (2018) and Li et al. (2019). Based on this data, we show that the effect of the new bus routes has decreased pollution for all pollutants examined, except for O_3. Also, our results enable us to identify that all phases analysed have reduced pollution. Finally, our results show that the main reduction in pollution is found in air quality stations located in traffic areas. This could be caused by the fact that new bus routes had an effect on vehicle traffic. As far as we know, this is the first time, at least in the case of Barcelona, that the new design of a route assignment has been assessed.

The rest of the paper is organised as follows. Section 2 presents an explanation of the new bus route assignment. Section 3 provides the data set. Section 4 presents the methodology, while Section 5 shows the results. Finally, Section 6 concludes.

Reform of the bus network: Nova Xarxa de Bus (NXB)

Until 2012, Barcelona Metropolitan Area's bus network was characterised by a structure that might be called 'point-to-point', where passengers make direct trips from their origin to their destination without the need for any type of transfer.

In 2012, the Barcelona Metropolitan Area had 5,029,000 inhabitants, in an area of 3,239 square kilometers, which represents a population density of 1,553 inhabitants per square kilometer; the sixth most dense in Europe, according to EMTA (2012). Additionally, it was the metropolitan region that had the highest population growth. Specifically, between 2001 and 2011 the population grew by 14.6%, above the average for European metropolitan regions, which was around 10%.

This fact meant that bus lines frequently overlapped, generating inefficiencies and the lowest speed in Europe, at only 12 kilometers per hour (EMTA, 2015). Unsurprisingly, this inefficiency led to one of the lowest rates of use among Europe's large urban regions with only 186 public transport trips per inhabitant per year, compared to 244 on average.

For this reason, Barcelona Metropolitan Transport Authority decided to modify the bus network to eliminate duplications and improve its efficiency by significantly reducing travel time and increasing the speed at which the buses circulate, mainly in the city of Barcelona. The reform consisted in creating a whole new set of lines with great fluency that cross the city horizontally, vertically, and diagonally. Therefore, it was a question of moving from the traditional bus network to an orthogonal network where to go from one point to another in the city it is possible that one or more changes would have to be made (mainly through interchanges), but that the high frequency of passage and the higher speed of circulation, significantly reduce the transport time.

Despite the reform's importance, insufficient evidence exists about its impact. One exception is Allen et al's study (2019) where, through a survey of more than 12,500 users, they observe econometrically how the new bus lines generate greater satisfaction for users, who are largely unaffected by having to exchange buses or use others means of transport together with the bus. The authors conclude that the design of more efficient bus lines can also provide a solution from users' perspectives. Perhaps this greater user satisfaction on the new bus lines generated greater use, explaining, at least partially, the reduction in pollution that we found.

Database

We collect information from the Catalonian government's Air Quality Monitoring website[5]. From January 2008 to December 2016 we collected hourly mean data from six types of pollutants: CO; NO; NO_2; SO_2 and O_3; and PM_{10}, for 20 air quality stations inside and outside Barcelona's metropolitan area. In this regard, there are seven air quality stations located within Barcelona, that are our 'treated stations' (Ciutadella, Eixample, Vall d'Hebron, Palau Reial, Poblenou, Sant Gervasi, and Sants) and 13 air quality stations located outside the city of Barcelona. Seven of these 13 air quality stations are located in the metropolitan area of Barcelona but outside the main area affected by the new routes (Badalona, Balldovina, Gornal, Prat Jardins, Prat Sagnier, Sant Adria, Sant Feliu), while the other six are located in Girona and Tarragona (Bonavista, Escola Musica, Gaudi, Parc Ciutat, Sant Salvador, Universitat Laboral).

Additionally, we gather information about the date that each phase was implemented from the TMB webpage. Finally, we gather information about weather conditions from the Meteocat, the Catalonian government's meteorological service. For our study, we collected hourly average data about atmospheric pressure, rain, relative humidity, temperature, and the wind's direction and force.

Table 1 shows some of the variables' descriptive statistics. In this regard, the hourly maximum level of NO_2 surpassed the hourly maximum recommended by 47%. Also, the PM_{10}

[5] From the Xarxa de Vigilància i Previsió de la Qualitat de l'Aire.

hourly maximum level was 2,868% greater than the 24h maximum recommended. In Barcelona, the level of NO_2 was about 9.8% greater than the yearly maximum recommended by the European Directive. In seven out of the nine years analysed, the yearly maximum recommended was exceeded between 0.168% and 25.995%. In eight years, the hourly maximum recommended for NO_2 was exceeded at least once. For the control group, although the yearly maximums of NO_2 were not exceeded, the hourly maximums were exceeded in five years, at least once.

