Transportation Research Part D 129 (2024) 104146

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Does urban bus route assignment improve air quality?

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A R T I C L E I N F O

JEL Codes:
L91
Q53
R41
R49

Keywords:
Air quality
Public transport
Traffic congestion
Bus route assignment

A B S T R A C T

Worldwide, one of the most important causes of mortality is air pollution. To solve this problem, governments have implemented policies to reduce on-road and industrial emissions. In this regard, the Barcelona city council and Transports Metropolitans de Barcelona (TMB) started implementing 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 2012 to 2018. In this context, this paper analyses the impact of this policy on Barcelona's air quality using a dataset from 2008 to 2016. Using a difference-in-difference approach, we show that implementing these new routes increased air quality in Barcelona. Additionally, we show that pollution decreased in each phase analysed, especially in the air quality stations near the main roads. From our results, we can infer that an optimal bus route design can improve air quality in urban areas.

1. Introduction

Worldwide, air pollution is one of the most important causes of mortality. Each year, seven million deaths are associated with it, three due to ambient air pollution (WHO, 2014). It is important to note that the main source of urban air pollution is on-road traffic (Holman, 1999, Raaschou-Nielsen et al., 2010) and its contribution to EU total CO_2 emissions is over 20 % (EEA, 2020); to tackle this problem, the European Union has implemented various policies. Nowadays, to control air pollution in the European Union, the reference sources are the Ambient Air Quality Directive, jointly with Directive 2004/107/EC. Additionally, the European Union also wants to reduce the GHG emissions due to transportation by about 20 % by 2030 compared with 2008 levels (European Commission, 2014).

Consequently, European city councils have implemented policies to reduce congestion or to improve air quality. In 2003 London introduced a congestion charge to enter the city centre to reduce congestion, while in 2006 Stockholm implemented its congestion charge, making it permanent in 2007, also to reduce congestion. 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 like Bogotá, Mexico and Santiago de Chile; or Asian cities like Beijing or Tianjin (Zhang et al., 2017). In the case of Barcelona, several policies have been introduced by the city council to facilitate the use of public and alternative transport modes, like bicycles, to reduce the utilisation of private cars in the city.

In general, what these policies have in common is to encourage private car users to switch to public transport as a means to reduce

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https://doi.org/10.1016/j.trd.2024.104146
Received 4 August 2023; Received in revised form 31 January 2024; Accepted 29 February 2024
Available online 13 March 2024
1361-9209/

congestion and air pollution. Specifically, they seek to reduce the utilisation 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 increasing the difficulty of using private cars, or expanding the provision of public transportation schemes 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 discourage the utilisation of private vehicles, being the congestion charge the most common. Beevers and Carslaw (2005) analysed the impact of London's congestion charge on vehicle emissions. They found that the policy was successful in decreasing pollution within the city centre (−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) found no 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 AQMAs on air pollution 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 0.12 μg m^3; while the reduction of PM_{10} was between 0.03 μg/m^3 and 0.5 μg/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 when cars are restricted from travelling 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 and Sun (2015), explored the effects of two different restrictions in Beijing and found that '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 %. Sun et al. (2022) analyzed vehicle restriction policies in 11 Chinese cities. The authors showed that these types of policies improve air quality. Focusing on Barcelona, Gonçalves et al. (2008) and Baldasano et al. (2010) analysed the speed limitation (80 km/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. The main reason is that better public transport schemes can increase commuters using public transport. Liu et al. (2016) showed that, in Tianjin, policies aimed at restricting driving could not be effective in encouraging commuters to use public transport if policymakers, at least, do not improve public transport. Schiller et al. (2010) conclude that public transportation can be a strategic factor in decreasing 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 transportation utilisation 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. In this regard, Almasri et al. (2011) concluded that by promoting public transport over private and increasing the use of green transport modes, Syria's pollution emissions will be lowered. 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 and 7.2 %, NO_x by 4.7–6.5 %, and PM_{10} by about 7.3–9.2 %. Finally, Sun et al. (2019), analyzing the link between urban public transport and air quality in 63 Chinese cities found that with an increase in the utilisation of bus vehicles by 1 %, the air quality index decreases by 0.082 % showing that public transport decreases air pollution.

