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DISCUSSION PAPER SERIES

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ABSTRACT

Putting Low Emission Zone (LEZ) to the Test: The Effect of London's LEZ on Education*

This paper evaluates the impact of London's Low-Emission Zone (LEZ) on test scores among elementary school students in England. Utilising administrative data for the years 2005-2015, we employ a difference-in-differences approach to assess the LEZ's effect on standardised Key Stage 2 results (age 11). Our analysis reveals a statistically and economically significant improvement of 0.09 standard deviations in test scores for students within the LEZ compared to those in other urban control areas. Importantly, we also find that the LEZ policy has larger positive effects in low-performing schools, demonstrating its potential to significantly reduce educational disparities.

JEL Classification: Q53, I20, I24

Keywords: air pollution, education, low emission zone

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1 Introduction

Air pollution is considered one of the leading global environmental risks mainly due to its profound implications for public health. In particular, the World Health Organization (WHO) estimates that ambient air pollution led to 4.2 million premature deaths worldwide in 2019 and that in the same year, a staggering 99 percent of the global population resided in areas where the air quality fell short of the WHO's guidelines (*WHO*, 2021). These shocking figures underscore the magnitude of this public health emergency and the widespread nature of this challenge. The adverse impacts of ambient air pollution and its associated costs have received substantial academic attention in economics and other disciplines, showing how exposure to air pollution affects not only mortality and morbidity (Currie & Walker, 2011; Schlenker & Walker, 2016) but also documenting its effects on other aspects of human life including worker productivity, crime and education (Bondy, Roth, & Sager, 2020; Ebenstein, Lavy, & Roth, 2016; Graff Zivin & Neidell, 2012).

Various sources contribute to ambient pollution, but vehicle traffic stands as a pivotal contributor to air pollution concentrations in urban areas worldwide, significantly impacting the quality of the air we breathe in cities. As such, various policies have been devised to address this critical environmental issue in urban areas. One notable example is the implementation of Low-Emission Zones (LEZs) in many cities around the world, which restrict the entry of high-emission vehicles into specific areas, aiming to curb the release of pollutants from vehicular exhaust. Previous literature has evaluated such policies in terms of their effects on pollution reduction and health outcomes (Gehrsitz, 2017; Margaryan, 2021; Pestel & Wozny, 2021; Wolff, 2014). However, despite the well-documented link between air pollution and scholastic achievements, there is no well-identified evaluation of the effect of LEZs on standardised exam scores to the best of our knowledge.

Our paper sought to address this gap in knowledge by evaluating the impact of London's LEZ on standardised exam scores among elementary school students in England. To do so, we utilise administrative data from the National Pupil Database (NPD), which provides information on exam results and various characteristics of pupils for the years 2005-2015. The NPD covers all students who study in state schools in England and is considered one of the richest education datasets in the world (DFE, 2015). Our focus in this study is on Key Stage 2 results, which are evaluated at year 6 (age 11). For identification, we employ a standard difference-in-differences approach in conjunction with fixed effects to overcome potential confounders. In particular, our control group consists of urban schools in the 20 largest cities in England which are also outside of a 100km buffer from the LEZ border to ensure that our control group is unaffected by the policy.

We show that students within London's LEZ exhibited significant improvements in test results. More specifically, we find that on average, primary schools within the LEZ experienced a 0.09 standard deviation improvement in test scores relative to primary school students in urban areas in our control group. This estimated effect is highly statistically and economically significant. To put the latter point in perspective, the magnitude of our results is slightly smaller than the estimated effects of increasing average teacher quality by one standard deviation and similar to the estimated effect of reducing class size by 10 students or paying teachers large financial bonuses (Lavy, 2009; Rivkin, Hanushek, & Kain, 2005). Importantly, we also show that London's LEZ provides more substantial positive effects in schools with lower initial test scores at baseline, suggesting that the policy might also reduce environmental and educational inequalities that can have long-term labour market impacts. Furthermore, we show that the positive effect of this long-term intervention appears to increase over time, suggesting that prolonged reductions in pollution concentrations yield increasingly significant improvements in educational outcomes. Finally, we conducted a comprehensive series of robustness tests to validate our findings. These tests which include employing our main difference-in-differences approach paired with matching techniques, and varying the size of our buffer zone, consistently show that the results are robust across various model specifications and sets of control schools.

Overall, this paper provides important contributions to the academic literature and policymakers more broadly. First, to the best of our knowledge, this is the first paper to link LEZs with standardised exam scores. Other papers in the economic literature that examined the impacts of LEZs focused solely on the pollution and health implications except for the paper by Brehm, Pestel, Schaffner, and Schmitz (2022) which examines the effect of LEZs on education outcomes in Germany. In particular, they study the impact of LEZs on the transition rates of elementary school students to academic tracks in the German State of North Rhine-Westphalia. Utilising a staggered difference-in-differences framework and school-level data they show that LEZs have led to an increase in the transition rates to the academic track by 0.9-1.6 percentage points. This is the closest paper to our work given the mutual interest in the educational impacts of LEZs and we see both studies as complementary. Nevertheless, there are several important differences between the studies. Most notably, our paper utilises data on standardised test scores, a broadly applicable measure of educational achievement, facilitating direct comparisons with other interventions aimed at improving educational performance. Furthermore, our research not only examines a different geographical area (England) but also delves into the nuanced effects of LEZs across different income groups and initial levels of academic achievement, offering a further detailed exploration of the policy's educational implications.

Second, our results suggest that previous studies which focused solely on the pollution and direct health impacts of LEZs underestimated the true benefits of LEZ policies, and highlight the importance of incorporating educational outcomes in evaluating environmental policies. Relatedly, the results also show the potential for environmental policies to improve educational outcomes. As such, we propose that environmental policies should be considered as a viable alternative or complement to traditional education interventions (such as smaller class sizes and providing incentives for teachers) as the former can provide similar, if not higher, improvement in test scores.

Third, the existing economic literature on the link between education and environmental factors primarily explores this relationship in terms of short-length exposure, predominantly examining contemporaneous effects. Moreover, most prior research overlooks the critical early education phases, which play a foundational role in a child's educational trajectory.

Our paper addresses these two gaps in the empirical literature and examines longer-term changes to the environment in primary education [1].

Finally, our analysis indicates that LEZs policies can effectively address both environmental and educational inequalities, offering potential long-term benefits for labor market outcomes as well. In particular, the more substantial positive impact of the policy on schools with lower initial test scores at baseline showed in this study is likely to extend into greater economic opportunities, highlighting the importance of incorporating such environmental policies into broader socio-economic strategies.