Table 1. Descriptive statistics by groups

Pollutant	Treated group	Control group
NO	19.448 (µg/m^3)	12.414 (µg/m^3)
	(35.360)	(25.946)
NO_2	43.921 (µg/m^3)	30.693 (µg/m^3)
	(27.267)	(22.427)
CO	0.446 (mg/m^3)	0.346 (mg/m^3)
	(0.331)	(0.191)
SO_2	2.653 (µg/m^3)	2.949 (µg/m^3)
	(3.172)	(4.284)
O_3	43.583 (µg/m^3)	47.300 (µg/m^3)
	(28.545)	(33.280)
PM_{10}	29.930 (µg/m^3)	25.410 (µg/m^3)
	(22.506)	(17.259)

Source: Own elaboration

Average data from meteorological stations are summarised in the following table:

Table 2. Descriptive statistics for the meteorological conditions in our sample

Variable (unit of measure)	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Temperature (°C)	16.663	6.593	-9.3	40.5
Atmospheric pressure (hPa)	1007.292	12.688	932.7	1041
Precipitation (mm)	0.037	0.437	0	33.6
Relative humidity (%)	67.013	16.980	4	100
Velocity of the wind (m/s)	2.254	1.571	0	16.4
Direction of the wind (°North)	195.070	102.014	0	359

Source: Own elaboration

Average data from meteorological stations, separated by groups, are summarised in the following table:

Table 3. Meteorological descriptive statistics by group

Pollutant	Treated hourly mean	Control hourly mean
Temperature (°C)	17.052	16.443
	(6.353)	(6.715)
Atmospheric pressure (hPa)	1003.948	1009.341
	(16.635)	(8.887)
Precipitation (mm)	0.046	0.032
	(0.498)	(0.398)
Relative humidity (%)	64.402	68.491
	(15.848)	(17.415)
Velocity of the wind (m/s)	2.201	2.284
	(1.635)	(1.533)
Direction of the wind (°North)	194.210	195.557
	(95.888)	(105.324)

Source: Own elaboration. Standard deviation in brackets.

Empirical strategy

In this section, we discuss the empirical strategy used. Our empirical strategy employs the implementation of each phase as a key explanatory variable, and we use the difference-in-difference (DID) approach.

The DID method assumes that the impact of the new bus routes is limited locally. With this assumption, we can define the control and treatment groups. The main advantage of the DID technique is that it can easily be adapted to examine potential heterogeneity in impacts. Moreover, with a DID approach, we do not need to know all variables affecting pollution if we consider that remain constant before and after the implementation of the new bus routes. Finally, this approach allows us to identify which part of the change in pollution is due to the new route assignment, and which would have occurred regardless of the new route assignment.

Our DID strategy compares four years and nine months before the new route bus started and four years and three months after the first phase was implemented.

We identify which air quality stations have been affected by this route assignment as the treatment group (air quality stations inside the city) and the air quality stations that have not been affected by these new routes as the control group (air quality stations in border municipalities with Barcelona and non-border municipalities, such as Girona and Tarragona, which are also capitals of their respective provinces).

The effects of the new bus routes on pollution are explained by this econometric approximation:

$$Y_{it} = \beta_0 + \beta_j Phase1_{it} + \beta_k Phase2_{it} + \beta_l Phase3_{it} + \beta_m Phase4_{it} + \gamma_n Treated * Phase1_{it} + \gamma_o Treated * Phase2_t + \gamma_p Treated * Phase3_{it} + \gamma_q Treated * Phase4_{it} + \beta_r X_{it} + \theta_i + \delta_t + \varepsilon_{it}$$

Where the dependent variable (Y_{it}) is the level of each of the pollutants[6] (NO_X, CO, SO_2, and O_3) analysed, X_{it} contains the vector of time-varying control covariates, $Treated$ is a treatment indicator that takes value 1 for air quality stations inside the city, $Phase1$, $Phase2$, $Phase3$, and $Phase4$ are dummy variables that take value 1 for each of the different phases of implementation of the new bus route assignment. As usual, θ_i and δ_t, are air quality stations with specific and time-specific fixed effects. ε_{it} is a mean-zero random error.

The parameters of interest are γ, these coefficients capture the impact of the new routes assignment on air pollution inside the city.

A basic assumption of DID models is that, in the absence of the new route assignment, air quality in the two areas (treatment and control air quality stations) follows parallel trends. We test that the average evolution of pollution before the new route assignment was implemented is equal. To test the parallel trends we evaluate the following regression for the period before the implementation of the new bus routes:

$$Y_{it} = \beta_0 + \beta_r X_{it} + \delta Treated_t * time + \theta_i + \delta_t + \varepsilon_{it}$$

The coefficient of interest is δ. Table 4 presents the results confirming parallel trends for NO_x. For the other pollutants, we cannot assume the hypothesis of parallel trends but we correct this problem by including in the DID approach different trends for the treated in comparison with the control, as Roth (2019) does; and also include different trends for each of the 20 air quality stations included in the database, following Besley and Burgess (2004). These DID approaches can be seen as a robustness check of the initial DID results. It is important to note that the inclusion of trends for the treated, and for each air quality station allow us to estimate the effect of changing

[6] We have insufficient PM10 data, so it cannot be properly analysed. We include the results in the annex.

routes, even though the evolution of pollution may be different in each of the groups. So, we can be confident that our results are well measured. In addition, as results show, the difference of parallel trends for the remaining pollutants is very small and the possibility of not being statistically equal to zero is due to a large number of observations.

Table 4. Parallel trend test

	NO_X	SO_2	CO	O_3
$Parallel\_Trend$	-9.66 e^{-6}	**2.18 e^{-5}*****	**1.74 e^{-6}*****	**-1,63 e^{-5}****
	(1.31 e^{-5})	**(1.89 e^{-6})**	**(1.08 e^{-7})**	**(7.93 e^{-6})**
Constant	**-539.440*****	**-39.856*****	**-1.899*****	**269.504*****
	(8.289)	**(1.276)**	**(0.082)**	**(6.598)**
Controlling by hour of day	YES	YES	YES	YES
Controlling by day of week	YES	YES	YES	YES
Controlling by month of the year	YES	YES	YES	YES
Controlling by year	YES	YES	YES	YES
Controlling by weather conditions	YES	YES	YES	YES
Controlling by air quality station	YES	YES	YES	YES
Controlling by time	YES	YES	YES	YES
No Obs.	580373	471045	396154	377196
F-Test	**2191.14*****	**367.34*****	**594.74*****	**4944.46*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**

Robust Standard errors to heterokedasticity and autocorrelation in brackets. (***) 1%, (**) 5%, (*) 10%.

