
“Have Low Emission Zones slowed urban traffic recovery after Covid-19?”

Daniel Albalade and Xavier Fageda

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Abstract

This paper provides a bridge between the literature on the effects of the pandemic on mobility and the literature on low emission zones (LEZ) impacts. Using data for large European cities in the period 2018-2021, we examine whether LEZ may explain differences in the recovery patterns of traffic in European cities after the covid shock. Controlling for several city attributes, we examine whether LEZ cities are less congested before and after the pandemic in comparison to non-LEZ cities. Our hypothesis is that LEZ may have been more effective in reducing congestion after the pandemics because the fleet renewal process has slowed down. Our results validate the traffic mitigating role of LEZ, which is robust to the lasting effects of Covid-19.

JEL classification: R41, R11, R52.

Keywords: Low Emission Zones, Congestion, Traffic, Access restrictions, Sustainability, Cities.

Daniel Albalade: (GiM-IREA). Observatori d'Anàlisi i Avaluació de Polítiques Públiques. Facultat d'Economia i Empresa. Universitat de Barcelona. Departament d'Econometria Estadística i Economia Aplicada. Secció Polítiques públiques. John Maynard Keynes 1-11, Torre 6, planta 3. 08034 Barcelona. Tel: +34.493031131. Email: albalate@ub.edu

Xavier Fageda: (GiM-IREA). Observatori d'Anàlisi i Avaluació de Polítiques Públiques. Facultat d'Economia i Empresa. Universitat de Barcelona. Departament d'Econometria Estadística i Economia Aplicada. Secció Polítiques públiques. John Maynard Keynes 1-11, Torre 6, planta 3. 08034 Barcelona. Tel: +34.93.4039721. Email: xfageda@ub.edu

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Introduction

The pandemic caused by COVID-19 has had a very important impact on mobility due to the restrictions imposed by governments, the fear of contagion and the extension of teleworking. This fall in mobility was very strong for all modes of transport in 2020, particularly in the spring, which coincides with the strict confinement resulting from the first wave of the pandemic. These impacts have been even stronger in urban areas where the high levels of social interaction accentuated the effects of the pandemic, also considering that urban areas concentrate the largest volume of trips either by public or private transport. However, the evolution of car traffic in 2021 has been more heterogeneous and evidence about the causes that explain the different recovery patterns of car traffic across cities is absent.

Before the pandemic, there was growing concern about the excessive weight of cars in urban mobility. Indeed, the great weight of private transportation in large cities generates important negative externalities in terms of congestion, pollution, accidents, occupation of public space and noise. In this sense, in the short term the pandemic has had a positive collateral effect, since fewer cars have meant less pollution, congestion, etc.

In this paper, we focus the attention on one of the main negative externalities of traffic that is congestion. Urban congestion results in traffic jams that increase travel time, negatively affecting drivers and pedestrians, who have to put up with increasing levels of gridlock, noise and pollution. In addition, congestion aggravates other negative externalities, such as pollution, GHG emissions, materials' deterioration, noise, etc. Particularly clear is the relationship between congestion and pollution, since prolonged car circulation at reduced speeds has a notable effect on the emission of polluting substances (Barth and Boriboonsomsin, 2008; Beaudoin *et al.*, 2015, and Parry *et al.*,

2007). Albalate and Fageda (2021) also show that higher levels of congestion may lead to worse safety performance outcomes.

Indeed, the economic cost of road congestion only is huge, due to loss of time. For example, a recent study by the European Commission (2019) revealed that congestion due to road transport in all European Union countries costs €271 billion.

Although there is a growing literature on the effects of Covid-19 pandemic on mobility, most studies are based on surveys or descriptive data for 2020. As expected, several studies find a reduction in the demand of transportation due to the increasing use of teleworking (Falchetta *et al.* 2021; Mouratidis *et al.* 2021, Barrero *et al.* 2020; Brick *et al.* 2020, US). However, the demand for public transport has fallen more sharply than that for private transport due to fear of contagion, and pre-covid levels were being recovered faster for private transportation modes (Albalate *et al.*, 2022). Indeed, it has been found evidence of a greater preference for private transport over public transport after the lockdown in studies for very different geographical areas (Abdullah *et al.*, 2021; Eisenmann *et al.* 2021, Przybylowski *et al.* 2021, Dias *et al.* 2021, Dingil *et al.* 2021; Echaniz *et al.* 2021, Awad-Nuñez *et al.* 2021, Aloi *et al.* 2020, Basu & Ferreira 2021). Moreover, another strand of literature has shown that the pandemic has caused an increase in suburbanization, that is, the shift of residence from the city center to the suburban area ((Chun *et al.* 2022; Murat *et al.* 2021; Stawarz *et al.* 2022). Some other studies find a higher decrease in the mobility for high-income citizens (Mejía *et al.* 2021) and an increase proportion of traffic coming from commercial vehicles (Villa i Monzón 2021).