2 Background

2.1 Key Stages in England's Education System

England's education system is structured into distinct phases known as "Key Stages" that span from early childhood through to secondary education. These stages are part of the National Curriculum, which sets out the content to be taught and the standards children should reach in each subject at each stage of their education journey. Overall, there are four key stages, starting at KS1, which covers the first two years of school education (pupils aged 5 to 7), up to Key Stage 4, which encompasses the final stage of compulsory education, for students aged 14 to 16. Each stage serves a specific developmental and educational purpose, ensuring that students acquire the necessary knowledge, skills, and competencies to succeed in their subsequent educational and life endeavours.[2]

In this study, we focus on Key Stage 2 (KS2) which covers Years 3 to 6 (pupils aged 7 to 11). The curriculum at this stage is fairly broad and includes English, Maths, Science, History, Geography, Art and Design, Music, Physical Education, Ancient and Modern Foreign Languages, and Computing. KS2 ends with national standardised tests that cover the core subjects of English (reading and grammar, punctuation, and spelling) and mathematics, with exams externally marked.[3] The national tests take place in May every year and lasts less than 4 hours overall. The KS2 assessments play a pivotal role in England's educational system, serving as a crucial benchmark for evaluating students' academic progress at the end of their primary education.

From an economic perspective, the analysis of KS2 test scores offers valuable insights into the human capital formation process at a relatively early stage of education. Human capital theory posits that investments in education are crucial for the development of skills and abilities that enhance productivity and contribute to economic growth (Barro et al.,

[1]It is important to mention that a limited number of studies have examined the effects of longer-term exposure to environmental factors during early development stages. For instance, a paper by Gazze, Persico, and Spirovska (2024) explores how lead exposure in children affects the long-run outcomes of their peers in terms of high school graduation, SAT-taking rates, and increased suspensions and absences. Additionally, a paper by Wen and Burke (2022) studies the negative impact of an increase in the average 9-month air pollution on US test scores, finding more pronounced effects on primary school students.

[2]More information on he national curriculum can be found here: https://www.gov.uk/national-curriculum

[3]This standardisation is critical for policymakers and researchers alike, as it provides a reliable dataset for analysing trends in educational achievement, evaluating the efficacy of policies, and identifying areas requiring intervention.

2013; Becker, 1964; Hanushek & Woessmann, 2008). The analysis of KS2 test scores also extends beyond educational achievement to encompass broader discussions on inequality, social mobility, and the efficacy of policy interventions. As such, KS2 assessments are not only a measure of educational attainment but also a lens through which the dynamics of human capital development and social inequality can be examined, offering a rich area for economic and policy analysis. Finally, recent economic research has increasingly focused on the role of environmental factors in shaping educational outcomes, with studies examining the impact of air quality and school infrastructure on test scores (Ebenstein et al., 2016; Gilraine, 2023; Stafford, 2015). In this context, the implementation of Low Emission Zones and their impacts on KS2 outcomes can provide important empirical evidence on the intersection of environmental policy and educational performance.

2.2 Policy Background

Low Emission Zones (LEZs) have been introduced across Europe to tackle the issue of air pollution from transport, and in particular, high-polluting vehicles (Wolff & Perry, 2010). Through banning their use or requiring them to undergo expensive retrofitting procedures before being permitted to enter designated LEZ spaces, LEZ implementation is considered an impactful way to limit the air pollution produced by inner-city roads (Holman, Harrison, & Querol, 2015). The first generation of LEZs, Sweden's Environmental Zones (*Miljözon*), were implemented towards the end of the 1990s, laying the groundwork for future LEZs across many European countries including France, Germany, Italy, and the UK. As of 2022, there were 320 LEZs in Europe alone and this number is project to reach 507 by 2025[4]. Other countries around the world such as China, Indonesia and Japan also have introduced LEZs in urban areas to tackle vehicle emissions.

In May 2007, following increasing dialogue surrounding urban air pollution in the UK and London most specifically, policymakers announced the upcoming implementation of the Greater London LEZ which, since its inception, has evolved into one of the largest and most rigorous traffic regulation policies globally (Zhai & Wolff, 2021). The policy itself was launched on 4th February 2008, and enforces a very large and rigid pricing scheme aimed at disincentivising the use of highly polluting motor vehicles across almost all of Greater London, an area of roughly 1,600 square kilometres with a population of 9 million people. The policy remains in force 24 hours per day, every day of the year with no exemptions during national and public holidays. It is enforced through monitoring a wide network of cameras installed across major and minor roads within the LEZ boundaries where Automatic Number Plate Recognition technologies are utilised in conjunction with Transport for London (TfL) databases to monitor and flag vehicle compliance (Zhai & Wolff, 2021).

From its inception, the Greater London LEZ has evolved according to several phases. The initial phase specifically targeted Heavy Goods Vehicles (HGVs) weighing over 12 tonnes and truck vehicles that were in violation of the Euro III standard of vehicle emissions. Drivers of such vehicles were are expected to make their vehicle compliant with LEZ regulations

[4]for more information on LEZs in Europe see: https://cleancitiescampaign.org/wp-content/uploads/2022/07/The-development-trends-of-low-emission-and-zero-emission-zones-in-Europe-1.pdf

(through engine replacement and/or retrofitting with particulate filters), to replace their non-compliant vehicle, or to pay a daily charge of £200 (Transport for London, 2006). Driving within the LEZ across midnight leaves drivers susceptible to a double charge, though charging does not apply to parked vehicles. In July 2008, shortly following the LEZ's launch, a second phase was implemented subjecting non-Euro III compliant Light Goods Vehicles (LGVs) weighing over 3.5 tonnes to LEZ vehicle standards or a £100 daily charge. These grounds were later extended to cover minibuses and large vans through a third phase in October 2010, and in January 2012 the policy was tightened, requiring HGVs, buses, and coaches to now meet Euro IV (rather than III) standards. Failure to both comply with the guidelines and to pay the daily entrance charge would result in a fine ranging between £250 and £1000 depending on vehicle type and speed of payment.

It is estimated that the costs associated with retrofitting non-compliant vehicles into LEZ compliance would result in an additional cost of 2-3% on top of standard HGV operation costs and an additional 2-4% for LGVs (Transport for London, 2008). As a result, a Vehicle Operator Survey conducted by TfL in 2006 concluded that up to 5% of vehicle owners would deliberately opt for non-compliance, choosing instead to either pay the daily charge to enter the zone, or to risk the consequences of evasion of the rules (Transport for London, 2008). This figure is reflected in the compliance rates reported by TfL in the summer of 2021 where compliance stood at 95.5%. This is almost double the 48% compliance reported upon the LEZ's announcement in 2007 (Mayor of London, 2021).

Analysis of the impacts of the Greater London LEZ by Broaddus, Browne, and Allen (2015) found that the LEZ effectively stimulated drivers' replacement of non-compliant vehicles with more efficient, less polluting, and often smaller vehicles. Through this, alongside those choosing to retrofit their existing vehicles, TfL claimed the LEZ to have affected a 20% reduction in London coarse Particulate Matter (PM10) within 5 years of operation (Mayor of London, 2021). This is significant given that vehicular emissions comprised approximately 60% of all PM10 emissions in London and 80% of those within central London prior to the LEZ (Transport for London, 2011). Later analysis by Zhai and Wolff (2021) examines the effect of the LEZ on PM10 concentrations. Using a stepwise difference-in-differences model they found that the second and more stringent phase of the LEZ did curtail PM10 concentrations, mainly near major roads. Interestingly, Zhai and Wolff also identified a negative spillover effect in sites beyond the LEZ boundaries where polluting vehicles have become increasingly concentrated.