In addition to the variables that analyse the impact of the new bus route assignment, we control for a whole set of variables that might affect the level of pollution: 1) the day of the week, 2) the month of the year 3) the different years, 4) atmospheric conditions also can affect pollution[7] 5) wind speed; 6) the wind direction We have included a trend variable and its square to capture the possibility that different pollutants follow a trend over time, and that this trend is not linear.

Due to the existence of heteroscedasticity and autocorrelation problems of order one in the database, the Newey-West estimator has been used, which provides us with robust standard errors. This type of estimator only provides results for Ordinary Least Squares (OLS), for which the fixed effects of air quality station (θ_i) and time (δ_t) have been introduced. The results are presented in the next section. The results are presented in the next section.

Results

[7] Following the studies of Bel and Rosell (2013), Viard and Fu (2015), Shlenker and Walker (2016), and Bel and Holst (2018), among others, we include atmospheric variables to control for the impact of these variables on pollutants analysed.

In the following tables, the reduced results of the econometric regressions can be found. The annex shows the complete results for the econometric regressions.

Table 5. Effects of new bus routes on NO_x

	NO_X		
	(1)	(2)	(3)
$Treated * Phase1$	**-5.747*** (0.283)**	**-6.162*** (0.404)**	**-6.262*** (0.409)**
$Treated * Phase2$	**-7.296*** (0.321)**	**-7.860*** (0.513)**	**-8.354*** (0.521)**
$Treated * Phase3$	**-3.470*** (0.291)**	**-4.208*** (0.584)**	**-5.212*** (0.600)**
$Treated * Phase4$	**-5.184*** (0.317)**	**-6.095*** (0.700)**	**-7.541*** (0.727)**
Constant	**-571.484*** (8.289)**	**-571.537*** (8.291)**	**-575.259*** (8.350)**
Controlling by hour of day	YES	YES	YES
Controlling by day of week	YES	YES	YES
Controlling by month of the year	YES	YES	YES
Controlling by year	YES	YES	YES
Controlling by weather conditions	YES	YES	YES
Controlling by air quality station	YES	YES	YES
Controlling by time	YES	YES	YES
Specific trend for treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES
No Obs.	1255867	1255867	1255867
F-Test	**3214.02*** (0.000)**	**3183.12*** (0.000)**	**2709.87*** (0.000)**

Robust Standard errors to heterokedasticity and autocorrelation in brackets. (***) 1%, (**) 5%, (*) 10%.

Table 6. Effects of new bus routes on SO_2, CO, and O_3

	SO_2			CO			O_3		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
$Treated * Phase1$	**0.130*****	**-0.561*****	**-0.915*****	**-0.022*****	**-0.065*****	**-0.066*****	**1.014*****	**1.675*****	**1.348*****
	(0.032)	**(0.046)**	**(0.050)**	**(0.003)**	**(0.004)**	**(0.004)**	**(0.201)**	**(0.268)**	**(0.276)**
$Treated * Phase2$	**-0.542*****	**-1.496*****	**-1.979*****	**-0.038*****	**-0.097*****	**-0.092*****	**1.737*****	**2.640*****	**2.162*****
	(0.032)	**(0.056)**	**(0.063)**	**(0.003)**	**(0.004)**	**(0.005)**	**(0.227)**	**(0.331)**	**(0.346)**
$Treated * Phase3$	**-0.376*****	**-1.644*****	**-2.294*****	**0.009*****	**-0.071*****	**-0.056*****	**2.623*****	**3.809*****	**3.175*****
	(0.029)	**(0.070)**	**(0.081)**	**(0.003)**	**(0.005)**	**(0.007)**	**(0.178)**	**(0.366)**	**(0.393)**
$Treated * Phase4$	**-0.438*****	**-2.014*****	**-2.762*****	**-0.022*****	**-0.121*****	**-0.094*****	**4.149*****	**5.610*****	**4.792*****
	(0.032)	**(0.086)**	**(0.101)**	**(0.003)**	**(0.006)**	**(0.008)**	**(0.218)**	**(0.449)**	**(0.487)**
Constant	**-24.180*****	**-24.435*****	**-26.278*****	**-2.354*****	**-2.360*****	**-2.305*****	**299.074*****	**298.537*****	**298.599*****
	(0.773)	**(0.774)**	**(0.780)**	**(0.065)**	**(0.065)**	**(0.066)**	**(4.780)**	**(4.781)**	**(4.794)**
Controlling by hour of day	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by day of week	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by month of the year	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by year	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by weather conditions	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by air quality station	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by time	YES	YES	YES	YES	YES	YES	YES	YES	YES
Specific trend for treatment group	NO	YES	NO	NO	YES	NO	NO	YES	NO
Specific trend for air quality station	NO	NO	YES	NO	NO	YES	NO	NO	YES
N	941258	941258	941258	633091	633091	633091	717121	717121	717121
F-Test	**287.58*****	**290.18*****	**290.52*****	**977.52*****	**968.91*****	**923.09*****	**9096.45*****	**8997.38*****	**8031.75*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**

Robust Standard errors to heterokedasticity and autocorrelation in brackets. (***) 1%, (**) 5%, (*) 10%.