Overall, the short-term effect of the pandemic has undoubtedly been a sharp drop in mobility, but the long-term effects are very uncertain, and may even end up involving an increase in mobility (Currie *et al.*, 2021; Eliasson, 2022; Zhang *et al.*, 2021). On the one hand, the increasing use of teleworking could reduce car traffic and congestion. On the

other hand, a more negative perception of public transport could be maintained over time with the consequent increase in the modal share of private transport and hence an increase in congestion. The pandemic may also accelerate the process of suburbanization in large cities, in the sense that many citizens will move to live in smaller municipalities in the metropolitan area. Suburbanization can increase the number of trips made from municipalities outside the central city to the central city. To the extent that public transport options are generally worse in terms of traffic penetration than mobility within cities, suburbanization may lead to increased car dependence. In addition, it can be expected a growth in traffic generated by commercial vehicles because of the e-commerce boom.

Thus, it may be even more necessary than before the pandemics to implement policies aimed at reducing car dependence (and reducing associated externalities), such as investment in public and non-motorized transport, price-based measures (tolls, parking costs, etc.) or restrictions via quantities (low emission zones, reduction of space for cars, etc.).

Among the policies most widely implemented low-emission zones (LEZ) is the most popular quantity-based measure in Europe. LEZs ban polluting vehicles (i.e., those not complying with emission standards) from city centers. Several studies have analyzed the effects of LEZ on pollution. Previous studies for German cities suggest that LEZs can be effective in improving air quality. Malina and Scheffler (2015) analyze the impact of LEZs on PM10 emissions with data for the period 2000-2009, finding a reduction of 13%. Still focusing on PM10 emissions and using data at a detailed geographical scale for 2008-2010, Wolff (2014) finds an average reduction of 9%. Morfeld *et al.* (2014) also find a significant impact of LEZs in reducing NO, NO₂, and NO_x. The magnitude of the impact is around 4%. Some other studies analyze the effect of LEZs on individual cities by comparing pollution levels before and after their implementation. Panteliadis *et al.* (2014)

study the LEZ implemented in Amsterdam, which gradually banned heavy-duty vehicles based on their emission category. They find a reduction in the concentration of different pollutants, ranging from 4% in terms of NO₂ and NO_x up to 10% in terms of PM10. Ellison *et al.* (2013) study the case of London, where an emission standard was imposed on trucks, coaches, and buses in an area covering most Greater London. They show that PM10 concentrations within the limits of the LEZ dropped by 2.46%-3.07% as compared to a lower decrease of 1% in limiting areas; however, no discernible differences are found for NO_x concentrations. Cesaroni *et al.* (2012) analyze intervention policies in Rome, including the exclusion of all cars from the historical city center and the prohibition of old diesel vehicles within the railway ring. In the intervention area, they find a PM10 and NO₂ reduction of 33% and 58%, respectively (but the results are modest city-wide). It is important to acknowledge that the latter two studies do not employ any econometric techniques allowing to control for potential confounders.

However, the literature on the effects of LEZ on congestion is much scarcer. Bernardo *et al.* (2021) do not find evidence that LEZ reduce congestion in a study that considers several European urban areas. In a different approach, Tassinari (2022) reaches the same conclusion in analysis for the city of Madrid.

Thus, previous literature suggests that LEZ has been effective in reducing pollution but not in reducing congestion. The main reason behind the reduction in pollution is that LEZ has spur the renewal of the car fleet from older to new and more efficient vehicles. Such renewal does not curb congestion given that the newer cars can enter in the restricted area.

This paper contributes to the literature by providing a bridge between the literature on the effects of the pandemic on mobility and the literature on LEZ impacts. Using data for large European cities in the period 2018-2021, we examine whether the implementation

of LEZ policies may explain differences in the recovery patterns of traffic in European cities after the covid shock. Indeed, we examine whether LEZ cities have less congestion before and after the pandemic in comparison to non-LEZ cities controlling for several city attributes – and other traffic restrictions - that may have an effect on congestion. Our hypothesis is that LEZ may have been more effective in reducing congestion after the pandemics because the fleet renewal process has slowed down.

The rest of the paper is organized as follows. The next section explains the data and variables used in the econometric analysis. Then, we show the methods and empirical equations that we estimate and discuss the identification strategy. This is followed by a section on the results of the econometric estimates. The last section is devoted to a discussion and concluding remarks.