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. Jiménez and Román (2016) show that it is possible to reduce emissions from pollutants through efficient bus fleet distribution. In this regard, in 2012, the Barcelona city council jointly with Transports Metropolitans de Barcelona (TMB),[1] implemented the Nova Xarxa de bus de Barcelona (NXB)[2] 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

[1] Barcelona Metropolitan Transport, in English.
[2] In English, New Barcelona Bus Network.

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 following Table 1 shows the date when each phase was implemented:

Our aim is to analyse the effect of the new route design in Barcelona on air pollution. Our hypothesis is that better route designs can be useful to reduce pollution. It is important to note that, starting in the fifth phase, new buses were introduced, mainly in the new routes. So, if we want to analyze the impact of the new bus routes, we should focus our analysis only on the first four phases. Using information about different pollutants from 20 air quality stations inside and outside Barcelona city, and periods before and after the different phases were implemented, we analyze their impact on Barcelona's air quality. To analyse this, we rely on difference-in-difference methods, following Bel and Holst (2018) and Li et al. (2019). Our results show that new bus routes 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, we also 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 affected vehicle traffic. It is noteworthy to mention that to analyze if our results can be affected by other policies, we analyze the impact of each phase subdividing them into periods of 3 months. If results were affected by other policies, results would be random. On the other hand, if the new bus routes decreased pollution, the expected decrease in pollution would be higher at the start of each phase or during the first months. Results confirm that the highest impact, in each of the 4 phases analyzed, was during the first 6 months while declining, but positive, after 6 months. As expected, the decrease in pollution happened at the start of each phase and then stabilized, confirming that the main reason for the decrease in air pollution in each phase was the new bus routes scheme. 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.

Not only this paper is the first one to analyse the impact of the new bus redesign on air quality in Barcelona but also it can be useful to draw policy recommendations for other cities with similar problems as Barcelona. As the redesign of the route, prioritizing bus speed improved air quality in Barcelona we can infer that this type of policy can be useful to improve air quality even in areas with restricted economic resources because there is no need for an expansion of the public transport but a better design of it.

These results indicate that redesigning bus routes, moving to a simpler layout, with a higher speed of circulation and a lower number of stops, would lead not only to a better evaluation by users, as Allen et al (2019) point out, but would significantly reduce pollution levels. Therefore, a better public transport service would be provided and a significant improvement in air quality would be obtained. These results can be especially useful for highly polluted cities that still have spider web-shaped bus networks, where different sections are duplicated by different routes, such as Madrid or Paris. Likewise, the results could indicate that the introduction of fast bus lines, to the extent that they reduce the number of stops and increase the speed of circulation, could be an efficient measure to reduce pollution levels.

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.

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

Until 2012, Barcelona Metropolitan Area[3]'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 2014, the Barcelona Metropolitan Area had 3,239,337 inhabitants, in an area of 636 square kilometres which represents a population density of 5,010 inhabitants per km^2. Taking into account the urban area of Barcelona and adjacent cities, the number of inhabitants increased to 5,375,774, representing a population density of 1,255 inhabitants per km^2 (Eurostat, 2012), 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 km 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, the 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 of creating a whole new set of lines with great fluency that crossed 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.

Fig. 1 shows the new bus lines implemented in Barcelona. As we can see, all cities have been covered with these new routes.

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 other 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

[3] The Barcelona Metropolitan Area is an official union of municipalities and cities that are adjacent, it's also called the Greater Barcelona.

Table 1
Implementation of the new bus lines.