The LEZ is not the first or the last policy to be implemented in London to reduce the negative externalities of vehicle use. The Congestion Charge Scheme (CCS), introduced in 2003 and still active today, subjects most vehicle drivers to a daily charge to enter a 21 square kilometres area in Central London (approximately 1.3% of Greater London) during high-traffic hours. The amount charged per day started at £5, and has been kept mostly stable in real terms. The push to reduce vehicle pollution and traffic has continued in recent years with the introduction of the T-charge (in 2017), and the Ultra Low Emission Zone introduction and expansion in 2019 and 2024. Following the London example, many UK cities have recently applied (between 2021 and 2023) or planned the application of their own

Low Emission Zones.[5]

3 Data and Empirical Strategy

Our analysis aims to comprehensively assess the impact of London's LEZ on standardised exam scores among elementary school students in England. In this section, we describe the various sources of data sets that we used in our study, the data itself, and our empirical strategy.

3.1 Data sources and Descriptive statistics

The primary data sources for this study are drawn from various governmental agencies and educational authorities in the United Kingdom. This provides comprehensive administrative information on exam results and various school-level characteristics, enabling us to examine varied treatment impacts across different subgroups of the student population. The primary dataset is the Key Stage 2 Performance Measures, obtained from the GOV.UK website[6]. This dataset provides annual information on Key Stage 2 test scores alongside various school-level characteristics for schools in England, covering an extensive period from 2005 to 2015[7], with the exception of a brief interruption in 2010 attributed to a national boycott of assessments. It includes essential variables such as test results, identifiers for schools, and demographic data, allowing for a detailed investigation into the evolution of examination scores before and after the introduction of the London LEZ.

This data set includes the Average Point Score (APS) in Key Stage 2, which quantifies student achievement across English and Maths in the following way: Initially, raw test by subject scores are transformed into Total Point Scores (TPS) based on year- and subject-specific thresholds. Then, these scores are averaged into a single APS that represents the academic achievement of students according to the following formula: $APS = \left((TPS_{Reading} + TPS_{Writing})/2 + TPS_{Math}\right)/2$ (Middlemas, 2014). This is then further averaged across the school to provide a school-wide average APS.

In addition to the Key Stage 2 data set, the study utilises the School Characteristics dataset, also known as the Pupil Census Data. This data set contains school-level data collected during the January school census each year and includes information on a wide variety of students, school and teacher characteristics including ethnicity, teacher information, and enrolment figures. The School Characteristics data complements the Key Stage 2 data by providing additional contextual information about the schools and their student populations.

In the last decade, the UK has witnessed a meaningful number of school mergers and splits. To account for potential changes in school organizational structures and to have a consistent panel data of schools, we also use the "School Links" dataset from the Get

[5] Between 2021 and 2023 the cities of Bath, Birmingham, Portsmuth, Aberdee, Bradford, Bristol, Dundee, Edinbrough, Newcastle, and Sheffield introduced their LEZ. Greater Manchester is expected to introduce a LEZ 2026.

[6] Available at https://www.compare-school-performance.service.gov.uk/download-data

[7] New performance measures were introduced in 2016, going from reporting an absolute value to a relative one that compared pupils' results of similar prior attainment.

Information About Schools service[8]. This dataset provides information on school links, including predecessor-successor relationships, mergers, and other relevant details. It allows for tracking schools across time and ensuring accurate identification, even if their unique reference numbers (URNs) have changed.

Overall, the final dataset comprises 32,919 observations from a total of 3,445 schools, split into 1,199 schools within the treatment group and 2,246 schools designated as the control group. Detailed summary statistics of the main variables are presented in Table 1. The table reveals that the average point scores are similar between the treatment and control groups, with scores of 27.66 and 27.5, respectively. The standardised Average APS in KS2 are marginally higher for the treatment group, consistent with the row APS. Interestingly, the standard deviations are negative, which suggests that the schools in our sample, located in large cities, exhibit lower test scores on average compared to other regions in the country. Moreover, the treatment group features a notably lower percentage of native English speakers and individuals from the white ethnic group compared to the control group.

Table 1: Summary Statistics

	Control			Treatment		
	Mean	SD	N	Mean	SD	N
Average point score (APS) in KS2	27.50	2.22	2,145	27.66	2.23	1,139
Standardized APS in KS2	-0.21	1.07	2,145	-0.14	1.07	1,139
Number of full-time equivalent pupils	269.16	116.49	2,245	310.66	127.11	1,196
% Eligible to free school meals	21.58	16.28	2,211	27.36	17.05	1,191
% English as first language	85.20	23.97	1,849	62.03	24.67	1,180
% White British ethnic origin	79.67	25.24	2,227	38.71	25.39	1,186
% Other white ethnic origin	1.39	2.05	1,462	8.96	7.16	1,136
Pupil-teacher ratio	21.44	4.57	2,245	21.51	5.28	1,197

Notes: All values from 2006. SD = Standard Deviation. N = Number of schools.

3.2 Empirical strategy

In order to estimate the impact of London's LEZ on standardised exam scores, we adopt an empirical strategy that leverages the strengths of our data. In particular, we estimate the causal effect of the LEZ policy by employing the following two-way fixed effects differences-in-differences (DiD) model:

$$TestScores_{it} = \beta\{LEZ_i \times Post_t\} + \gamma_i + \delta_t + \varepsilon_{it} \tag{1}$$

Where $TestScores_{it}$ is the average test score of school i at academic year t, LEZ_i is an indicator that has value 1 only if school i is inside the London LEZ, and $Post_t$ is an indicator if it is after the LEZ was applied (2008 or latter). Finally, we allow for ε_{it} to be heteroskedastic and correlated within postcode districts.

[8]Available to download at https://get-information-schools.service.gov.uk/Downloads

The above DiD estimation yields valid causal inferences of the average treatment effect if several key assumptions hold. First and foremost, the key identifying assumption in such models is the parallel trends assumption which implies that the application of the policy is exogenous to the potential outcome paths of treated and control units, and thus treatment and control units would exhibit parallel outcome trajectories for all periods in the absence of treatment. In the next paragraph, we discuss a potential threat to this assumption and describe the measures we take to address this concern. Additionally, we offer evidence that this assumption likely holds in our case by visually inspecting the pre-treatment trends in the following section.

A possible threat to this assumption, and therefore to the causal interpretation of our empirical strategy, is the application of the "Pupil Premium" in England. This policy, which started in the 2011-2012 school year, gives extra funding to schools for each pupil who meets certain characteristics, the most common being eligibility for Free School Meals (FSMs) at any point in the last six years[9]. The extra funding per pupil steadily increased in real terms (2022-2023 prices) from £629 in the 2011-2012 school year to £1596 in 2014-2015 (the last year in our sample) (Roberts, 2023). This national policy would not be a concern if treated and control schools had a similar proportion of FSM eligibility, and thus received a similar amount of financial help. However, treated schools happen to have a larger (although not statistically significant) percentage of FSM eligible pupils (27% instead of 21%, from Table 1).