Data and variables

Our analysis draws on a novel database created for the purpose of this research with information for all metropolitan areas with more than 300.000 inhabitants in the European Union (plus United Kingdom and Switzerland) between 2018 and 2021.¹ Our dependent variable is the level of congestion experienced in 144 metropolitan areas.² Data for congestion were obtained from TomTom (https://www.tomtom.com/en_gb/tra_cindex). It is measured as the additional travel time a vehicle needs to undertake as compared to a free-flow situation. TomTom obtains real data from drivers' travel time from every city where they operate. Based on actual GPS-based measurements for each city, TomTom registers data from local roads, arterials, and highways. Several recent articles have employed this

¹ We only exclude metropolitan areas with road pricing schemes which are stricter access restrictions policies that could confound the effect of LEZ and due to its low number, do not offer enough variability to be included as a covariate (binary variable).

² Unfortunately, our final sample for the analysis loses 143 observations due to missing information, particularly regarding year 2018, rail per capita and the motorization variables. Results without these variables are available upon reasonable request. They do not change our main conclusions respect the support to the hypothesis tested in this research.

measure of congestion (see Albalade and Fageda, 2021; Bernardo et al., 2021, among others).

Although the variable measures the average congestion for a given year, what has the obvious limitation that it hides substantial differences between peak and off-peak periods- as well as seasonality-, it seems appropriate for the purpose of this research, which is not focused on the dynamics of congestion but on the reaction of traffic after Covid-19. This logarithm of congestion is regressed on the presence of traffic restrictions regulations, and a vector of confounding covariates. All of them are described below.

Traffic restrictions variables considered in our analysis are binary variables denoting with 1 the presence of a particular traffic restriction and 0 otherwise. D^{LEZ} denotes the presence of low emission zones, which is our main variable of interest, while D^{LTZ} refers to limited traffic zones – other traffic access regulations- and acts as a necessary control variable. Data to construct these variables were mainly obtained from the database Urban Access Regulations in Europe (<https://urbanaccessregulations.eu/>) and author's own investigations. D^{LEZ} variable is also divided into two categories in our empirical analysis: D^{WIDE} and D^{CITY} . They are also binary variables that distinguish whether the low emissions zone has a large territorial scope, or it is delimited within the core area of the city. This distinction is made to potentially capture heterogeneous effects of the role of low emission zones according to their territorial scope.

Figure 1 displays the Mspline of the relationship between congestion and time comparing metropolitan areas with low emission zones to areas without. The 2021 traffic recovery seems to be descriptively lower in the case of areas with low emission zones. Figure 2 depicts a stricter comparison between cities with only low emission zones – excluding those with also limited traffic zones regulations- and cities with neither low emission zones nor limited traffic zones. Again, the rate of increase of traffic for cities

with low emission zones seems to be lower than for the comparison group. However, these are just bivariate relationships that neglect confounding factors and other determinants of congestion. A multivariate approach is needed.

Figure 1. Mspline of the relationship between congestion and time, by low emission zone regulation.