As we can see in the tables above, the new bus route assignment has improved air quality throughout the city, in general, for all pollutants[8] and phases implemented. For the case of NO_x, SO_2, and CO, all three models confirm an improvement in air quality for all phases.

For the case of NO_x, all models show that the new bus route assignment has decreased pollution in all phases implemented, with the second phase showing a greater decrease in pollution, between 7.30 μg/m^3 and 8.35 μg/m^3; representing a decrease of about 13.56% and 15.52% in comparison with the average pollution one year before the policy's implementation. Taking into account all phases, the decrease in NO_x pollution ranges between 3.47 μg/m^3 and 8.35 μg/m^3. Results differ depending on the model analysed: for example, if we take into account the traditional DiD, the results are lower, with a decrease of between 3.47 μg/m^3 and 7.30 μg/m^3. Taking into account results including different trends for the treated group or trends for all air quality stations, the decrease in pollution is relatively higher, varying between 4.21 μg/m^3 and 8.35 μg/m^3. However, as all models confirm, the implementation of the new route assignment decreased NO_x pollution throughout the city.

In terms of SO_2 pollution, the results are very similar between the three models. For all phases (except the first one), the three models confirm the reduction in the level of SO_2 pollution[9], between 0.38 μg/m^3 and 2.76 μg/m^3, a decrease between 12.01% and 88.26% for the previous average. The three models identify phases 2, 3, and 4 as those with the greatest reduction. Similar to the case of NO_x, the traditional DiD results show a lower pollution decrease (from an increase of 0.13 μg/m^3 to a decrease of 0.54 μg/m^3 during the second phase). Results for the models considering trends for treated stations, or trends for individual air stations, show that all phases have decreased pollution in a range between 0.56 μg/m^3 and 2.76 μg/m^3, with the last phase showing a greater decrease in SO_2 pollution.

For the case of CO, results are similar to those found with SO_2. In general, the three models found that the implementation of the new bus route assignment has decreased CO pollution in Barcelona in a range that varies between 0.022 mg/m^3 and 0.121 mg/m^3; that is, a reduction between 5.57% and 30.65% on the previous average. As before, results for the traditional DiD are lower than the reduction from the other two models. DiD results show that the policy increased pollution from CO in 0.13 mg/m^3 at the third phase and decreased the CO

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[8] Except for O_3

[9] Despite being surprising, results are in line with Gonzalez et al. (2021)

pollution in the other three phases between 0.022 mg/m^3 and 0.038 mg/m^3. DiD with trends showed better results, all four phases decreased pollution between 0.561 mg/m^3 and 0.121 mg/m^3.

About the control variables, all have the expected signs[10]:

The dummy variables of the different days of the week illustrate how Sunday is the day of least weekly pollution, on the other hand, working days show significantly higher levels of pollution, mainly due to greater economic activity.

Regarding the evolution of the pollution throughout the year, it can be observed that the winter months (December, January, and February) have the highest level of pollution, while the summer months have the lowest[11]. This pattern is repeated, with greater or lesser intensity, for all pollutants.

Once we take into account the daily evolution of the pollution collected in the variable "time", we see that in general there has been a decrease in pollution over the last five years for CO_2, NO_x, and O_3.

The following tables show the results when we differentiate air quality stations between traffic and background ones.

Table 7. Effects of new bus routes on NO_x

	NOX		
	(1)	(2)	(3)
$Treated * Phase1 * traffic$	**-9.413*** **	**-10.020*** **	**-12.977*** **
	(0.617)	**(0.688)**	**(0.901)**
$Treated * Phase2 * traffic$	**-12.634*** **	**-13.454*** **	**-17.782*** **
	(0.703)	**(0.819)**	**(1.137)**
$Treated * Phase3 * traffic$	**-10.728*** **	**-11.796*** **	**-17.770*** **
	(0.630)	**(0.817)**	**(1.289)**
$Treated * Phase4 * traffic$	**-13.058*** **	**-14.373*** **	**-21.991*** **
	(0.706)	**(0.943)**	**(1.535)**

[10] Coefficients for control variables can be seen in annex.

[11] Except for O_3. NOx and Volatile Organic Compounds (VOC) combine chemically with oxygen to form ozone during sunny, high-temperature conditions of late spring, summer and early fall.

$Treated * Phase1 * background$	**-4.303********	**-4.891********	**-3.368********
	(0.282)	**(0.401)**	**(0.398)**
$Treated * Phase2 * background$	**-5.185********	**-5.986********	**-4.154********
	(0.318)	**(0.507)**	**(0.508)**
$Treated * Phase3 * background$	**-0.594******	**-1.644********	0.499
	(0.294)	**(0.582)**	(0.583)
$Treated * Phase4 * background$	**-2.039********	**-3.336********	-0.809
	(0.310)	**(0.738)**	(0.711)
Constant	**-572.320********	**-572.398********	**-574.195********
	(8.286)	**(8.287)**	**(8.348)**
Controlling by hour of day	YES	YES	YES
Controlling by day of week	YES	YES	YES
Controlling by month of the year	YES	YES	YES
Controlling by year	YES	YES	YES
Controlling by weather conditions	YES	YES	YES
Controlling by air quality station	YES	YES	YES
Controlling by time	YES	YES	YES
Specific trend for treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES
No Obs.	1255867	1255867	1255867
F-Test	**3098.39********	**3069.84********	**2626.65********
	(0.000)	**(0.000)**	**(0.000)**

Robust Standard errors to heterokedasticity and autocorrelation in brackets. (***) 1%, (**) 5%, (*) 10%.