To control for any possible differential effect on treated and control regions, we amend Equation 1 and estimate the following model:

$$\begin{aligned} TestScores_{it} = \; & \beta\{LEZ_i \times Post_t\} + \\ & \alpha_1\{FSM_{2006,i} \times PostPremium_t\} + \alpha_2\{FSM_{2006,i} \times PostPremium_t \times t\} + \\ & \gamma_i + \delta_t + \varepsilon_{it} \end{aligned} \tag{2}$$

with $FSM_{2006,i}$ being the percentage of pupils eligible for free school meals on school i in the year 2005-2006 (pre-treatment) and $PostPremium_t$ being 1 only after the introduction of the Pupil Premium and 0 otherwise. This allows α_1 and α_2 to control for the resources received by school i due to the pupil premium and its steady increase in funding per pupil during our study period[10]. Equation 2 is our preferred specification for all the results presented below.

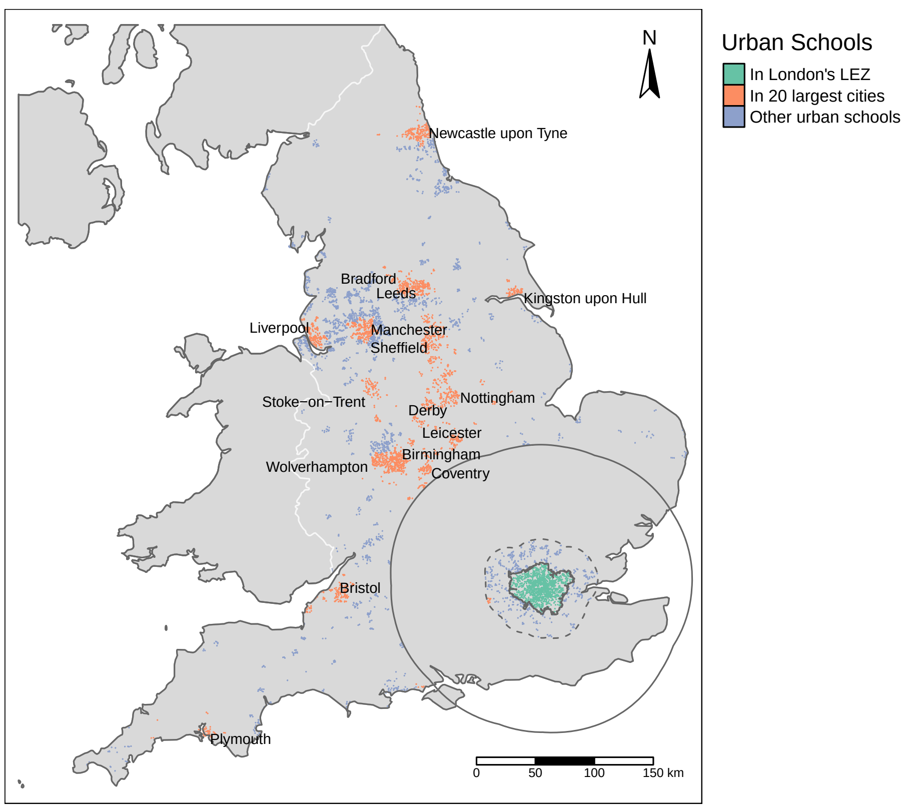
Another key identification assumption is that the potential outcomes for any unit should not vary with the treatment assigned to another unit. This is the non-interference (spillovers) assumption. For our specific case, this can happen through various channels including the spillover of air pollution via wind current and changes in traffic volume and/or vehicle fleets

[9]The other conditions are being a "Looked after" or "previously looked after" children (these are pupils who are in charge of the local council instead of their family) and pupils with a parent serving in the regular armed forces.

[10]Reassuringly, the results are robust to not including these controls.

of neighbouring regions. In fact, prior literature provides evidence for such cases. For example, Wolff (2014) shows how the application of a LEZ correlates with a change towards cleaner vehicles in surrounding cities, and Sarmiento, Wagner, and Aleksandar (2021) find air pollution spillover effects up to 25km.[11] As such we define our treatment and control group very carefully. In particular, the treatment group comprises urban schools located within London's LEZ boundary. These schools are directly affected by the LEZ policy measures aimed at reducing total vehicular emissions. Conversely, the control group consists of urban schools which are located more than 100km outside the LEZ boundary, similar to Zhai and Wolff (2021), and within the 20 largest cities in England. This creates a control group that is similar to our treated sample and minimizes the risk of contamination between treated and control units. Figure 1 shows the treatment and control schools used in our study and the 100 kilometer buffer that we use around the London's LEZ.

Figure 1: Urban Schools in England



Notes: This map illustrates the urban schools included in the analysis, with each point representing a school. The solid line represents the 100km distance from the border of the LEZ (as in Zhai and Wolff (2021)) while the dotted line represents the 20km distance used for spillover effects. Treated schools are in green while the control schools are those in orange that are outside the solid line. In the spillover analysis the blue schools are included in the analysis.

[11]These are positive (increases in pollution) for the first 500m in the case of O_3, PM_{10} and NO_2, and negative from 500m up to 10-25km for CO, PM_{10} and NO_2.

The last relevant assumption for our model is that the policy should not have unaccounted anticipation effects. This is a possible concern in our setting as the London LEZ was announced 1 year before its implementation, aiming to encourage people to upgrade their vehicles beforehand. As demonstrated by Wolff (2014), this proactive behaviour was observed in Regensburg, a German city, where there was a notable increase in environmentally friendly vehicles between the LEZ announcement and its enforcement. In the next section we explore this concern empirically and conclude this is not the case in our study.

We also study possible spillover effects of the policy on schools located outside, but in close proximity to the LEZ boundary to explore the broader impacts of the policy. As in Butts (2021), this is done simply by taking the urban schools in the first 20km buffer around the LEZ as treated and using urban cities that are more than 100km away from the LEZ boundary as controls.

To explore the dynamic effects of the policy and also to provide another test for pretrends we use a slightly more complex event-study specification. This is done by interchanging $\beta(LEZ_i \times Post_t)$ with $\sum_{k=2005}^{2015} \beta_k \mathbb{1}\{(LEZ_i \times Post_t) = 1\}$ in Equation 2.

To investigate if treatment effects varied by a given school-level characteristic Z_i we estimate the following model:

$$\begin{aligned} TestScores_{it} = \beta_1\{LEZ_i \times Post_t\} + \beta_2\{LEZ_i \times Post_t \times Z_i^{hi}\} + \\ \alpha_1\{FSM_{2006,i} \times PostPremium_t\} + \alpha_2\{FSM_{2006,i} \times PostPremium_t \times t\} + \\ \eta\{Z_i^{hi} \times Post_t\} + \gamma_i + \delta_t + \varepsilon_{it} \end{aligned} \tag{3}$$

with Z_i^{hi} (or Z_i^{lo}) being a dichotomous variable that has value of 1 if the school pre-treatment value of Z is above (below) the median and 0 otherwise. This allows us to estimate the treatment effect for schools that have a high- and low-level of characteristic Z separately, and to interpret β_2 as a test of that difference.