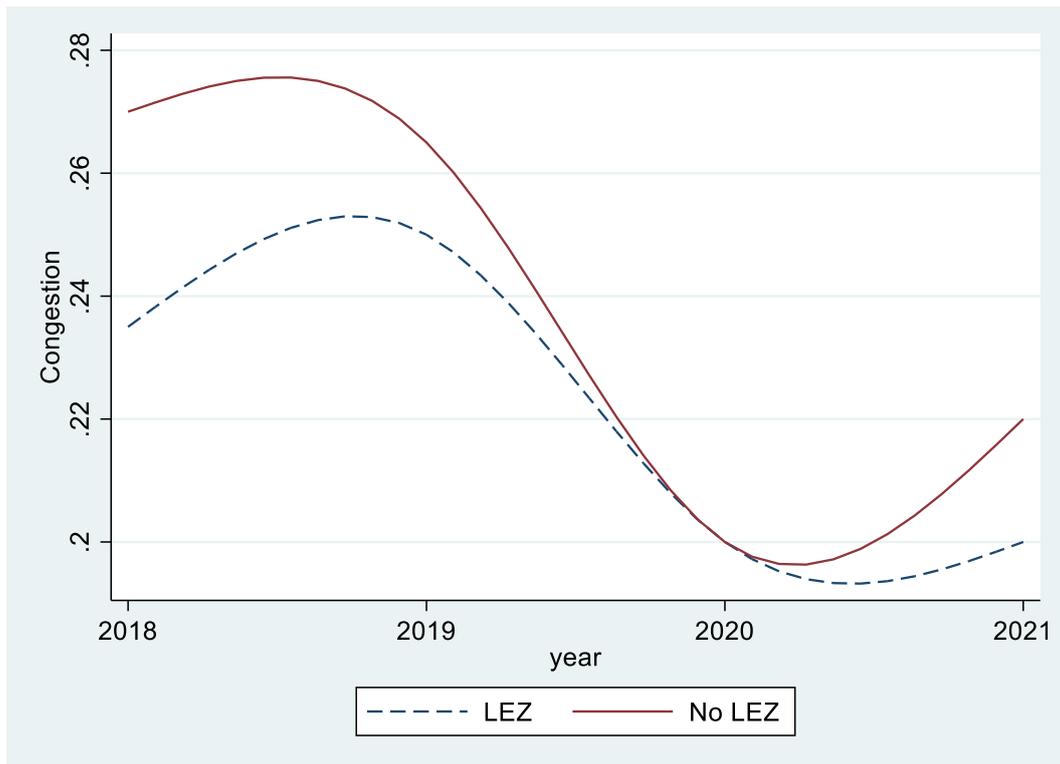
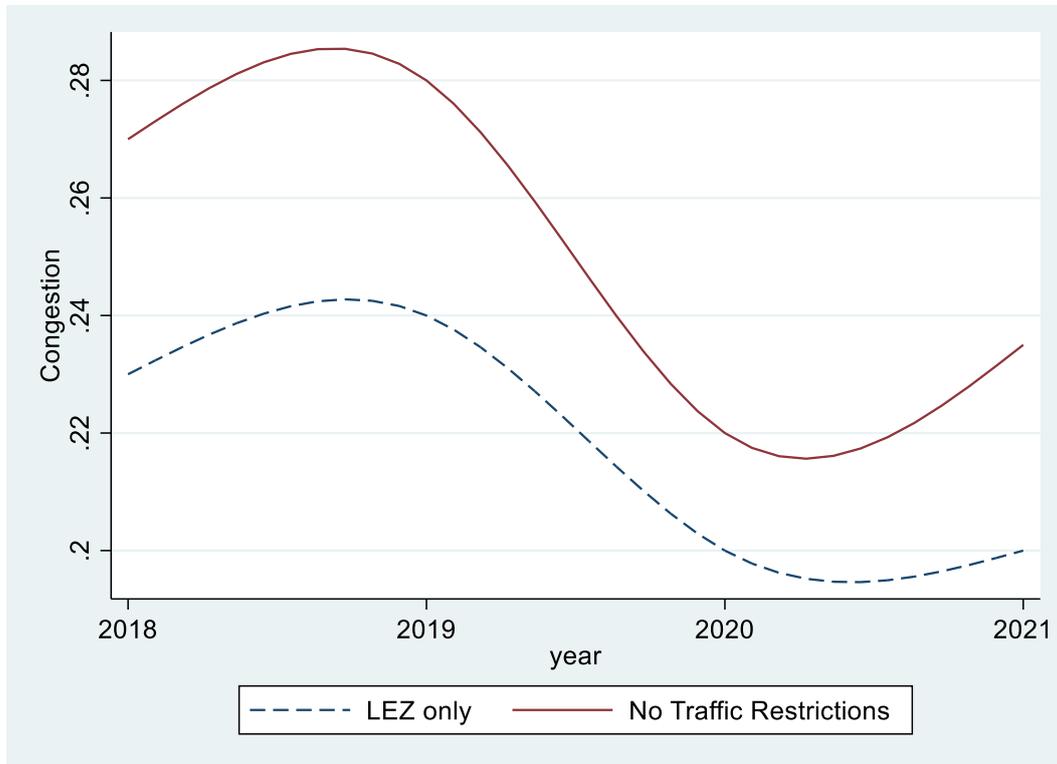


Figure 1. Mspline of the relationship between congestion and time, by low emission zone regulation (against no traffic regulations cities).



The vector of covariates in our multivariate analysis is composed by seven variables, which are expected to determine the level of congestion in metropolitan areas. The main sources of these variables are the OECD Regions and Cities Database (Metropolitan Areas), Eurostat and authors' investigations.

Public transportation supply is proxied by two variables. Firstly, the endowment of surface railways per capita (*Rail*). Secondly, by the number of lines of underground rail services (*Metro*). We expect a negative relationship between congestion and public transportation supply because public transportation is the most direct alternative private transportation.

Private transportation demand is captured by the *Motorization* variable, which is constructed as the number of cars per 1000 inhabitants. We have expectations of a positive

relationship between motorization and congestion given the stock of cars is highly correlated with their use, and the latter with congestion.

Socioeconomic and demographic variables are also considered in our analysis. The number of inhabitants (in thousands) is used to build our variable *Population*, which captures the size of potential mobility needs of a metropolitan area. We expect more populated areas to be prone to suffer from high congestion. The GDP per capita (in thousands) is also included as control, to account for income, but we do not have a particular expectation about the direction of its effect on congestion. First, because higher income is usually associated with higher use of private transportation. However, and second, higher GDP per capita is also associated with better transportation systems and public transportation networks and services.