Table 8. Effects of new bus routes on SO_2, CO, and O_3

	SO_2			CO			O_3		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
$Treated * Phase1 * traffic$	**-1.274*** **	**-2.103*** **	**-1.581*** **	**-0.050*** **	**-0.093*** **	**-0.088*** **	**1.437*** **	**2.222*** **	**1.824*** **
	(0.052)	**(0.061)**	**(0.082)**	**(0.004)**	**(0.005)**	**(0.006)**	**(0.255)**	**(0.313)**	**(0.347)**
$Treated * Phase2 * traffic$	**-1.572*** **	**-2.692*** **	**-1.852*** **	**-0.034*** **	**-0.092*** **	**-0.079*** **	**3.648*** **	**4.711*** **	**4.184*** **
	(0.053)	**(0.070)**	**(0.100)**	**(0.004)**	**(0.005)**	**(0.007)**	**(0.287)**	**(0.378)**	**(0.428)**
$Treated * Phase3 * traffic$	**-1.295*** **	**-2.766*** **	**--1.568*** **	**0.061*** **	**-0.018*** **	0.004	**4.541*** **	**5.931*** **	**5.256*** **
	(0.051)	**(0.081)**	**(0.123)**	**(0.004)**	**(0.006)**	(0.008)	**(0.226)**	**(0.396)**	**(0.475)**
$Treated * Phase4 * traffic$	**-1.537*** **	**-3.353*** **	**-1.739*** **	**-0.014*** **	**-0.113*** **	**-0.077*** **	**5.137*** **	**6.845*** **	**6.023*** **
	(0.053)	**(0.095)**	**(0.150)**	**(0.005)**	**(0.007)**	**(0.010)**	**(0.282)**	**(0.488)**	**(0.587)**
$Treated * Phase1$	**1.032*** **	**0.290*** **	**-0.706*** **	**0.006* **	**-0.038*** **	**-0.024*** **	**0.658*** **	**1.406*** **	**0.922*** **
$* background$	**(0.035)**	**(0.049)**	**(0.052)**	**(0.003)**	**(0.004)**	**(0.005)**	**(0.233)**	**(0.290)**	**(0.323)**
$Treated * Phase2$	-0.023	**-1.059*** **	**-2.499*** **	**-0.053*** **	**-0.112*** **	**0.101*** **	0.365	**1.392*** **	0.598
$* background$	(0.032)	**(0.058)**	**(0.066)**	**(0.003)**	**(0.004)**	**(0.005)**	(0.263)	**(0.354)**	(0.410)
$Treated * Phase3$	0.036	**-1.353*** **	**-3.328*** **	**-0.052*** **	**-0.131*** **	**-0.127*** **	**1.278*** **	**2.633*** **	**1.483*** **
$* background$	(0.028)	**(0.071)**	**(0.085)**	**(0.003)**	**(0.005)**	**(0.007)**	**(0.209)**	**(0.378)**	**(0.474)**
$Treated * Phase4$	**0.160*** **	**-1.570*** **	**-4.022*** **	**-0.040*** **	**-0.138*** **	**-0.137*** **	**3.411*** **	**5.082*** **	**3.570*** **
$* background$	**(0.031)**	**(0.087)**	**(0.106)**	**(0.003)**	**(0.006)**	**(0.008)**	**(0.255)**	**(0.465)**	**(0.592)**
Constant	**-24.277*** **	**-24.565*** **	**-26.501*** **	**-2.354*** **	**-2.360*** **	**-2.316*** **	**299.297*** **	**298.682*** **	**298.451*** **
	(0.771)	**(0.772)**	**(0.780)**	**(0.065)**	**(0.065)**	**(0.065)**	**(4.780)**	**(4.780)**	**(4.792)**
Controlling by hour of day	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by day of week	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by month of the year	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by year	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by weather conditions	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by air quality station	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by time	YES	YES	YES	YES	YES	YES	YES	YES	YES
Specific trend for treatment group	NO	YES	NO	NO	YES	NO	NO	YES	NO
Specific trend for air quality station	NO	NO	YES	NO	NO	YES	NO	NO	YES
N	941258	941258	941258	633091	633091	633091	717121	717121	717121

F-Test	**290.88***** **(0.000)**	**293.43***** **(0.000)**	**296.42***** **(0.000)**	**1004.69***** **(0.000)**	**952.30***** **(0.000)**	**908.24***** **(0.000)**	**8565.53***** **(0.000)**	**8476.70***** **(0.000)**	**7694.14***** **(0.000)**

Robust Standard errors to heterokedasticity and autocorrelation in brackets. (***) 1%, (**) 5%, (*) 10%.