Finally, we conduct a sensitivity analysis by exploring various variations in our sample and specification to show the robustness of our main findings. These include restricting our sample to those schools in which we have information for all years (balanced panel), running a matching algorithm (CEM) to compare a subset of treatment and control regions that are very similar in various pre-treatment characteristics, using an alternative and much more restricted control group which consist of the 5 largest cities in England, and looking at the results by changing the minimum distance buffer around the LEZ border from 100km (main specification) to 75km, 50km, and 20km.

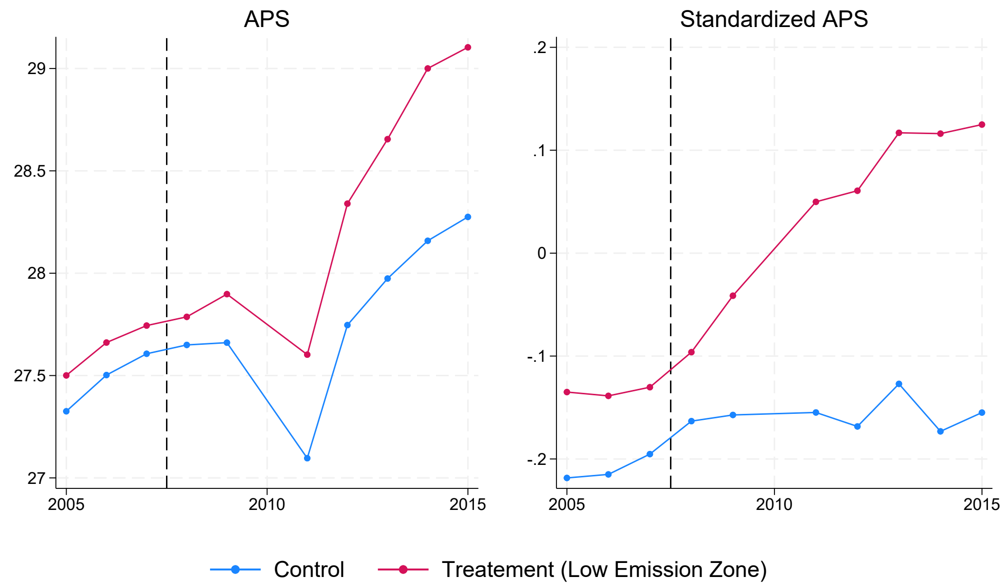
4 Results

In this section, we present and discuss the empirical findings of our study, examining the impact of London's LEZ on KS2 standardised test scores. Our analysis not only assesses the overall effect of the LEZ but also investigates how this impact varies over time and across schools with different income and achievement levels. This nuanced approach allows us to understand the broader implications of environmental policies on educational outcomes.

Our primary analysis is visually represented in Panels A and B of Figure 2, which track the evolution of average KS2 test scores from 2005 to 2015, both in terms of raw Average Point Score (APS) and standardised scores, respectively. There are two important observations from these figures. First, the figures show parallel trends in the pre-treatment period across the treatment and control groups. This is a critical observation as it support the parallel trend assumption underlying our difference-in-differences empirical strategy, implying that any post-treatment divergences can be attributed to the intervention rather than pre-existing trends. Second, the figures illustrate a clear divergence between the treatment group (schools within the LEZ area, depicted in red) and the control group (schools outside the LEZ area, depicted in blue) following the implementation of the LEZ policy. This divergence is notable very soon after the introduction of the LEZ, with the gap in standardised test scores between the two groups widening in favor of the treatment group. Such findings suggest that the LEZ policy has had a positive impact on educational achievement within the LEZ area, supporting the hypothesis that improving air quality can contribute to better academic outcomes. Following this visual analysis, Table 2 presents more formal estimates using our difference-in-differences estimator described in Section 3.2. The results show that the introduction of the LEZ improves test scores by 0.37 APS, or 0.88 of a standard deviation. This estimate is statistically significant at the 0.1 percent level and also economically significant, underscoring the policy's significant positive impact on educational achievement. To put the effect size in context, it is slightly smaller than the estimated effects of increasing average teacher quality by one standard deviation and similar to the estimated effect of reducing class size by 10 students or paying teachers large financial bonuses (Lavy, 2009; Rivkin et al., 2005).

We continue our analysis by exploring the temporal dynamics of the LEZ policy's effects on KS2 scores through a dynamic difference-in-differences analysis (Event Study). This approach allows us to observe both the immediate and the evolving impacts of the LEZ policy over the years, with detailed results presented in Figure 3 for both raw and standardised scores. The dynamic analysis exhibits a notable trend: the positive effect of the LEZ policy on KS2 scores not only persists but appears to amplify over time. This finding is consistent with the hypothesis that sustained reductions in pollution exposure yield increasingly significant improvements in educational outcomes. The right panel of Figure 3 reveals that the effects range from 0.07 of a standard deviation in the 2008-2009 school year to 0.17 in 2014-2015. Such a trend is of great importance as it suggests that the benefits of the LEZ extend beyond initial impacts, accumulating positively as students experience prolonged periods of improved air quality. The gradual enhancement of test scores within the LEZ area, relative to the control, highlights the importance of continuous and long-standing policy measures

Figure 2: Average Point Score (APS) over time



Notes: Yearly averages of APS and standardized APS by year and treatment status.
Data for 2010 is not reported due to a marking boycott.

in achieving substantial educational improvements.

Relatedly, we also study the effect of the policy by modeling the effect on KS2 standardised test scores as a function of the duration of exposure to the policy, rather than merely comparing before and after the policy's implementation. This approach, which is a parametric version of the event study above, allows us to interpret the LEZ's influence on educational outcomes through the lens of cumulative effects, acknowledging that the benefits of improved air quality on test scores may accumulate over time. To study this idea, we introduce an interaction term in our model which is the number of years a student has been exposed to the LEZ policy interacted with an indicator for being in the LEZ area. This modification enables us to capture the incremental effect of the policy over time on academic performance, captured in a single coefficient representing the slope of improvement. Our findings, presented in Table A.1, show that for each additional year a student is educated within the LEZ, there is a statistically significant increase of 0.02 in standardised test scores. This result not only underscores the positive influence of the LEZ on educational attainment but also highlights the policy's cumulative benefits over time.

Overall, our analysis corroborates the initial findings of a significant positive effect on educational achievement and also illuminates the increasing magnitude of this impact as the duration of exposure extends and the cumulative effect of the policy. Such results lend strong support to the argument for sustained environmental interventions as a means to foster academic success, highlighting the critical role of time in the realization of policy benefits.