Type of bus line	Code	Origin-Destination
1st Phase: October 1, 2012		
Horizontal	H6	Zona Universitària – Fabra i Puig
Horizontal	H12	Gornal – Besòs/Verneda
Vertical	V7	Pl. Espanya – Sarrià
Vertical	V21	Montbau – Pg. Maritim
Diagonal	D20	Ernest Lluch – Pg. Marítim
2nd Phase: November 18, 2013		
Horizontal	H8	Camp Nou – La Maquinista
Horizontal	H10	Badal – Olimpic de Badalona
Horizontal	H16	Paral.lel – Fòrum
Vertical	V3	Zona Franca – Can Caralleu
Vertical	V17	Port Vell - Carmel
3rd Phase: September 15, 2014		
Horizontal	H14	Paral.lel – Sant Adrià
Horizontal	H16	Pg. Zona Franca – Fòrum
Vertical	V15	Barceloneta – Vall d'Hebron
Vertical	V27	Pg. Maritim – Canyelles
4th Phase: February 29, 2016		
Horizontal	H4	Zona Universitària – Bon Pastor
Vertical	V11	Estació Maritima – Bonanova
Vertical	V13	Pla de Palau – Av. Tibidabo
5th Phase: November 13, 2017		
Vertical	V5	M. Deú del Port – Pedralbes
Vertical	V29	Fòrum – Roquetes
Vertical	V31	Mar Bella – Trinitat Vella
Diagonal	D40	Pl. Espanya – Roquetes
6th Phase: June 25, 2018		
Vertical	V9	Av. Paral.lel – Sarrià
Vertical	V33	Fòrum – Santa Coloma
Diagonal	D50	Ciutat Meridiana- Pl. Catalunya
7th Phase: November 26, 2018		
Horizontal	H2	Av Esplugues – Trinitat Nova
Vertical	V1	Gran Via ĹHospitalet – Av. Esplugues
Vertical	V19	Barceloneta – Pl. Alfonso Comín
Vertical	V23	Poblenou – Can Marcet
Vertical	V25	Poblenou – Horta

Source: Own elaboration based on information from the Metropolitan Transport Authority.

satisfaction on the new bus lines generated greater use, explaining, at least partially, the pollution reduction that we found.

3. Database

We collect information from the website of the Catalonian government: Air Quality Monitoring.[4] We collected data from January 2008 to December 2016. Are 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, which are our 'treated stations' (Ciutadella, Eixample, Vall d'Hebron, Palau Reial, Poblenou, Sant Gervasi, and Sants) and our control group, the rest of air quality stations located outside the city of Barcelona (13 stations). 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).