Urban form might also be a relevant determinant of traffic demand and mobility patterns, which might also influence the level of congestion. We use two variables to measure this relationship. First, *Urban Sprawl* variable accounts for the core-periphery structure of the metropolitan area. It is the ratio between the population living in the functional area of the city over the population living just in the city area. Thus, we expect this variable to be positively correlated with congestion if people living in the functional areas have higher mobility needs towards and from the main city, increasing congestion. Alternatively, we would expect a negative correlation if the fact of having more people living in the functional areas does imply lower density in the core city, where congestion is more likely located. Second, we employ the variable *Polycentric*, to account for differences between monocentric metropolitan areas and polycentric areas. Our expectation is that monocentric areas are more prone to suffer from congestion due to the concentration of activity in the central business district than polycentric cities.

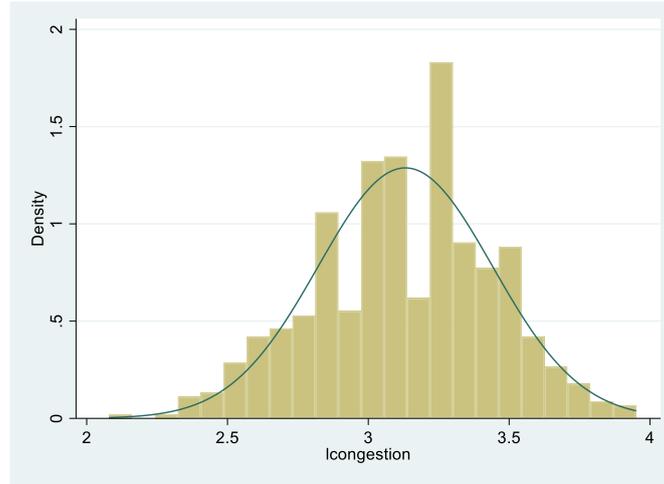
Methods

To evaluate the role of low emission zones on traffic congestion we implement a variety of econometric models, exploiting both the cross section and the short time series of our data. These models estimate the contribution of low emission zones on the average of congestion. First, employing a pool data model with an OLS estimator. Later applying different panel data models such as the Generalized Estimating Equations (with gaussian family), the Random Effects and the Fixed Effects models. These models are replicated using different options, such as yearly specific ($year_i$) and/or country specific fixed effects (s_i), clustered standard errors, and other alternative specifications. Equation 1 displays our baseline specification for these models:

$$\begin{aligned} \log(\text{Congestion}) = & \alpha + \beta D_i^{LEZ} + \gamma D_i^{LTZ} + \delta_1 \log(\text{Rail})_{it} + \delta_2 \text{Metro}_{it} \\ & + \delta_3 \log(\text{Motorization})_{it} + \delta_4 \log(\text{Population})_{it} + \delta_5 \log(\text{GDP})_{it} + \delta_6 \text{Urban_Sprawl}_{it} + \delta_7 \text{Polycentric}_i + \\ & D_t^{2019} + D_t^{2020} + D_t^{2021} + \varepsilon_{it} \end{aligned} \quad (1)$$

The average congestion variable was not normally distributed, so we employed its log-transformation, which produced a normally distributed dependent variable for our analysis (See Figure 1), as confirmed – or at least not rejected- by the Shapiro-Wilk W test for normal data (p-value 0.26). The log-transformation also facilitates the interpretation of coefficients as elasticities or semi-elasticities. The Ramsey Reset test for omitted variables also rejected specification errors (Prob > F = 0.4687).

Figure 3. Histogram of the dependent variable $\log(\text{Congestion})$.



The baseline specification is later modified to estimate a potential differentiated effect of low emission zones depending on their territorial scope. As displayed in equation 2 below, the binary variable D^{LEZ} is substituted by two binary variables D^{WIDE} and D^{CITY} .

$$\begin{aligned} \log(\text{Congestion}) = & \alpha + \beta_1 D_i^{\text{WIDE}} + \beta_2 D_i^{\text{CITY}} + \gamma D_i^{\text{LTZ}} + \delta_1 \log(\text{Rail})_{it} + \delta_2 \text{Metro}_{it} \\ & + \delta_3 \log(\text{Motorization})_{it} + \delta_4 \log(\text{Population})_{it} + \delta_5 \log(\text{GDP})_{it} + \delta_6 \text{Urban_Sprawl}_{it} + \delta_7 \text{Polycentric}_i + \\ & D_i^{2019} + D_i^{2020} + D_i^{2021} + \varepsilon_{it} \end{aligned} \quad (2)$$

