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Effects of Low Emission Zones on Air Quality, New Vehicle Registrations, and Birthweights: Evidence from Japan

Shuhei Nishitateno[1,3] · **Paul J. Burke**[2]

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Abstract
In October 2003 four contiguous prefectures in Greater Tokyo introduced Low Emission Zones (LEZs) from which diesel trucks and buses without particulate filters have been banned from entering. This paper analyzes the effects of this large-scale intervention on air quality, new vehicle registrations, and birthweights. We use a matching approach to construct a control group comparable to the designated areas in terms of propensity scores based on municipality characteristics during the pre-intervention period and apply a difference-in-differences design. We find evidence that the intervention led to reductions in hourly particulate matter concentrations and the incidence of low birthweights in the Greater Tokyo LEZ relative to the control group. We also find that the LEZs led to increases in registrations of new trucks and buses. This is not the case for passenger cars, which were exempt from the regulations. Our paper provides the first evidence of a significant link between LEZs and reduced incidence of low birthweights.

Keywords Low Emission Zone · Urban Air Pollution · Birthweight

JEL Classification Q53 · R48 · I18

1 Introduction

Motor vehicles are a major source of urban air pollution around the world. Tightened vehicular emission standards and regulations of fuel content are among factors that have contributed to improvements in air quality over recent decades. Nevertheless, many cities continue to face serious air pollution problems. In 2021, 1,453 cities in high-income

✉ Shuhei Nishitateno
shuhei0828@kwansei.ac.jp

Paul J. Burke
paul.j.burke@anu.edu.au

1 School of Policy Studies, Kwansei Gakuin University, Sanada, Japan

2 Arndt-Corden Department of Economics, Crawford School of Public Policy, Australian National University, Canberra, Australia

3 Research Institute of Economy, Trade and Industry, Tokyo, Japan

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countries (excluding the Arab oil-producing countries) exceeded air quality guidelines in terms of particulate matter smaller than 2.5 μ m concentration (5 μ g/m^3) (World Health Organization 2023). Examples include Milan (20 μg/m^3), Paris (13), Berlin (13), Tokyo (11), London (11), and Los Angeles (11).

Low Emission Zones (hereafter, LEZs) – geographic areas from which the most polluting vehicles are restricted from entering – have been an important measure taken to seek to improve local air quality in European cities. Since the first implementation in Sweden in 1996, the LEZ approach has spread, with 199 LEZs being recorded across Europe as of July 2023 (Sadler Consultants Ltd. 2023). LEZs vary substantially in terms of implementation dates, the sizes of designated areas, regulated vehicle types, the stringency of emission standards, and the monitoring systems used (Holman et al. 2015). The main aim has been to reduce emissions of pollutants including particulate matter (PM) and nitrogen dioxide (NO_2) in cities in order to protect human health.

In Europe, LEZs have often divided public opinion. An IPSOS survey showed that large proportions of citizens in Germany (43%), Belgium (40%), and France (40%) opposed LEZs (European Federation for Transport and Environment (EFTE) 2019). The unpopularity emanates mainly from fairness issues and the fact that the restrictions require some vehicle owners to implement vehicle retrofits or upgrade to an alternative vehicle, imposing a financial burden. The effectiveness of LEZs in improving air quality and public health has also been questioned (Boogaard et al. 2012; Ellison et al. 2013; Ferreira et al. 2015; Santos et al. 2019). Madrid's LEZ, called Madrid Central, was reversed within a year of its introduction and a less stringent LEZ, Madrid 360, was introduced.

The world's largest cluster of LEZs has been introduced in Japan. With the aim of reducing ambient concentrations of particulate matter with a diameter less than or equal to 10 μm (PM_{10}), LEZs were introduced in four contiguous prefectures in Greater Tokyo in October 2003: Tokyo, Saitama, Kanagawa, and Chiba. We call this the giant LEZ in Greater Tokyo. The LEZs banned diesel trucks and buses that violate PM_{10} emission standards specified by prefectural governments from entering designated areas, except vehicles for which a diesel particulate filter designated by the prefectural government was installed. From April 2006 the emission standard was tightened in Tokyo and Saitama but not Kanagawa and Chiba.