As we can see, for SO_2 and CO, results are similar to those in Table 6; confirming that the new routes have been effective in reducing pollution. Comparing the results for the traffic air quality stations and background ones, our results show that, although the new routes similarly impacted both background and traffic areas, in the case of SO_2 the impact was greater on traffic air quality stations. Meanwhile, for CO, results are similar both in background and traffic air quality stations. These results confirm the idea that the new routes not only impacted traffic areas but also throughout the city.

On the other hand, results for NO_x confirm that the pollution reduction has been greater in traffic areas. That is, as we can see in Table 7, the reduction in NO_x is between 1.6 and 3.7 times higher in traffic areas in comparison with background areas. Not only that but also, comparing results with those for the whole city (Table 5), we can see that the reduction in pollution in traffic areas has been between 1.1 and 2.6 times higher, on average, in traffic areas than the average for the whole city. Therefore, the main impact of new bus routes on NO_x reduction has been in traffic areas. Nevertheless, the reduction of NO_x in background air quality stations is not negligible, as results confirm that the reduction was about 0.594 $\mu g/m^3$ and 5,986 $\mu g/m^3$.

In sum, these results show that the new bus routes have been effective in reducing pollution in traffic areas - but also throughout the city; although the main impact, as expected, was in traffic areas. In traffic areas, the reduction in NO_x pollution was about 9.413 $\mu g/m^3$ and 21.991 $\mu g/m^3$, between 1.274 $\mu g/m^3$ and 3.353 $\mu g/m^3$ in the case of SO_2 and about 0.014 mg/m^3 and 0.113 mg/m^3 in the case of CO. In comparison with the average pollution in traffic areas, the year before the implementation of the new routes, NO_x pollution was reduced by 8.9% and 20.8%, between 24.45% and 64.33% for SO_2, and in the case of CO, the reduction was about 2.17% - 17.49%.

Finally, to contrast the validity of our results, as robustness checks, first, we redo the DID regressions but using different control groups. First, drawing on our database, we divided the air quality stations used to create the control group into two different categories: the first only includes as control group the air quality stations located in Tarragona and Girona, while the second only includes as a control group the air quality stations located outside Barcelona - but also not located either in Tarragona or Girona. Next, we estimated the DID regression for the general scenario (not differentiating by type of air quality station) using first as a control group only air quality stations placed in the first category and second only air quality stations located in the second category. These new results can be found in the annex. To sum up, in general, results show the same trend as for the general results found in Tables 5 and 6 for all pollutants in each phase of the implementation of the new bus routes. Not only do results show a similar trend for each pollutant for the different phases - comparing the auxiliary regressions with the main one - but there are no differences, in general, for the significant phases where the new bus route affected pollution. Additionally, there is no change in the sign of the variable, demonstrating that, using different control groups to estimate the effect of the policy on air quality, results show that the policy decreased pollution for all phases and all pollutants analysed, independently of the control group used. As the results are similar, in terms of variables that are significant and the sign of these variables found in Tables 5 and 6, we are confident that our results are well measured.

Second, we redo our DID regressions subdividing each phase into periods of 3 months. We subdivide each phase into periods of three months to capture better the short-term effect of the policy. We assume that the shorter the period related analysed in each phase, the lower the possible incidence of other scenarios affecting pollution. So, we redo the diff-in-diff equation including new variables for each of these subdivisions.[12] In addition, we redo the analysis, not only for all the city but also taking into account the different types of air quality stations in our database.

In the following tables, the reduced results of the econometric regressions, including the results when we differentiate air quality stations between traffic and background ones, can be found for NO_x. The annex shows the complete results for the econometric regressions for all pollutants.

[12] Note that as each phase has a different time length, some of them will be divided in 3 periods (the first 3 months, months from 4 to 6 and months above 7 months) and the other will be divided in 4 periods (the first 3 months, months from 4 to 6, months from 7 to 9 and above 9 months)

Table 9. Effects of new bus routes on NO_X

	NO_X		
	(1)	(2)	(3)
$Treated * Phase1\_3m$	**-7.517*****	**-7.184*****	**-7.149*****
	(0.597)	**(0.643)**	**(0.645)**
$Treated * Phase1\_6m$	**-7.344*****	**-6.975*****	**-7.026*****
	(0.624)	**(0.680)**	**(0.683)**
$Treated * Phase1\_9m$	**-3.684*****	**-3.279*****	**-3.454*****
	(0.445)	**(0.534)**	**(0.537)**
$Treated * Phase1\_ > 9m$	**-4.960*****	**-4.509*****	**-4.766*****
	(0.374)	**(0.497)**	**(0.502)**
$Treated * Phase2\_3m$	**-7.072*****	**-6.574*****	**-6.962*****
	(0.716)	**(0.805)**	**(0.810)**
$Treated * Phase2\_6m$	**-7.471*****	**-6.936*****	**-7.406*****
	(0.503)	**(0.639)**	**(0.647)**
$Treated * Phase2\_ > 6m$	**-7.325*****	**-6.749*****	**-7.341*****
	(0.331)	**(0.540)**	**(0.550)**
$Treated * Phase3\_3m$	**-4.669*****	**-4.080*****	**-4.769*****
	(0.587)	**(0.743)**	**(0.754)**
$Treated * Phase3\_6m$	**-7.882*****	**-7.228*****	**-8.024*****
	(0.693)	**(0.848)**	**(0.858)**
$Treated * Phase3\_9m$	**-3.054*****	**-2.364*****	**-3.217*****
	(0.472)	**(0.697)**	**(0.712)**
$Treated * Phase3\_ > 9m$	**-1.626*****	-0.865	**-2.066*****
	(0.395)	(0.680)	**(0.702)**
$Treated * Phase4\_3m$	**-8.986*****	**-8.155*****	**-9.421*****
	(0.408)	**(0.744)**	**(0.768)**
$Treated * Phase4\_6m$	**-6.249*****	**-5.382*****	**-6.635*****
	(0.385)	**(0.755)**	**(0.782)**
$Treated * Phase4\_ > 6m$	**-1.659*****	-0.748	**-2.192****
	(0.574)	(0.882)	**(0.918)**
Constant	**-581.211*****	**-581.159*****	**-585.074*****
	(8.420)	**(8.422)**	**(8.485)**
Controlling by hour of day	YES	YES	YES
Controlling by day of week	YES	YES	YES
Controlling by month of the year	YES	YES	YES
Controlling by year	YES	YES	YES
Controlling by weather conditions	YES	YES	YES
Controlling by air quality station	YES	YES	YES
Controlling by time	YES	YES	YES
Specific trend for treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES
No Obs.	1255867	1255867	1255867
F-Test	**2704.22*****	**2681.94*****	**3495.46*****
	(0.000)	**(0.000)**	**(0.000)**