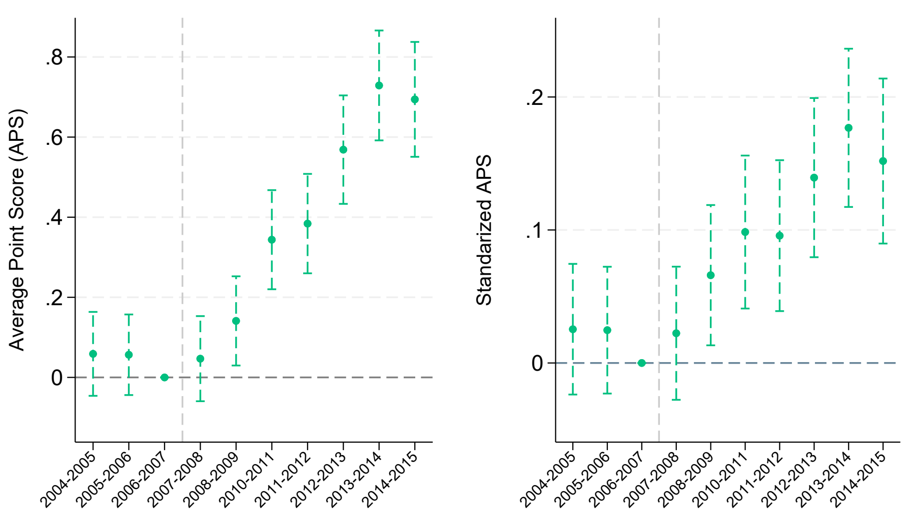
Next, we delve into the heterogeneous effects of the LEZ policy on KS2 standardised

Table 2: Impact of LEZ on KS2's Average Point Score (APS)

	APS	Standardised APS
	(1)	(2)
Post × Treatment	0.37***	0.088***
	(0.043)	(0.020)
Constant	27.2***	-0.25***
	(0.020)	(0.0092)
School FE	Yes	Yes
Year FE	Yes	Yes
R2	0.21	0.12
Schools	3386	3386
Clusters	632	632
Observations	32415	32415

Notes: Standard Errors in parenthesis and clustered by postcode district.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 3: Event Study Results of the Impact of LEZ on KS2's Average Point Score (APS)



Notes: Estimates by year with 95% CI, SE clustered by postcode district.
Data for 2010 is not reported due to a marking boycott.

Table 3: Heterogeneity in the impact of LEZ on KS2's Average Point Score (APS)

	APS		Standardized APS	
	(1)	(2)	(3)	(4)
Post × Treatment	0.32***	0.26***	0.077***	0.049*
	(0.044)	(0.045)	(0.019)	(0.020)
Post × Treatment × Low APS	0.18*		0.066*	
	(0.070)		(0.031)	
Post × Low APS	0.63***		0.36***	
	(0.042)		(0.019)	
Post × Treatment × High eligibility		0.14		0.043
		(0.074)		(0.035)
Post × High eligibility		0.22***		0.12***
		(0.048)		(0.022)
Constant	27.2***	27.2***	-0.24***	-0.25***
	(0.020)	(0.020)	(0.0088)	(0.0091)
School FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R2	0.23	0.22	0.15	0.12
Schools	3386	3386	3386	3386
Clusters	632	632	632	632
Observations	32415	32415	32415	32415

Notes: Standard Errors in parenthesis and clustered by postcode district.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

test scores, with a particular focus on initial test scores before the policy implementation and varying income groups as proxied by eligibility for free school meals. Our results of this analysis, detailed in Table 3 and estimated as described in Equation 3, document the differential impact of the LEZ policy across these distinct subgroups, revealing insightful patterns about whom the policy benefits the most. First, we explore the policy's effects relative to the average test scores of schools before the LEZ implementation. Our findings indicate that the observed benefits, in terms of higher test scores post-policy, predominantly accrue to schools that had lower (below median) test scores before the LEZ policy was introduced. In particular, the point estimates for the interaction terms are 0.18 and 0.66 in terms of APS and standardised scores respectively, and are statistically significant. This pattern is consistent with prior research on the unequal effects of air pollution on cognition, which find larger negative impacts in those with lower abilities (La Nauze & Severnini, 2021) and further highlights the LEZ policy's capacity in contributing to narrowing the achievement gap.

We also examine the interaction between the LEZ policy and the proportion of students eligible for free school meals within a school, a reliable indicator of the socio-economic status of the student body. In particular, schools with a higher percentage of students eligible for free school meals (defined as having above-median eligibility) are considered high-eligibility schools. Our findings, also presented in Table 3, indicate a pronounced increase in test scores within these high-eligibility schools compared to schools with lower free school meal eligibility. Specifically, we find that schools below the median in terms of eligibility increased their tests scores by 0.26 and 0.04 in terms of raw average points and standardised scores respectively while those above the median experienced an additional improvement of 0.14 and 0.04 in APS and standardised scores, respectively. Whilst the interaction results are slightly noisy, they still highlight the significance of the LEZ policy's impact on schools, with additional benefits for more economically disadvantaged students, and underscore its potential role in reducing educational disparities.

The analysis presented in Table 3 suggests that the LEZ policy can not only improve environmental conditions, and therefore alleviate some of the environmental injustice concerns, but can also foster educational equity. By enhancing test scores in schools with higher proportions of students eligible for free school meals and in those with lower initial test scores, the LEZ policy demonstrates a potentially impactful approach to addressing educational disparities. These heterogeneous effects of the policy shed light on the broader social implications of environmental interventions, emphasizing the importance of targeted policy measures in supporting vulnerable populations and potentially promoting social mobility through improved educational outcomes.

Motivated by prior research indicating that LEZ implementation can lead to increased traffic and pollution just outside the boundaries of the zone (Zhai & Wolff, 2021), we move on to examine the potential spillover effects of London's LEZ on surrounding areas. This displacement could potentially neutralize some benefits of the LEZ or even exacerbate conditions in adjacent areas. To empirically test the hypothesis that these changes might also affect educational outcomes, we shift our focus to urban schools within a 20km buffer outside the LEZ (see dotted line in Figure 1) instead of schools within the LEZ, and compare them to any urban school outside of the 100km buffer. Our results, detailed in Appendix Table A.2, indicate a relatively modest positive impact on the test scores of schools situated just outside the LEZ, with an increase of 0.026 of a standard deviation. This estimate is less than a third of the positive impact observed within the schools directly inside the LEZ boundary (0.09 of a standard deviation) and statistically insignificant. Nevertheless, this analysis highlights the empirical danger of using adjacent areas as controls, providing further support to our research design.