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

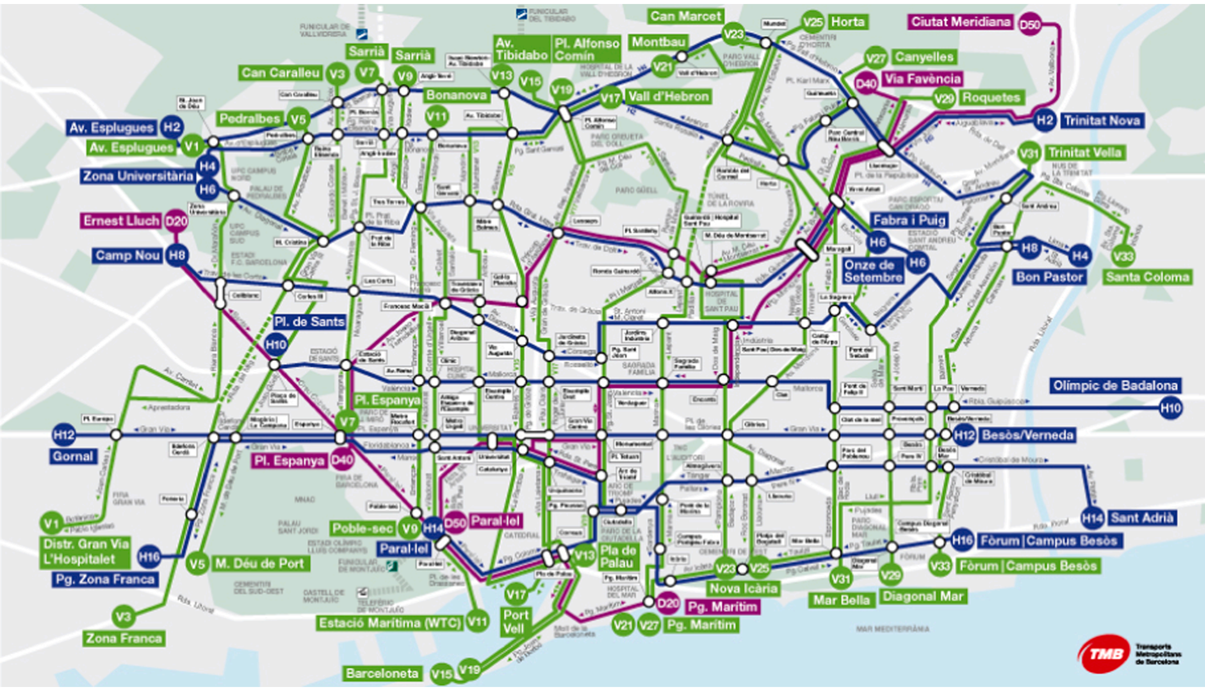

Fig. 1. New Bus Routes Source: Transport Metropolitans de Barcelona.

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 2 shows some of the variable's descriptive statistics. In this regard, the hourly maximum level of NO_2 surpassed the hourly maximum recommended by 47 %. Also, the PM_{10} hourly maximum level was 2,868 % greater than the 24-hour 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.

Average data from meteorological stations, separated by groups, are summarised in Table 3:

Average data from meteorological stations, separated by groups, are summarised in the following Table 4:

4. Empirical strategy

Section 4 presents our empirical strategy. We employ 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. One of the main advantages of the DID technique is its adaptation to examine potential heterogeneity in impacts. Moreover, with a DID approach, we do not need to know all variables affecting pollution if we assume that they 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:

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

Table 2
Descriptive statistics by groups.

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

Source: Own elaboration. Standard deviations in brackets.

Table 3
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/h)	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. Standard deviations values in brackets.

Table 4
Meteorological descriptive statistics by group.

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

Source: Own elaboration. Standard deviation in brackets.

The dependent variable (Y_{it}) is the level of each of the pollutants[5] (NO_X,[6] 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, *Phase*1, *Phase*2, *Phase*3, and *Phase*4 are dummy variables that take value 1 for each of the different phases of implementation of the new bus route assignment. As usual, $\theta_i and \delta_t$, are air quality stations with specific and time-specific fixed effects. ε_{it} is a mean-zero random error.

Note that, as we are using a fixed effects model, with air quality stations specific fixed effects, we do not include the *Treated* variable in the model directly. When we use fixed effects by air quality station, the summatory of the dummy variables of the affected air quality stations are equal to the *Treated* variable, so including the variable *Treated* in the model is going to create a perfect multicollinearity problem.[7]

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

[5] We have insufficient PM10 data, so it cannot be properly analysed. We include the results in the annex.
[6] $NO_x = NO + NO_2$.
[7] Results using random effects and the treated variable generates are very similar. The main conclusions of the paper do not change. Results are upon request.

One of the main assumptions of DID models is that, in the absence of the new route assignment, both areas (treatment and control group) follow 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 5 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 allows us to estimate the effect of changing 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 in 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.

In addition to the variables that analyse the impact of the new bus route assignment, we introduce different variables that can be correlated with the level of pollution: 1) the day of the week, 2) the month of the year 3) the different years, 4) atmospheric conditions (other than wind) also can affect pollution[8] 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. Results of the previous econometric specification are presented in section 5.

5. Results

The reduced results can be found in the following tables. The complete results can be found in the annex.

As we can see in Tables 6 and 7, the new bus route assignment has improved air quality throughout the city, in general, for all pollutants[9] 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,[10] 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 CO, the 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 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.

Control variables have the expected signs[11]:

Dummy variables for the days of the week illustrate that Sunday is the day with the lower level of pollution, on the other hand, working days show significantly higher levels of pollution, mainly due to greater economic activity.

Regarding the evolution of pollution during the course of the year, the winter months (December, January, and February) have the

[8] Following the studies of Bel and Rosell (2013), Viard and Fu (2015), Schlenker 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.

[9] Except for O_3.

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

[11] In the annex we show the coefficients for the control variables.

Table 5
Parallel trend test.