Table 10. Effects of new bus routes on NO_X

	NO_X		
	(1)	(2)	(3)
Treated ∗ Phase1_3m*traffic	**-12.212*****	**-13.034*****	**-15.374*****
	(1.244)	**(1.270)**	**(1.363)**
Treated ∗ Phase1_6m*traffic	**-13.365*****	**-13.168*****	**-15.841*****
	(1.377)	**(1.407)**	**(1.512)**
Treated ∗ Phase1_9m*traffic	**-5.237*****	**-5.021*****	**-8.067*****
	(0.978)	**(1.025)**	**(1.187)**
Treated ∗ Phase1_ > 9m*traffic	**-7.281*****	**-7.041*****	**-10.493*****
	(0.835)	**(0.902)**	**(1.118)**
Treated ∗ Phase2_3m*traffic	**-12.581*****	**-12.587*****	**-16.499*****
	(1.576)	**(1.623)**	**(1.783)**
Treated ∗ Phase2_6m*traffic	**-11.194*****	**-10.910*****	**-15.152*****
	(1.095)	**(1.168)**	**(1.406)**
Treated ∗ Phase2_ > 6m*traffic	**-13.540*****	**-13.235*****	**-17.876*****
	(0.724)	**(0.848)**	**(1.194)**
Treated ∗ Phase3_3m*traffic	**-9.479*****	**-9.152*****	**-14.207*****
	(1.320)	**(1.401)**	**(1.664)**
Treated ∗ Phase3_6m*traffic	**-14.394*****	**-14.048*****	**-19.463*****
	(1.500)	**(1.582)**	**(1.848)**
Treated ∗ Phase3_9m*traffic	**-11.328*****	**-10.963*****	**-16.690*****
	(1.009)	**(1.139)**	**(1.517)**
Treated ∗ Phase3_ > 9m*traffic	**-9.618*****	**-9.216*****	**-15.730*****
	(0.845)	**(1.017)**	**(1.493)**
Treated ∗ Phase4_3m*traffic	**-20.706*****	**-20.267*****	**-27.371*****
	(0.834)	**(1.048)**	**(1.597)**
Treated ∗ Phase4_6m*traffic	**-17.167*****	**-16.710*****	**-24.078*****
	(0.787)	**(1.029)**	**(1.625)**
Treated ∗ Phase4_ > 6m*traffic	**-4.450*****	**-3.970*****	**-11.840*****
	(1.348)	**(1.507)**	**(1.991)**
Treated ∗ Phase1_3m*background	**-5.282*****	**-5.110*****	**-3.738*****
	(0.609)	**(0.652)**	**(0.650)**
Treated ∗ Phase1_6m*background	**-5.013*****	**-4.823*****	**-3.352*****
	(0.614)	**(0.670)**	**(0.668)**
Treated ∗ Phase1_9m*background	**-3.059*****	**-2.850*****	**-1.329****
	(0.445)	**(0.531)**	**(0.527)**
Treated ∗ Phase1_ > 9m*background	**-4.052*****	**-3.819*****	**-2.142*****
	(0.367)	**(0.490)**	**(0.486)**
Treated ∗ Phase2_3m*background	**-4.791*****	**-4.533****	**-2.744*****
	(0.707)	**(0.796)**	**(0.794)**
Treated ∗ Phase2_6m*background	**-6.002*****	**-5.725*****	**-3.840*****
	(0.502)	**(0.636)**	**(0.636)**
Treated ∗ Phase2_ > 6m*background	**-4.874*****	**-4.576*****	**-2.596****
	(0.327)	**(0.535)**	**(0.535)**
Treated ∗ Phase3_3m*background	**-2.797*****	**-2.476*****	-0.384
	(0.577)	**(0.735)**	(0.735)
Treated ∗ Phase3_6m*background	**-5.294*****	**-4.955*****	**-2.779*****
	(0.692)	**(0.846)**	**(0.846)**
Treated ∗ Phase3_9m*background	0.254	0.613	**2.910*****