Japan's LEZs provide an interesting setting to study as they were implemented prefecture-wide over large areas. As of 2003, about 36 million people (30% of the total population of Japan) lived in Greater Tokyo's LEZ. Examination of Japan's LEZs also allows us to assess implications of increases in the stringency of emission standards through heterogeneity analyses by prefecture. Prior studies of Japan's LEZs have analyzed their effectiveness in reducing PM_{10} emissions from road transport (Ishii and Tsukigawa 2004; Rutherford and Ortolano 2008), carried out an ex-ante estimate of costs and benefits (Iwata 2011), and undertaken hedonic price analysis to quantify the benefits (Kang et al. 2024). Kang et al. (2024) also estimated effects on some health variables such as infant mortality. However evidence on the effects of Japan's LEZs on public health remains scarce.

The goal of this paper is to estimate the effects of Japan's LEZs on the number of new vehicle registrations by vehicle type, ambient PM_{10} concentrations, and birthweights. We use a matching approach to construct a control group comparable to the designated areas in terms of propensity scores based on underlying municipal characteristics during the pre-intervention period and apply a difference-in-differences (DD) design. Our analysis utilizes hourly air pollution data at the monitor level and data for each birth over 2000–2008. We also use administrative data on new vehicle registrations for 1999–2008.

Birthweights are an important variable to study given evidence of long-term effects of low birthweight on future health, education, and labor market outcomes (Currie 2009; Almond and Currie 2011). For example evidence from Scandinavia suggests that a 1 percent increase in birthweight on average increases the probability of high school completion by 0.7–1 percentage points and lifetime income by 8–12 percent (Black et al. 2007; Bharadwaj et al. 2018). Maruyama and Heinesen (2020) found that birthweight is negatively associated with the probability of being disabled.

Our results suggest that the intervention on average led to a 7% reduction in the hourly mean PM_{10} concentration in the LEZ in Greater Tokyo relative to the control group over October 2003–September 2008. We also find evidence that the pollution-reducing effects vary across prefectures. The largest effects are found for Tokyo (10%) and Saitama (10%), with temporal variation in their treatment effects being relatively stable across the post-intervention period. This may be linked to the fact that these two prefectures upgraded their LEZ rules to apply the 2003 national emission standard levels in April 2006. The pollution-reducing effects are more modest for Kanagawa (2%) and Chiba (5%), with mixed evidence on the dynamics of these effects. These two prefectures did not upgrade their LEZ emission requirements during the sample period.

We find that the annual number of registrations of new trucks and buses in the Greater Tokyo LEZ increased by 34–40% on average over 2003–2008 relative to the control group. This accounted for only about 13–15% of the initial stock of regulated diesel trucks and buses, meaning that most owners of non-compliant vehicles likely responded to the policy by installing a diesel particulate filter, which was a cheaper option but not feasible in all cases, as some old vehicles could not be retrofitted with a filter. A placebo test confirms that the LEZs did not significantly affect new vehicle registrations of passenger cars relative to the control group, which is as expected given they were not subject to the regulations. We calculate that the cost of replacing non-compliant vehicles and installing diesel particulate filters amounted to around US$12 billion in year-2023 dollars.[1]

An important finding is that the LEZs appear to have reduced the incidence of low birthweights, holding gestational age and other factors constant. Evidence suggests that the implementation of the LEZs on average led to about a 0.2% (around 6 g) increase in birthweight over July 2004–June 2008 for newborn babies inside the Greater Tokyo LEZ relative to those outside. The results also suggest that of the 471,275 births that we observe in the Greater Tokyo LEZ over July 2004–June 2008, about 1,272 switched from being below 2,500 g to above as a result of the interventions. The time patterns of the effects on birthweights mirror the dynamics of the effects on air pollution.

To check the robustness of our results, we examine the potentials for pollution leakages and compositional changes in parental characteristics in the treatment and control groups after the implementation of LEZs. We do not find noticeable evidence that these factors are a threat to our identification strategy. We also find that our baseline estimates are relatively robust across specifications that control for anticipation effects, day fixed effects, and other vehicular control policies, or that cluster standard errors at a higher level (by prefecture). Our baseline estimates are also robust to alternative samples using different matching approaches.