Although these two baseline specifications are of interest because they estimate the general role of LEZ on traffic congestion, the main goal of this paper is to estimate whether low emission zones are having any differentiated impact on traffic recovery after covid19 shock. For this purpose, our main contribution comes from an alternative specification that consider different timing effects of low emission zones, considering 2021 as the first year of the pandemic recovery (*PostCovid*). Equation 3 details the specification that allows us to evaluate the effect of LEZ on congestion in 2021.

$$\log(\text{Congestion}) = \alpha + \beta_1 D_i^{\text{LEZ_PRE}} + \beta_2 D_i^{\text{LEZ_POSTCOVID}} + \gamma D_i^{\text{LTZ}} + \delta_1 \log(\text{Rail})_{it} + \delta_2 \text{Metro}_{it}$$

$$+ \delta_3 \log (Motorization)_{it} + \delta_4 \log (Population)_{it} + \delta_5 \log (GDP)_{it} + \delta_6 Urban_Sprawl_{it} + \delta_7 Polycentric_i + D_t^{2019} + D_t^{2020} + D_t^{2021} + \varepsilon_{it} \quad (3)$$

where D^{LEZ_PRE} accounts for cities with low emission zones in years 2018, 2019 and 2020 and $D^{LEZ_POSTCOVID}$ account for cities with low emission zones in year 2021. Note that all cities with low emission zones kept that regulation for the whole period 2018-2021. Thus, these binary variables are capturing time differences for cities with LEZ rather than variations in traffic regulations over time.

Results

Our estimates on the baseline specification in pooled data models are displayed in table 2. Columns 1 and 2 display results for equation (1) presented above. Column 3 displays results for equation (2), considering the territorial scope of low emission zones.

Overall, the fit of our models is correct. All models show a good fit ($R^2 > 0.50$) and the joint significant test validates the explanatory power of our specification (F-test 57.03; p-value=0.000). In all cases, low emission zones have associated coefficients that are statistically significant at 1% level with negative sign. This indicates that cities with low emission zones suffer lower congestion levels than the cities not having this traffic restriction. Note this is an average correlation for all four years in our sample. Specifications in columns 1 and 2 only differ in the use of clustered standard errors. Our results suggest that the average reduction achieved by low emission zones is about 8,5% in congestion level. Considering the average congestion level of 24% of our sample, this implies a reduction of 2 percentage points. The territorial scope of low emission zones does not seem to significantly affect their effect according to the estimates displayed in column 3. Coefficients are both statistically significant at 5% level, and coefficients are quite close, although it is higher for the type of LEZ that are constrained to the core city.

Other restrictions, such as limited traffic zones, also seem to produce congestion relief, but due to splitting its estimation is less precise because it is only statistically significant at 10%. In addition, the magnitude of its effect is half the effect produced by low emission zones.

Regarding our control variables, public and private transportation variables are statistically significant and display the expected sign. Public transportation supply diminishes congestion, while motorization increases it. Population is also positively associated with congestion but GDP per capita shows a negative correlation. This means the effect produced by better transportation infrastructure and systems that are linked to income is the force driving this result instead of the usual higher mobility demand of higher income groups.

Urban form also seems to matter. Both the ratio of the functional area over the core city area and the polycentric feature of a city are negatively associated with congestion and highly statistically significant at 1%, as expected.

Table 1. Pooled data OLS models' estimates on the logarithm of congestion.

Covariates	Pooled OLS (1)	Pooled OLS (2)	Pooled OLS (3)
LEZ	-0.0851*** (0.0243)	-0.0851** (0.0155)	-
Wide LEZ	-	-	-0.0684** (0.0167)
Center LEZ	-	-	-0.0866** (0.0173)
LTZ	-0.0426* (0.0261)	-0.0426* (0.0157)	-0.0458* (0.0172)
Rail	-0.1906*** (0.0445)	-0.1906*** (0.0158)	-0.1883*** (0.0164)
Metro	-0.0182*** (0.0040)	-0.0182*** (0.0019)	-0.0183*** (0.0021)
log(Motorization)	0.2936*** (0.0601)	0.2936** (0.0578)	0.2938** (0.0602)
log(Population)	0.3363*** (0.0170)	0.3363*** (0.0134)	0.3349*** (0.0142)
log(GDP)	-0.1305*** (0.0294)	-0.1421*** (0.0109)	-0.1454*** (0.0102)
Urban sprawl	-0.0387*** (0.0030)	-0.0387*** (0.0014)	-0.0385*** (0.0070)
Polycentric	-0.1841*** (0.0306)	-0.0387*** (0.0014)	-0.1829*** (0.0070)
Year FE	Yes	Yes	Yes
Clusters (YEAR)	No	Yes	Yes
N. Observations	433	433	433
R2	0.54	0.54	0.54
F-joint significance	57.03***	57.03***	38.44***

Notes: Significance levels based on p-values at *** 1%, ** 5%, * 10%. Standard Errors in Parentheses, clustered by year in columns 2 and 3.