	NO_X	SO_2	CO	O_3
Parallel_Trend	−9.66 e-6 (1.31 e-5)	**2.18 e-5*** (1.89 e-6)**	**1.74 e-6*** (1.08 e-7)**	**−1,63 e-5** (7.93 e-6)**
Constant	**−539.440*** (8.289)**	**−39.856*** (1.276)**	**−1.899*** (0.082)**	**269.504*** (6.598)**
Controlling by the hour of the day	YES	YES	YES	YES
Controlling by day of the 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.	580,373	471,045	396,154	377,196
F-Test	**2191.14*** (0.000)**	**367.34*** (0.000)**	**594.74*** (0.000)**	**4944.46*** (0.000)**
R-squared[1]	0.306	0.063	0.142	0.580

Robust Standard errors to heteroskedasticity and autocorrelation in brackets. (***) 1%, (**) 5%, (*) 10%.
[1] The R-squared (in all tables) is included to see how the model fits but its not part of the estimation table.

Table 6
Effects of new bus routes on NO_x.

	NO_X		
	(1)	(2)	(3)
*Treated*Phase*1	**−5.747*** (0.283)**	**−6.162*** (0.404)**	**−6.262*** (0.409)**
*Treated*Phase*2	**−7.296*** (0.321)**	**−7.860*** (0.513)**	**−8.354*** (0.521)**
*Treated*Phase*3	**−3.470*** (0.291)**	**−4.208*** (0.584)**	**−5.212*** (0.600)**
*Treated*Phase*4	**−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 the hour of the day	YES	YES	YES
Controlling by day of the 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 the treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES
No Obs.	1,255,867	1,255,867	1,255,867
F-Test	**3214.02*** (0.000)**	**3183.12*** (0.000)**	**2709.87*** (0.000)**
R-squared	0.299	0.299	0.300

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

highest level of pollution, while the summer months have the lowest.[12] In general, this pattern is similar for all pollutants.

Looking at the variable "time", we show that the levels of CO_2, NO_x, and O_3 have been decreasing over the last five years. Tables 8 and 9 show the results when we differentiate air quality stations between traffic and background ones.

Results for SO_2 and CO are similar to those in Table 7; confirming that the new routes have been effective in reducing pollution. Comparing the results for traffic and background air quality stations, 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 the background and traffic air quality stations. These results confirm the idea that the new routes not only impacted traffic areas but also throughout Barcelona.

However, results for NO_x confirm that the reduction has been greater in traffic areas. As we can see in Table 8, the reduction in NOx is between 1.6 and 3.7 times higher in traffic areas compared to background areas. Not only that but also, comparing results with those

[12] Except for O_3 This is due to the fact that Volatile Organic Compounds (VOC) and NOx combine with oxygen forming ozone during high-temperature and sunny conditions of late spring, summer and early fall.

Table 7
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*Phase*1	**0.130*** (0.032)**	**−0.561*** (0.046)**	**−0.915*** (0.050)**	**−0.022*** (0.003)**	**−0.065*** (0.004)**	**−0.066*** (0.004)**	**1.014*** (0.201)**	**1.675*** (0.268)**	**1.348*** (0.276)**
*Treated*Phase*2	**−0.542*** (0.032)**	**−1.496*** (0.056)**	**−1.979*** (0.063)**	**−0.038*** (0.003)**	**−0.097*** (0.004)**	**−0.092*** (0.005)**	**1.737*** (0.227)**	**2.640*** (0.331)**	**2.162*** (0.346)**
*Treated*Phase*3	**−0.376*** (0.029)**	**−1.644*** (0.070)**	**−2.294*** (0.081)**	**0.009*** (0.003)**	**−0.071*** (0.005)**	**−0.056*** (0.007)**	**2.623*** (0.178)**	**3.809*** (0.366)**	**3.175*** (0.393)**
*Treated*Phase*4	**−0.438*** (0.032)**	**−2.014*** (0.086)**	**−2.762*** (0.101)**	**−0.022*** (0.003)**	**−0.121*** (0.006)**	**−0.094*** (0.008)**	**4.149*** (0.218)**	**5.610*** (0.449)**	**4.792*** (0.487)**
Constant	**−24.180*** (0.773)**	**−24.435*** (0.774)**	**−26.278*** (0.780)**	**−2.354*** (0.065)**	**−2.360*** (0.065)**	**−2.305*** (0.066)**	**299.074*** (4.780)**	**298.537*** (4.781)**	**298.599*** (4.794)**
Controlling by the hour of the day	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by day of the 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 the 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	941,258	941,258	941,258	633,091	633,091	633,091	717,121	717,121	717,121
F-Test	**287.58*** (0.000)**	**290.18*** (0.000)**	**290.52*** (0.000)**	**977.52*** (0.000)**	**968.91*** (0.000)**	**923.09*** (0.000)**	**9096.45*** (0.000)**	**8997.38*** (0.000)**	**8031.75*** (0.000)**
R-squared	0.061	0.063	0.068	0.160	0.161	0.168	0.570	0.570	0.571