The literature analyzing the effectiveness of LEZs has mostly focused on Europe. Analyzing a monitor-day panel with DD regressions, Wolff (2014) investigated the effects

[1] Throughout the paper we convert compliance costs measured in Japanese yen into 2023-dollar terms using Japan's consumer price index and the average year-2023 exchange rate of 140 Japanese yen per US$.

of LEZs on vehicle replacements and air quality in Germany. Subsequent articles have explored the health effects of German LEZs, analyzing implications for outcomes including birthweights and the occurrence of stillbirths (Gehrsitz 2017), pharmaceutical expenditures for asthma and heart diseases (Rohlf et al 2020), outpatient and inpatient health (Margaryan 2021), hospital shares of diagnosed ischemic heart diseases, chronic lower respiratory diseases and low birthweights (Pestel and Wozny 2021), and the number of medical prescriptions and costs of prescriptions per child (Klauber et al. 2021). Zhai and Wolff (2021) examined the environmental effects of London's LEZ, finding that it led to worse air quality during the initial phase due to an increase in inflows of heavy vehicles and temporarily-exempted light goods vehicles. See Appendix 1 for a summary of this literature.

A recent paper by Kang et al. (2024) investigated the effects of Japan's LEZs on air quality, land prices, and infant health. They concluded that the benefits of air quality improvements are about 14 times the cost. Estimated effects on infant health indicators were inconclusive.

Our paper also relates to a broader literature studying other types of traffic-related policy interventions (see Appendix 2). Currie and Walker (2011) investigated the environmental and health impacts of the E-ZPass in Pennsylvania and New Jersey, finding that its adoption led to reduced NO_2 concentrations and lowered the incidences of premature births and low birthweights. He et al. (2019) analyzed a newly-built beltway in São Paulo designed to keep heavy diesel trucks away from congested truck routes, finding that the intervention reduced traffic congestion, air pollution, and cardiovascular and respiratory admissions around the original truck routes. Simeonova et al. (2019) studied the impacts of Stockholm's Congestion Pricing Zone (CPZ), finding that it led to improved air quality in designated areas and a reduction in acute asthma episodes among children aged under 5 years. Green et al. (2020) studied congestion pricing in London, finding evidence of improvements in air quality and a reduction in pollution per mile driven.

Japan's LEZs offer substantial potential to contribute to understanding the environmental and health impacts of LEZs. Unique features of Japan's LEZs are that the entire prefecture was designated as an LEZ and that LEZs were implemented by contiguous prefectures. The designated area of Greater Tokyo's combined LEZ is 13,500 km^2, much larger than the Greater London LEZ (1,500 km^2), the largest in Europe. Other LEZs in Europe are typically small: 8.2 km^2 for Milan, 20 km^2 for Amsterdam, and 44 km^2 for Munich. Despite the widespread use of LEZs in Europe, air pollution has often still exceeded European Union (EU) air quality limits, with France, Germany, and Italy facing legal action from the EU Commission over their failure to comply (Abnett 2020). Japan's experience of introducing a supersized LEZ through cooperation among neighboring geographical areas serves as a relevant example of a potential approach.

The second key contribution of the paper is to use the largest sample of births to date (in absolute number) to examine the effects of LEZs on the incidence of low birthweights per gestational age.[2] Prior research has revealed that traffic-related policy interventions, including LEZs, are effective in improving air quality and protecting public health for the current generations (He et al. 2019; Simeonova et al. 2019; Rohlf et al. 2020; Margaryan 2021; Pestel and Wozny 2021; Klauber et al. 2021). However relatively little is known about effects on fetal health. Currie and Walker (2011) found that the E-ZPass reduced the incidence of low birthweights in the United States, whereas Gehrsitz (2017), Pestel and Wozny (2021), and Kang et al. (2024) found no significant evidence that LEZs had an influence on birthweights in Germany and Japan.

[2] We use this term to refer to the effect while controlling for gestational age.