Table 2 displays our key selected results on the differentiated role of LEZ before and after Covid19. All estimations include all covariates and year-specific and country-specific fixed effects. Column 4 displays again the Pooled OLS model, while models 5-7 consider Panel Data methods. Consistently, our results indicate that low emission zones are only contributing to congestion relief in the post-covid year (2021), while it was not statistically significant in the previous years (2018-2020). Only very slight differences exist between Population Averaged Models (GEE), Random Effects Model (RE) and Fixed Effects Model (FE). Coefficients associated to LEZ are always negative and

statistically significant at 1% across models. Thus, estimates seem to confirm our main hypothesis, which suggested that cities with low emission zones experienced slower recoveries of traffic than those cities without these traffic restrictions. Moreover, in terms of magnitude of effects, coefficient size also suggests an average reduction between 5.2-5.6% in congestion, depending on the model. For the average congestion of our sample, this implies a reduction of 1.3 percentage points.

Table 2. Pooled and Panel Data estimates on the logarithm of congestion, by period.

Covariates	Pooled OLS (4)	Panel GEE (5)	Panel RE (6)	Panel FE (7)
LEZ				
<i>PreCovid</i>	-0.0158 (0.0130)	0.0161 (0.0169)	0.0169 (0.0207)	0.0207 (0.0209)
<i>PostCovid</i>	-0.0952*** (0.0143)	-0.0563*** (0.0197)	-0.0554*** (0.0205)	-0.0521*** (0.0205)
All Covariates	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Clusters (YEAR)	Yes	No	No	No
Country FE	Yes	Yes	Yes	Yes
N. Observations	433	433	433	433
R2	0.76	-	0.75	0.62
F-joint significance	39.12***	-	-	-
Wald Chi2	-	897.96***	-	-

Notes: Significance levels based on p-values at *** 1%, ** 5%, * 10%. Standard Errors in Parentheses, clustered by year.

Robustness check to Covid-19 lasting effects and vaccination exposure

A concern regarding our estimates would emerge if cities with LEZ were precisely those experiencing lower traffic demand in 2021 – and therefore congestion recovery- due to Covid-19 lasting impacts, rather than due to the policy. This would be the case if cities with LEZ had been particularly and relatively more hit by the virus - with high death rates during the pandemic - than the group of cities without LEZ. Although we do not find a theory or logical channel that could justify why LEZ cities could experience a different impact from Covid-19, it could just be an empirical feature of our dataset. If this is true in our data, then one could argue that citizens living where the virus was more mortal

could be more cautious, adopting the new normal at a slower path and with it, slower mobility and traffic recovery as a result.

Indeed, one aspect that allowed the new normal because was precisely the extension of vaccination in 2021. We could also be worried about confounding the effects of different rates of vaccinations with LEZ effects, if cities with LEZ had been less exposed to vaccination against Covid-19 than the rest of cities. Again, we do not find an explanation for that relationship. And that being true would imply that because vaccination rates are lower, mobility might be recovered with some lag respect to other areas with higher vaccination rates.

In the two circumstances mentioned, our estimates would be confounding the effects of LEZ with Covid-19 lasting effects on mobility behavior, always overestimating the role of LEZ in slowing traffic down. To check the robustness of our analysis under these confounding threats, we estimate whether there are statistical differences between LEZ and no-LEZ cities in terms of death and vaccination rates. Because data at local level is not available, we can only make this statistical comparison employing national data as a proxy of death rates and vaccination rates at the metropolitan area level for 2021.³

Results displayed in table 3 shows that in our sample we reject the null hypothesis of equal means between LEZ and cities without LEZ on death and vaccination rates. Nonetheless, mean differences had the opposite sign to what could be expected in terms of confounding threats. The mean of covid-related death rates is lower for cities with LEZ than for cities without LEZ in our sample. The opposite happens with the rate of

³ Before, we tested differences in variance and found that equal variances were only rejected for vaccination rate. Thus, our test of means takes that into account employing the Welch's approximation for the degree of freedom, what makes a t-test valid even in a case of unequal variances.

vaccinations. In average, our units with LEZ enjoyed higher vaccination rates. And these differences were statistically significant at 5%.

To get additional evidence, we also run a logistic regression model in which we regress the likelihood of being a city with LEZ on death and vaccination rates. Our results show that only death rate is statistically significant at 10%, meaning there is a difference in probability between both groups of observations. But again, the sign of the coefficient shows that cities with low emission zones are, in average, in countries with lower death rates. With these results, we think our results are robust to the lasting effects of Covid-19 and to the potentially different vaccination exposure.