	(0.480)	(0.699)	(0.704)
$Treated * Phase3\_>$ 9m*background	1.518***	1.913***	4.223***
	(0.404)	(0.684)	(0.690)
$Treated * Phase4_$3m*background	-4.278***	-3.846***	-1.258*
	(0.413)	(0.743)	(0.757)
$Treated * Phase4_$6m*background	-1.849***	-1.398*	1.387*
	(0.392)	(0.755)	(0.771)
$Treated * Phase4\_>$ 6m*background	-0-559	-0.086	2,769**
	(0.546)	(0.866)	(0.885)
Constant	-582.287***	-582.259***	-584.222***
	(8.318)	(8.418)	(8.482)
Controlling by hour of day	YES	YES	YES
Controlling by day of week	YES	YES	YES
Controlling by month of the year	YES	YES	YES
Controlling by year	YES	YES	YES
Controlling by weather conditions	YES	YES	YES
Controlling by air quality station	YES	YES	YES
Controlling by time	YES	YES	YES
Specific trend for treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES
No Obs.	1255867	1255867	1255867
F-Test	2448.34***	2430.40***	2155.02***
	(0.000)	(0.000)	(0.000)

First, as it can be seen in table 9, the great reduction in pollution appears to be during the first 6 months of each phase. In these periods, the reduction of pollution throughout the city is between 4.080 μg/$m^3$and 9.420 μg/m^3 (in comparison with a reduction in pollution for months above 6 between 1.659 μg/m^3 and 7.340 μg/m^3). In this regard, as the main reduction in pollution is at the beginning of the implementation of each phase we are confident that the reduction in pollution we find is due to the implementation of the new bus routes and not due to other policies or scenarios that can affect pollution. In addition, from 6 months and above the pollution reduction is lower but not zero, confirming that the reduction produced at the beginning of each phase does not disappear with time. These results may be due to a behavioral change from private cars users. At first, these new routes attract private cars users to these new buses prompting a pollution reduction. As time passes, some of the users of private cars that were attracted to the bus return to them.

These results are confirmed when we analyse the results differentiating the air quality stations by type. As it can be seen in table 10, for phases 1 and 4, the reduction was, mainly during the first 6 months (with a reduction of about 12.212 μg/m^3 and 27.371 μg/m^3) in comparison with a reduction of about 4.450 μg/m^3 and 11.840 μg/m^3 for periods above 6 months. For phases 2 and 3, the reduction lasted longer. It is important to remark that the duration of each phase is not similar, from roughly 10 months in phase 2 to near 18 months for phase 3. So, what we analyse here is the effect of the new phases for the first 9 months of the implementation of each phase. In this regard, our results show that for all the city, the reduction was higher for the 6 initial months and then the decrease declined but not disappeared. For the case of the stations located in traffic areas, the result is mixed, for phases 1 and 4, the main reduction was for the initial 6 months while for phases 2 and 3 the decrease was similar during all the periods of the phase. Additionally, as can be seen in Table 10, the higher reduction in pollution was, as expected, in traffic areas with a decrease between 4.450 $\mu g/m^3$ and 27.371 $\mu g/m^3$ in comparison with a maximum decrease of 6.002 $\mu g/m^3$ for the case of background stations. As the results for all the city show that the main decrease was at the initial period of the implementation of each phase and the main decrease were in traffic areas, we are confident that the results shown in our study are valid and the decrease in pollution was due to the implementation of the new bus routes.

Conclusions

To reduce traffic congestion and air pollution in Barcelona, the local government is undertaking different policies to increase the use of public transport reducing the use of private cars. In this regard, in 2012 the city council jointly with the metropolitan transport authority implemented new bus routes. Between 2012 and 2018, 28 new bus routes were introduced in Barcelona city.

Although previous literature had analysed the 'congestion relief' of using public transport, there is little evidence about the impact of how a new bus route design can reduce air pollution. The objective of this article has been to measure the effects of the new bus routes implemented in Barcelona on pollution throughout the city. Using a difference-in-difference approach, we show that the new bus routes had an impact on pollution by decreasing the levels of the pollutants analysed, except for O_3. In the case of NO_x, this policy reduced pollution by about 15% throughout the city and about 21% in traffic areas. For SO_2 and CO, this policy also reduced pollution throughout the city. It is important to note that, in general, pollution has decreased in all phases implemented, and especially in the air quality stations near the main roads. Finally, the analysis when subdividing the phases into 3 months periods shows that the policy decreased pollution higher in the initial 6 months, mainly due to changes in the behaviour of private cars users. In this regard, we assume that initially some private cars' users witch to the new buses but, after some time, some of these users return to use their cars. But, as the main reduction is at the start of each phase, and also the main reduction is in traffic areas we can confidently state that the reduction is due to the implementation of the new routes. As far as we know, this is the first time, at least in the case of Barcelona, that a new design of a route assignment has been analysed. The results of our study provide useful information for drawing up policies to improve air quality in urban areas with limited ability to expand public transportation. As our results show, an efficient bus route design can reduce air pollution. Not only this policy can improve air quality in urban areas but also it can be an effective method to reduce the use of fossil fuels. As our results confirm a reduction in pollution, mainly in traffic areas, this effect may be due to the reduction in the use of private cars, achieving, in turn, a reduction in the use of fossil fuels. While it is not the aim of our paper to calculate the health benefits caused by this policy, this estimation could be used for calculating if the health benefits exceed, or not, the costs associated with the new bus routes design. Furthermore, this analysis might be useful to evaluate if the health benefits are greater than the costs associated with the purchase of new buses in the next phases.

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