Prior studies have revealed that more stringent LEZ requirements led to larger pollution reductions (Gehrsitz 2017; Pestel and Wozny 2021; Zhai and Wolff 2021), but the implications for health outcomes have yet to be fully examined. We here find robust evidence of treatment effects on air pollution and birthweight only for Tokyo and Saitama, where more stringent emission standards were introduced in April 2006. Effect sizes are smaller and less robust for Kanagawa and Chiba, where emission standards applied for the LEZs remained stable during our sample period. The findings highlight that tightening of emission standards over time is thus one credible option to enhance the effectiveness of LEZ policies.

The remainder of this paper is structured as follows. Section 2 provides information on Greater Tokyo's LEZ, followed by a description of the data in Sect. 3. In Sect. 4 we document our method for selecting the treatment and control groups and show the temporal trends of the outcome variables. Section 5 presents empirical evidence on the effects of the LEZs on air pollution, new vehicle registrations, and birthweights. Section 6 examines the robustness of our baseline estimates. Section 7 concludes.

2 Japan's Low Emission Zones

Japan has introduced three major vehicle emission policies. The first is an emission standard applied to all newly-sold motor vehicles. For PM_{10}, this was introduced in 1993 and set at 0.43 g/km for standard trucks and buses. It has been tightened over time and is currently 0.007 g/km. The second is an automobile NOx/PM control (ANPC) that has banned vehicles that did not meet national emission standards from being registered in designated municipalities. The ANPC was introduced in some municipalities in Tokyo, Saitama, Chiba, Kanagawa, Osaka, and Hyogo in June 1992. In June 2001 its coverage was expanded to some municipalities in Aichi and Mie and additional municipalities in Saitama and Hyogo.[3]

The third key policy, analyzed in this paper, is the use of LEZs. Despite tightened vehicular emission standards and the ANPC, air quality in Tokyo remained poor in the 1990s: as of 1998, around 90% of air pollution monitors in Tokyo violated the national PM_{10} standard.[4] Over 1996–2000 more than 500 patients with respiratory diseases filed lawsuits against the national government, Tokyo Metropolitan Government, Tokyo Expressway Public Corporation, and carmakers. The plaintiffs argued that the defendants had responsibility for air pollution – not only at roadsides, but also in background areas away from roadsides (Tokyo Metropolitan Government 2003). The judges recognized that PM pollutants, particularly diesel exhaust particles, were responsible for adverse health effects and ordered the defendants to implement measures to reduce PM_{10} emissions from road transport.

In response to these developments, the Tokyo Metropolitan Government enacted the Tokyo Metropolitan Environmental Protection Ordinance in December 2000. The key measure was the introduction of an LEZ that applied to the entire prefecture (2,200 km^2). The implementation date was set as October 2003, with the LEZ banning the entry of diesel trucks and buses that violate the PM_{10} emission standards specified

[3] See Nishitateno and Burke (2020, 2021).

[4] The national air quality standard for PM_{10} required that the 98th-percentile of the daily-mean PM_{10} concentration be below 100 $\mu g/m^3$ throughout the year.

by the prefectural government. Trucks and buses were targeted given they were major sources of PM emissions (Tokyo Metropolitan Government 2003). The PM_{10} emission standards were equivalent to the 1997 national emission standard levels: 0.08 g/km for vehicles with gross vehicle weights of less than 1.7 tons, 0.09 g/km for 1.7–2.5 tons, and 0.25 g/kWh for more than 2.5 tons. From 1 April 2006 the standards were tightened to the 2003 national emission standard levels: 0.052 g/km for gross vehicle weights of less than 1.7 tons, 0.06 g/km for 1.7–2.5 tons, and 0.18 g/kWh for over 2.5 tons. Passenger cars were not subject to the regulation.

The LEZ went into effect in October 2003 for non-compliant trucks and buses first registered before 1997. Only compliant vehicles, including those for which a diesel particulate filter designated by the prefectural government had been installed, could legitimately enter the LEZs. Once a particulate filter was properly installed, a sticker was issued that was required to be placed on the side of the vehicle. Implementation of the LEZ was monitored by on-road oversight, cameras, anonymous tip-offs, and on-site inspections of truck and bus companies. Those not in compliance could be ordered to pay a fine of up to 500,000 Japanese yen (US$5,000).