Table 3. Two sample Mean Tests for vaccination and death rates.

	Mean LEZ	Mean No LEZ	T-test Diff (Equal Variances)	T-test Diff (Unequal Variances)
Deaths per 100.000	235.63	263.39	-27.76**	-
Vaccination rate per 100	80.19	77.74	-	2.44**

Notes: Significance levels based on p-values at *** 1%, ** 5%, * 10%.

Table 4. Logistic regression on the probability of being a city with LEZ

	LEZ
Deaths per 100.000	-0.0063* (0.0036)
Vaccination rate per 100	0.0248 (0.0222)
Wald Chi2	6.31**

Notes: Significance levels based on p-values at *** 1%, ** 5%, * 10%. Heteroskedasticity Robust Standard Errors in Parentheses.

Discussion and concluding remarks

According to the evidence reported in this research, metropolitan areas with low emission zones available are experiencing a less pronounced traffic recovery after Covid-19 shock. Although congestion seems to be increasing everywhere, and there is evidence showing it is increasing at a higher rate than public transportation demand, its rate of increase seems smoother where low emission zones are in place. The mechanisms that could

explain this difference could be related to the own features of this type of access restriction regulation.

LEZ are aimed at producing a change in the composition of traffic, expelling the most polluting vehicles, and promoting the renewal of fleets. This is consistent with the results reported in the recent literature that highlighted that LEZ are more effective reducing pollution and improving air quality than as an effective solution against congestion (Bernardo et al., 2021). However, the covid-19 shock could have set a perfect scenario for LEZ regulations to play the double role, now acting as well against congestion recovery after Covid-19.

On the one hand, there is sufficient evidence that shows how the covid-19 pandemic has influenced and changed consumer behavior (see Cruz-Cardenas et al., 2021 for a literature review). The automobile industry has been one of the hardest hit by Covid-19. The pandemic significantly reduced the number of sales and displaced purchasing decisions to the future due to uncertainty. No doubt, the epidemic's negative income effects reduced the automobile purchase propensity (Yan et al., 2022). Factors such as lowered household income, travel vulnerabilities and epidemic severity in local regions have influenced the purchase decision-making process of individuals. This adds to the break of the logistic supply chain and major challenges faced by all participants in the automobile industry, such as auto dealers, auto suppliers and makers, vehicles' transportation services, finance companies, etc.

Due to the major impact on the automobile industry, the expected change in fleet composition towards a greener fleet under LEZ schemes would have been slowed down by the effects of Covid-19 on vehicles purchases. Thus, part of the most polluting traffic, excluded from the LEZ areas, have not been replaced by newer vehicles but travelers had to change their mobility behavior before the impossibility of using their old and dirty

vehicles, by traveling less or opting for alternative modes. All of them potentially leading to lower congestion levels.

On the other hand, Covid-19 has promoted new patterns of mobility also related to the new labor organization, fundamentally the emergence of teleworking and more flexible work schedules (Albalade et al., 2022), all of them less in person to some extent. Less travel demand implies a lower need to have your own vehicle and, therefore, to substitute your old and dirty vehicle before LEZ regulations for a new and greener one.

In any of the two cases, a lower propensity to replace vehicles, which is the main driver of a regulation such as that of low emission zones, seems to have been able to occur with the pandemic and just after it, when uncertainties remained in 2021.

In all, our research shows that traffic restriction measures are effectively acting as a mitigating force against the recovery of traffic after Covid-19, contributing to the reduction of negative externalities and their associated costs. Although LEZ have been more associated to air quality improvements due to changes in the mix of traffic, the Covid-19 shock created the appropriate scenario to make possible a slowdown in the usual offsetting behavior of drivers when they face LEZ, which is renewing their old and polluting vehicles to new ones.

Our research has some limitations that must be discussed. First, note we can only assess the short-term effects of Covid-19 on the effectiveness of LEZ against congestion due to data availability problems. Our main results should be confirmed once data on more post-covid periods are available. Second, during 2021 Covid-19 contagion waves were already hitting different parts of the continent. Although new normal was a general rule applying to all countries and vaccination started in January 2021, spikes in infections and different rates of vaccinations could still slow down mobility and, with it, traffic

recovery. Although we have checked the lasting effects of Covid-19 in our robustness check section, we could only do it employing national data. Then, regional, and local disparities may remain.

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Institut de Recerca en Economia Aplicada Regional i Pública
Research Institute of Applied Economics

Universitat de Barcelona

Av. Diagonal, 690 • 08034 Barcelona

WEBSITE: www.ub.edu/irea • **CONTACT:** irea@ub.edu

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