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

Table 8
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)**
*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 the hour of the day	YES	YES	YES
Controlling by day of the 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 the treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES
No Obs.	1,255,867	1,255,867	1,255,867
F-Test	**3098.39*****	**3069.84*****	**2626.65*****
	(0.000)	**(0.000)**	**(0.000)**
R-squared	0.314	0.314	0.315

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

for the whole city (Table 6), 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 between 0.594 μg/m^3 and 5,986 μg/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 between 9.413 μg/m^3 and 21.991 μg/m^3, between 1.274 μg/m^3 and 3.353 μg/m^3 in the case of SO_2 and between 0.014 mg/m^3 and 0.113 mg/m^3 in the case of CO. Compared 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 between 2.17 % – 17.49 %.

Finally, to check 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 the control group the air quality stations located in Tarragona and Girona, while the second only includes as the 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 placed in the second category. These new results can be found in the annex. To sum up, in general, results show the same trend as the general results found in Tables 6 and 7 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 6 and 7, 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 analysed in each phase, the lower the possible incidence of other factors affecting pollution. Our hypothesis is that if the previous results found were biased by

Table 9
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*** (0.052)	−2.103*** (0.061)	−1.581*** (0.082)	−0.050*** (0.004)	−0.093*** (0.005)	−0.088*** (0.006)	1.437*** (0.255)	2.222*** (0.313)	1.824*** (0.347)
*Treated*Phase2*traffic*	−1.572*** (0.053)	−2.692*** (0.070)	−1.852*** (0.100)	−0.034*** (0.004)	−0.092*** (0.005)	−0.079*** (0.007)	3.648*** (0.287)	4.711*** (0.378)	4.184*** (0.428)
*Treated*Phase3*traffic*	−1.295*** (0.051)	−2.766*** (0.081)	–1.568*** (0.123)	0.061*** (0.004)	−0.018*** (0.006)	0.004 (0.008)	4.541*** (0.226)	5.931*** (0.396)	5.256*** (0.475)
*Treated*Phase4*traffic*	−1.537*** (0.053)	−3.353*** (0.095)	−1.739*** (0.150)	−0.014*** (0.005)	−0.113*** (0.007)	−0.077*** (0.010)	5.137*** (0.282)	6.845*** (0.488)	6.023*** (0.587)
*Treated*Phase1*background*	1.032*** (0.035)	0.290*** (0.049)	−0.706*** (0.052)	0.006* (0.003)	−0.038*** (0.004)	−0.024*** (0.005)	0.658*** (0.233)	1.406*** (0.290)	0.922*** (0.323)
*Treated*Phase2*background*	−0.023 (0.032)	−1.059*** (0.058)	−2.499*** (0.066)	−0.053*** (0.003)	−0.112*** (0.004)	0.101*** (0.005)	0.365 (0.263)	1.392*** (0.354)	0.598 (0.410)
*Treated*Phase3*background*	0.036 (0.028)	−1.353*** (0.071)	−3.328*** (0.085)	−0.052*** (0.003)	−0.131*** (0.005)	−0.127*** (0.007)	1.278*** (0.209)	2.633*** (0.378)	1.483*** (0.474)
*Treated*Phase4*background*	0.160*** (0.031)	−1.570*** (0.087)	−4.022*** (0.106)	−0.040*** (0.003)	−0.138*** (0.006)	−0.137*** (0.008)	3.411*** (0.255)	5.082*** (0.465)	3.570*** (0.592)
Constant	−24.277*** (0.771)	−24.565*** (0.772)	−26.501*** (0.780)	−2.354*** (0.065)	−2.360*** (0.065)	−2.316*** (0.065)	299.297*** (4.780)	298.682*** (4.780)	298.451*** (4.792)
Controlling by the hour of the day	YES	YES	YES	YES	YES	YES	YES	YES	YES
Controlling by day of the 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 the 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	941,258	941,258	941,258	633,091	633,091	633,091	717,121	717,121	717,121
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)
R-squared	0.059	0.060	0.067	0.155	0.156	0.161	0.592	0.592	0.592

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

Table 10
Effects of new bus routes on NO_X.