There is substantial demand for intra-metropolitan truck freight transport in Japan (Tokyo Metropolitan Area Transport Planning Council 2005). Given this, to ensure that the Tokyo LEZ would work effectively, the Tokyo Metropolitan Government requested three neighboring prefectures – Saitama, Kanagawa, and Chiba – to also introduce LEZs. All agreed to introduce LEZs in an almost identical manner to the Tokyo LEZ in terms of PM_{10} emission standards, implementation dates (October 2003), and the vehicles to be targeted (trucks and buses). These prefectures also designated their entire areas as LEZs: 3,800 km^2 for Saitama, 2,400 km^2 for Kanagawa, and 5,100 km^2 for Chiba, meaning that the world's largest overall LEZ was formed (Fig. 1). Like Tokyo, Saitama tightened its emission standard for its LEZ in April 2006. The other two prefectures did not.

As of 2003, the giant Greater Tokyo LEZ had about 14 million registered four-wheel motor vehicles (about 19% of the national total) and annual economic output of about US$1.6 trillion (about 32% of national gross domestic product). The number of affected vehicles was large. As of March 2003, the number of diesel trucks that had been first registered before 1997 in the area was 796,000, accounting for 51% of the trucks registered in this area. Likewise, the number of regulated diesel buses was 26,000, accounting for 57% of the buses registered in the Greater Tokyo LEZ. The regulated trucks and buses accounted for about 20% of the four-wheel motor vehicle fleet in the Greater Tokyo LEZ.

The LEZ prefectures also introduced incentives for owners to replace their non-compliant vehicles with cleaner trucks and buses via subsidies, low-interest loans, and tax reductions. For example, Tokyo subsidized the purchase of hybrid trucks by around US$1,600–5,700 per vehicle, depending on vehicle weight. For a new purchase of a hybrid bus, the maximum subsidy was US$25,000. New vehicle purchases of natural gas trucks and buses were also supported by subsidies of US$1,000–2,000 per vehicle. Such favorable treatment was limited to small and medium-sized enterprises registering their vehicles in Tokyo.

An LEZ was also introduced in Hyogo prefecture on 1 October 2004. This restricted non-compliant trucks and buses from entering six of Hyogo's municipalities (Nada, Higashinada, Amagasaki, Nishinomiya, Itami, and Ashiya), representing a total area of 260 km^2, or about 3% of the area of the prefecture. We exclude Hyogo from our sample for two reasons. First, the Hyogo LEZ is small and its impact could differ from that of the Greater Tokyo LEZ. Second, excluding Hyogo makes it possible to avoid the issue of multiple treatment timing.