Finally, we provide a rich set of robustness tests to show that our results are robust across various model specifications and choice of control groups. Column 1 of Table 4 presents our preferred specification results for raw APS in Panel A and standardised APS in Panel B, serving as a benchmark for subsequent analyses. In Column 2, we apply the same preferred specification but on a balanced sample and reassuringly find that results align closely with our initial findings. Column 3 changes the year of treatment from the year of implementation (2008) to the year of announcement (2007) to account for any pre-intervention effects, finding virtually no change with respect to the main results. Column 4 estimates the main results without controlling for the potential effect of the "Pupils Premium" (estimates

Equation 1 instead of 2), finding an even larger effect than in our preferred specification. In Column 5 of Table 4, we provide an alternative specification that combines a differences-in-differences approach with Coarsened Exact Matching (CEM). The analysis is motivated by the differences that we observe between the control and treatment groups in terms of covariates presented in Table 1. Whilst our DiD model does not require the treatment and control groups to be balanced, more comparable observations might further enhance the credibility of the causal interpretations of our results, although it also reduces the sample size significantly[12]. Table A.3 which provides summary statistics for the matched sample, certainly shows that this new sample has a much more balanced treatment and control groups compared to our main DiD sample. Reassuringly, the estimated effects using the combined DiD approach with CEM presented in Column 5 of Table 4 remain remarkably similar to those from our main specification. Relatedly, in Column 6 we use only schools situated in the 5 largest cities in England as our control group. The rationale for this analysis is to use a very restricted set of relatively comparable cities to further test the robustness of our results to the choice of the control. Again, we find very similar results even with this restricted sample. We conclude our analysis by testing the sensitivity of our findings to variations in our buffer zone by adjusting the distance buffer around the LEZ to 75, 50, and 20 kilometers, deviating from our original 100-kilometer buffer. The results, which are presented in Table A.4 show that these adjustments do not affect our estimates significantly.

Overall, the robustness tests presented in Table 4 and Table A.4 provide strong reassurance that our findings are stable across different specifications and methodological choices, reinforcing the reliability of our conclusions regarding the impact of LEZ policies on educational outcomes.

[12]The algorithm matches on the distribution of pre-policy values of Standardized APS, share of pupils with English as their first language, and the shares of 'white British' and 'other white' ethnic origin.

Table 4: Robustness

	Outcome: Average Point Scores (APS) in KS2					
	Main Results	With balanced panel	Treatment at Announcement	No Pupil Premium controls	Matching and DID	Restricted Control Group
A: APS						
Post × Treatment	0.37***	0.36***	0.38***	0.47***	0.28***	0.34***
	(0.043)	(0.046)	(0.042)	(0.045)	(0.079)	(0.049)
Constant	27.2***	27.4***	27.3***	27.3***	27.3***	27.2***
	(0.020)	(0.022)	(0.019)	(0.020)	(0.052)	(0.024)
School FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.21	0.23	0.21	0.19	0.20	0.25
Schools	3386	2541	3672	3740	2295	2225
Clusters	632	602	696	696	568	429
Observations	32415	24751	35166	35760	22272	21304
B: Standardised APS						
Post × Treatment	0.088***	0.089***	0.092***	0.17***	0.088*	0.088***
	(0.020)	(0.021)	(0.019)	(0.022)	(0.035)	(0.022)
Constant	-0.25***	-0.19***	-0.23***	-0.21***	-0.24***	-0.25***
	(0.0092)	(0.010)	(0.0088)	(0.0097)	(0.023)	(0.011)
School FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.12	0.12	0.11	0.043	0.080	0.13
Schools	3386	2541	3672	3740	2295	2225
Clusters	632	602	696	696	568	429
Observations	32415	24751	35166	35760	22272	21304

Notes: Standard Errors in parenthesis and clustered by postcode district. Main results as in Table 2 with 100km buffer and treatment at the application of the LEZ (2008). The restricted control group includes the 5 largest cities in England outside of London (in 2005): Birmingham, Liverpool, Bristol, Sheffield, and Manchester.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5 Conclusions

This paper provides compelling evidence of the beneficial impact of London's Low-Emission Zone on standardised exam scores among elementary school students, marking a significant addition to both academic literature and policy discussions. Utilising the National Pupil Database, and employing a rigorous difference-in-differences approach complemented by fixed effects, our findings reveal that primary schools within the LEZ experienced a meaningful improvement in test scores, comparable to traditional education interventions such as enhancing teacher quality or reducing class sizes.

Importantly, we also show that the benefits are disproportionately greater in schools serving a larger share of economically disadvantaged populations and those with historically lower academic performance. This indicates that LEZs can play a critical role in leveling the educational playing field and supporting vulnerable communities. Furthermore, our results suggest that previous evaluations of LEZs may have underestimated their broader societal benefits, focusing primarily on immediate health and pollution reductions.

Several potential mechanisms could explain the observed relationship between LEZ implementation and improved test scores. For example, reduced air pollution may directly enhance cognitive performance and cognition. Additionally, by lowering air pollution, LEZs likely reduce respiratory-related school absences, allowing students to attend more consistently, which can enhance academic performance. Future research should aim to disentangle such influences, providing clearer insights into the underlying mechanisms of this newly documented relationship between LEZs and educational outcomes.

Overall, this research provides a valuable framework for future studies and policy discussions, emphasizing the importance of incorporating educational outcomes into the assessment of environmental policies. As we continue to explore and understand these intersections, it is clear that environmental interventions can and should be part of a holistic strategy to enhance both public health and educational achievement.

References

Barro, R. J., et al. (2013). Education and economic growth. *Annals of economics and finance*, *14*(2), 301–328.

Becker, G. S. (1964). *Human capital: A theoretical and empirical analysis, with special reference to education.* Chicago: University of Chicago Press. Retrieved from https://www.nber.org/books-and-chapters/human-capital-theoretical-and-empirical-analysis-special-reference-education-first-edition

Bondy, M., Roth, S., & Sager, L. (2020). Crime is in the air: The contemporaneous relationship between air pollution and crime. *Journal of the Association of Environmental and Resource Economists*, *7*(3), 555–585.

Brehm, J., Pestel, N., Schaffner, S., & Schmitz, L. (2022). *From low emission zone to academic track: Environmental policy effects on educational achievement in elementary school* (No. 980). Ruhr Economic Papers.

Broaddus, A., Browne, M., & Allen, J. (2015). Sustainable freight: Impacts of the london congestion charge and low emissions zones. *Transportation Research Record*, *2478*(1), 1–11.

Butts, K. (2021). Difference-in-differences estimation with spatial spillovers. *arXiv preprint arXiv:2105.03737*.

Currie, J., & Walker, R. (2011). Traffic congestion and infant health: Evidence from e-zpass. *American Economic Journal: Applied Economics*, *3*(1), 65–90.

DFE. (2015). *The national pupil database: User guide* (Tech. Rep.). Department for Education. Retrieved from https://doc.ukdataservice.ac.uk/doc/7627/mrdoc/pdf/7627userguide_2015.pdf

Ebenstein, A., Lavy, V., & Roth, S. (2016). The long-run economic consequences of high-stakes examinations: Evidence from transitory variation in pollution. *American Economic Journal: Applied Economics*, *8*(4), 36–65.

Gazze, L., Persico, C., & Spirovska, S. (2024). The long-run spillover effects of pollution: How exposure to lead affects everyone in the classroom. *Journal of Labor Economics*, *42*(2), 357–394.

Gehrsitz, M. (2017). The effect of low emission zones on air pollution and infant health. *Journal of Environmental Economics and Management*, *83*, 121–144.

Gilraine, M. (2023). Air filters, pollution, and student achievement. *Journal of Human Resources*.

Graff Zivin, J., & Neidell, M. (2012). The impact of pollution on worker productivity. *American Economic Review*, *102*(7), 3652–3673.