	NO_X		
	(1)	(2)	(3)
*Treated**Phase1_3m*	**−7.517***** **(0.597)**	**−7.184***** **(0.643)**	**−7.149***** **(0.645)**
*Treated**Phase1_6m*	**−7.344***** **(0.624)**	**−6.975***** **(0.680)**	**−7.026***** **(0.683)**
*Treated**Phase1_9m*	**−3.684***** **(0.445)**	**−3.279***** **(0.534)**	**−3.454***** **(0.537)**
*Treated**Phase1_ > 9m*	**−4.960***** **(0.374)**	**−4.509***** **(0.497)**	**−4.766***** **(0.502)**
*Treated**Phase2_3m*	**−7.072***** **(0.716)**	**−6.574***** **(0.805)**	**−6.962***** **(0.810)**
*Treated**Phase2_6m*	**−7.471***** **(0.503)**	**−6.936***** **(0.639)**	**−7.406***** **(0.647)**
*Treated**Phase2_ > 6m*	**−7.325***** **(0.331)**	**−6.749***** **(0.540)**	**−7.341***** **(0.550)**
*Treated**Phase3_3m*	**−4.669***** **(0.587)**	**−4.080***** **(0.743)**	**−4.769***** **(0.754)**
*Treated**Phase3_6m*	**−7.882***** **(0.693)**	**−7.228***** **(0.848)**	**−8.024***** **(0.858)**
*Treated**Phase3_9m*	**−3.054***** **(0.472)**	**−2.364***** **(0.697)**	**−3.217***** **(0.712)**
*Treated**Phase3_ > 9m*	**−1.626***** **(0.395)**	−0.865 (0.680)	**−2.066***** **(0.702)**
*Treated**Phase4_3m*	**−8.986***** **(0.408)**	**−8.155***** **(0.744)**	**−9.421***** **(0.768)**
*Treated**Phase4_6m*	**−6.249***** **(0.385)**	**−5.382***** **(0.755)**	**−6.635***** **(0.782)**
*Treated**Phase4_ > 6m*	**−1.659***** **(0.574)**	−0.748 (0.882)	**−2.192**** **(0.918)**
Constant	**−581.211***** **(8.420)**	**−581.159***** **(8.422)**	**−585.074***** **(8.485)**
Controlling by the hour of the day	YES	YES	YES
Controlling by day of the 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 the treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES
No Obs.	1,255,867	1,255,867	1,255,867
F-Test	**2704.22***** **(0.000)**	**2681.94***** **(0.000)**	**3495.46***** **(0.000)**
R-squared	0.314	0.314	0.315

being affected by other policies or scenarios affecting pollution, the results found in this analysis for each subphase will be random. On the contrary, if the main impact is due to the new bus routes, we expect that the reduction in emissions will be higher at the start of each phase, or during the first months, when new users are attracted to the new routes or because the buses are more energy-efficient due to a better-designed route, while declining after. So, we redo the diff-in-diff equation including new variables for each of these subdivisions.[13] In addition, we redo the analysis, not only for the city but also taking into consideration 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.

First, as can be seen in Table 10, 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 $\mu g/m^3$and 9.420 $\mu g/m^3$ (in comparison with a reduction in pollution for months above 6 between 1.626 $\mu g/m^3$ and 7.340 $\mu g/m^3$). In this regard, as the main reduction in pollution is at the beginning of the implementation of each phase we are confident that the pollution reduction 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

[13] 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 11
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 the hour of the day	YES	YES	YES
Controlling by day of the 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 the treatment group	NO	YES	NO
Specific trend for air quality station	NO	NO	YES

(continued on next page)

Table 11 (*continued*)

	NO_X		
	(1)	(2)	(3)
No Obs.	1,255,867	1,255,867	1,255,867
F-Test	**2448.34*****	**2430.40*****	**2155.02*****
	(0.000)	**(0.000)**	**(0.000)**
R-squared	0.315	0.315	0.316

with time. These results may be due to a behavioural change from private car users. At first, these new routes attract private car 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. We have not found previous empirical evidence of this rebound effect after an improvement in public transport, although we do find that an improvement in mobility, which reduces congestion levels, can generate this type of effect. Coulombel et al., (2019) show how the introduction of ridesharing in the city of Paris has a positive effect by transferring passengers to this mode of transport and generating a decrease in congestion. However, the reduction in congestion causes passengers from public transport (and other modes of transport) to switch to the car, cancelling between 68 and 77 % of the reduction in CO2 that had been generated. We believe that in this case, the improvement of public transportation may be causing a similar effect.

These results confirmed what we have shown in Table 10. Our results confirm that the main reduction was higher during the first months both in traffic and background areas. In traffic areas, for phases 1 and 4, the reduction was, mainly during the first 6 months (with a reduction of about 12.212 $\mu g/m^3$ and 27.371 $\mu g/m^3$) in comparison with a reduction of about 4.450 $\mu g/m^3$ and 11.840 $\mu g/m^3$ for periods above 6 months in those areas. 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 nearly 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 did not disappear. Comparing traffic and background areas, as it can be seen in Table 11, 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 was 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. Note that these results should not be affected by the allocation of bus stops before and after the implementation of the new bus routes. In this regard, we have calculated the distance between the bus stops, both for eliminated and new lines, to the nearest air quality station located in Barcelona. Results confirm that there is no significant difference in this distance for eliminated lines in comparison with new lines. The difference in the distance between the new and the old bus lines to the air quality stations is less than 60 m. Results can be found in Table A96 in Annex.

6. Conclusions and policy implications

To reduce air pollution and traffic congestion in Barcelona, the local government is undertaking different policies to increase the utilisation of public transportation 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 has 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 paper has been to measure the impact 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. Note that, in general, pollution has decreased in all phases implemented, particularly in air quality stations located near the main roads. Finally, the analysis when subdividing the phases into 3 monthly periods shows that the policy decreased pollution higher in the initial 6 months, mainly due to changes in the behaviour of private car users. In this regard, we assume that initially, some private car users switch 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.

These results provide valuable information for formulating policies to improve air quality in urban areas with limited ability to expand public transportation. Redistributing existing buses to well-designed routes can reduce air pollution, even without the need to increase the number of vehicles. So, in this regard, an effective and non-costly policy to improve air quality in urban areas is redesigning bus routes eliminating duplicated routes, prioritizing buses over other transportation methods, increasing bus speed and, reducing the time buses are stopped. It is important to remark that during the first four phases, the main objective was to reorganize routes with a better design. In this regard, this objective was achieved by letting buses go faster, in straight directions, lowering the time that they were stopped in stops and prioritizing buses in the semaphores. Taking that into account, our results could be helpful not only for the Barcelona case but also for other similar cities with similar problems. Eliminating duplicated routes, improving bus speed and creating more efficient routes can be a less costly measure to improve air quality rather than increasing supply. These types of policies can be implemented in cities where bus routes have not been properly designed.

In addition, it is noteworthy that environmental and pollution aspects should be taken into account when designing bus routes. As seen in Barcelona, policymakers usually tend to include efficiency and technical aspects when designing routes (speed, stops…) but as the routes' design is going to affect air quality, it should be included during the design phase to maximize the reduction of air pollution.

Finally, 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 utilisation of private cars, achieving, in turn, a reduction in the use of fossil fuels. While our paper does not aim to calculate the health benefits caused by this policy, this estimation could be used to calculate 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 health benefits are bigger than costs related to the purchase of new buses in the last 3 phases not included in our analysis.

CRediT authorship contribution statement

Àlex Sanz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing. **Jordi Perdiguero:** Formal analysis, Investigation, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work has been supported by the Barcelona Council (20S01909-001). Jordi Perdiguero thanks comments and suggestions of Chinguirito del Ruben.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trd.2024.104146.

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