Hanushek, E. A., & Woessmann, L. (2008). The role of cognitive skills in economic development. *Journal of economic literature*, *46*(3), 607–668.

Holman, C., Harrison, R., & Querol, X. (2015). Review of the efficacy of low emission zones to improve urban air quality in european cities. *Atmospheric Environment*, *111*, 161–169.

La Nauze, A., & Severnini, E. R. (2021). *Air pollution and adult cognition: evidence from brain training* (Tech. Rep.). National Bureau of Economic Research.

Lavy, V. (2009). Performance pay and teachers' effort, productivity, and grading ethics. *American Economic Review*, *99*(5), 1979–2011.

Margaryan, S. (2021). Low emission zones and population health. *Journal of Health Economics*, *76*, 102402.

Mayor of London. (2021). *London low emission zone - six month report.* https://www.london.gov.uk/sites/default/files/lez_six_month_on_report-final.pdf. London: Greater London Authority. (Accessed: April 5, 2024)

Middlemas, J. (2014). *Quality and methodology information: Attainment in primary schools in england* (Tech. Rep.). Sanctuary Buildings, Great Smith Street, London SW1P 3BT, England: UK Department for Education. Retrieved from https://assets.publishing.service.gov.uk/media/5a7de769e5274a2e8ab44918/SFR50_2014_Qualityandmethodology.pdf

Pestel, N., & Wozny, F. (2021). Health effects of low emission zones: evidence from german hospitals. *Journal of Environmental Economics and Management*, *109*, 102512.

Rivkin, S. G., Hanushek, E. A., & Kain, J. F. (2005). Teachers, schools, and academic achievement. *econometrica*, *73*(2), 417–458.

Roberts, N. (2023). *The pupil premium (england).* House of Commons Library. Retrieved from https://researchbriefings.files.parliament.uk/documents/SN06700/SN06700.pdf (Accessed: 29th April 2024)

Sarmiento, L., Wagner, N., & Aleksandar, Z. (2021). Effectiveness, spillovers, and well-being effects of driving restriction policies. DIW Berlin Discussion Paper No. 1947.

Schlenker, W., & Walker, W. R. (2016). Airports, air pollution, and contemporaneous health. *The Review of Economic Studies*, *83*(2), 768–809.

Stafford, T. M. (2015). Indoor air quality and academic performance. *Journal of Environmental Economics and Management*, *70*, 34–50.

Transport for London. (2006). *Proposed london low emission zone economic and business impact assessment: Non-technical summary.* https://content.tfl.gov.uk/economic-impact-assessment-non-technical-summary.pdf. London: Steer Davies Gleave. (Accessed: April 5, 2024)

Transport for London. (2008). *Low emission zone: Impacts monitoring baseline report.* https://content.tfl.gov.uk/lez-impacts-monitoring-baseline-report-2008-07.pdf. London: Transport for London. (Accessed: April 5, 2024)

Transport for London. (2011). *Stricter emissions standards for central or inner london: A provisional assessment of potential feasibility and effectiveness.* London, UK: Transport for London.

Wen, J., & Burke, M. (2022). Lower test scores from wildfire smoke exposure. *Nature Sustainability*, *5*(11), 947–955.

Who. (2021). World Health Organization. Retrieved from https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (Accessed: 29th April 2024)

Wolff, H. (2014). Keep your clunker in the suburb: low-emission zones and adoption of green vehicles. *The Economic Journal*, *124*(578), F481–F512.

Wolff, H., & Perry, L. (2010). Policy monitor. *Review of Environmental Economics and Policy*.

Zhai, M., & Wolff, H. (2021). Air pollution and urban road transport: evidence from the world's largest low-emission zone in london. *Environmental Economics and Policy Studies*, 1–28.

A Appendix Tables and figures

Table A.1: Impact of LEZ on KS2's Average Point Score (APS) by duration of exposure

	APS (1)	Standardised APS (2)
Post × Treatment	0.0013	0.017
	(0.037)	(0.017)
Years since treatment × Treatment	0.10***	0.020***
	(0.0081)	(0.0033)
Constant	27.2***	-0.25***
	(0.019)	(0.0085)
School FE	Yes	Yes
Year FE	Yes	Yes
R2	0.22	0.12
Schools	3386	3386
Observations	32415	32415

Standard Errors in parenthesis and clustered by postcode district.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.2: Impact of LEZ on neighbouring areas KS2's Average Point Score (APS)

	APS (1)	Standardised APS (2)
Post × 20km buffer outside LEZ	0.037	0.026
	(0.049)	(0.022)
Constant	27.4***	-0.19***
	(0.016)	(0.0073)
School FE	Yes	Yes
Year FE	Yes	Yes
R2	0.14	0.071
Schools	4802	4802
Clusters	987	987
Observations	45872	45872

Notes: Standard Errors in parenthesis and clustered by postcode district. Treated and control units are urban schools. Control schools are >100km from LEZ buffer but do not have to be in the largest 20 cities as the main specification.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.3: Summary Statistics - Matched Sample

	Control			Treatment		
	Mean	SD	N	Mean	SD	N
Average point score (APS) in KS2	27.36	2.01	1,726	27.74	2.07	554
Standardized APS in KS2	-0.28	0.96	1,726	-0.10	1.00	554
Number of full-time equivalent pupils	295.70	118.56	1,762	322.80	123.59	566
% English as first language	66.52	28.29	1,437	66.60	27.71	553
% White British ethnic origin	48.71	29.27	1,754	47.45	28.56	558
% Other white ethnic origin	2.94	2.92	1,152	4.92	3.55	525
Pupil-teacher ratio	21.44	3.59	1,762	22.05	4.39	567

Notes: All values from 2006. SD = Standard Deviation. N = Number of schools.

Table A.4: Robustness by distance buffer

	Outcome: Average Point Scores in KS2							
	Raw values				Standardised values			
	(1) > 100km	(2) > 75km	(3) > 50km	(4) > 20km	(5) > 100km	(6) > 75km	(7) > 50km	(8) > 20km
Post × Treatment	0.37^{***}	0.37^{***}	0.38^{***}	0.38^{***}	0.088^{***}	0.089^{***}	0.091^{***}	0.091^{***}
	(0.043)	(0.043)	(0.043)	(0.042)	(0.020)	(0.020)	(0.019)	(0.019)
Constant	27.2^{***}	27.2^{***}	27.3^{***}	27.3^{***}	-0.25^{***}	-0.24^{***}	-0.24^{***}	-0.23^{***}
	(0.020)	(0.020)	(0.019)	(0.019)	(0.0092)	(0.0090)	(0.0089)	(0.0088)
School FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.21	0.21	0.21	0.21	0.12	0.11	0.11	0.11
Schools	3386	3517	3577	3663	3386	3517	3577	3663
Clusters	632	665	679	696	632	665	679	696
Observations	32415	33665	34247	35077	32415	33665	34247	35077

Notes: Standard Errors in parenthesis and clustered by postcode district. Treated and control units are urban schools in the largest 20 cities that are further away than the threshold. The main specification corresponds with columns (1) and (5) with a threshold of >100km from LEZ buffer.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$