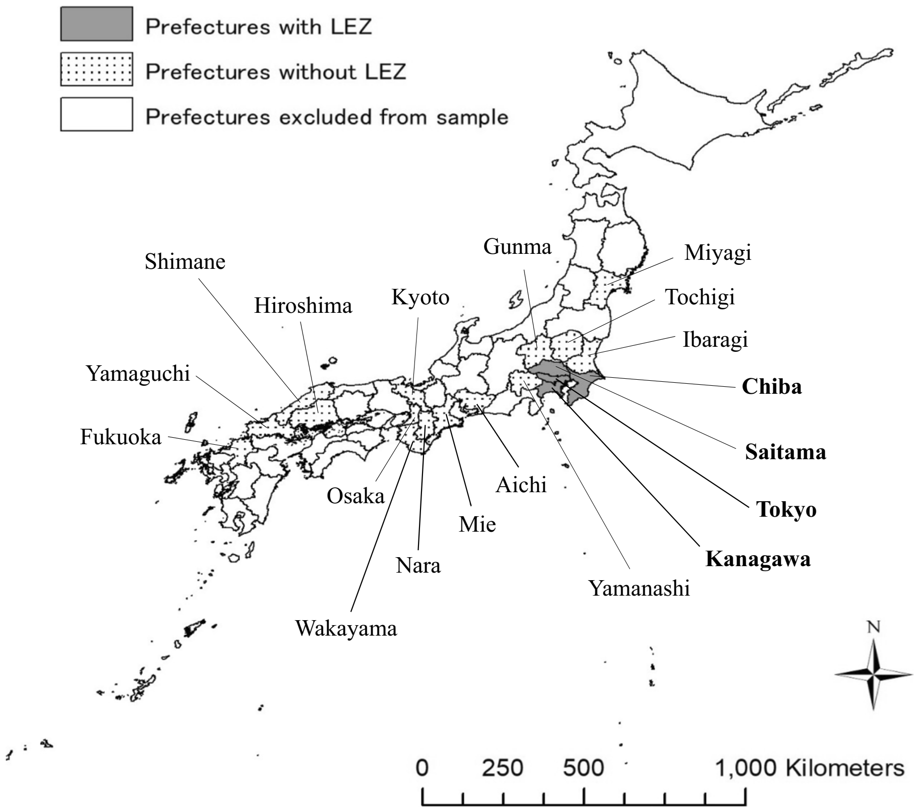


Fig. 1 Low emission zones in greater Tokyo. Notes: LEZs were introduced in Tokyo, Saitama, Kanagawa, and Chiba in October 2003. In these four prefectures the entire prefecture was designated. The dotted areas show the control group in this study. For other areas, either data on air pollution are unavailable, all municipalities are dropped in the matching process, or a small-scale LEZ was introduced (Hyogo)

Inflows and outflows of vehicles to LEZs were not monitored by cameras. However, on-road monitoring and on-site inspections indicated that compliance was high (Ministry of Environment 2013). For example, the Tokyo Metropolitan Government undertook on-road monitoring during October 2003–September 2005, finding that 12,502 out of 12,782 affected vehicles were compliant (98%). Based on similar on-road monitoring, compliance rates were reported to be 92% in Saitama and 97% in Chiba.

Data from the Ministry of Economy, Trade and Industry (2008) suggest that about 70 percent of replaced vehicles under the intervention were scrapped and about 28 percent exported overseas. Domestic pollution leakage due to vehicle transfers to non-LEZ areas thus appears not to have been a major issue.

3 Data

Our initial analysis is based on a two-dimensional monitor-hour panel dataset constructed using hourly air pollution and meteorological data for October 2000–September 2008. We avoid extending beyond 2008 in order to minimize potential estimation bias emanating from two major events: the global financial crisis, which severely affected Japan's economy in 2009 and had heterogeneous impacts across prefectures, and the Great East Japan earthquake and nuclear accident of March 2011, which had large implications for some locations.

Ambient PM_{10} concentration is used as a key measure of air quality and a proxy of the broader air quality situation. Data were obtained from the environmental statistics database compiled by the National Institute for Environmental Studies (NIES). Access to hourly pollution readings is limited to 20 prefectures, including the four that implemented LEZs by 2008 (Tokyo, Saitama, Kanagawa, and Chiba) and 16 that did not (Miyagi, Ibaragi, Tochigi, Gunma, Yamanashi, Aichi, Mie, Kyoto, Osaka, Nara, Wakayama, Okayama, Hiroshima, Tokushima, Yamaguchi, and Fukuoka). This is because Japan's Air Pollution Control Act did not require all 47 prefectures to report hourly readings until 2009. The sample includes both roadside and background air pollution monitors.

The analysis controls for meteorological variables including temperature, precipitation, wind speed, pressure, and humidity, using data from the Japan Meteorological Agency (JMA) as measured at meteorological stations. We use geographical information systems (GIS) to match the nearest meteorological station to each air pollution monitor.

To estimate the effects of the LEZs on new vehicle registrations we constructed a prefecture-year-vehicle size (three-dimensional) panel for 1999–2008. Vehicle registration data are from the Automobile Inspection & Registration Information Association (AIRIA). The AIRIA provides administrative data on vehicle registrations at the prefecture level on an annual basis, disaggregated by dimensions including vehicle type, first registration year, and registration location. We also accessed the System of Social and Demographic Statistics compiled by the Ministry of Internal Affairs and Communications (MIAC) to obtain prefecture-level control variables such as population, per capita income, and the unemployment rate.

To estimate the effects of the LEZs on birthweights we constructed a dataset of 1.8 million births over July 2000–June 2008. To do so we obtained access to confidential data on birth certificates from the Ministry of Health, Labor and Welfare (MHLW) based on Article 33 of the Statistics Act of Japan. The Family Registration Law requires all Japanese citizens to submit a birth certificate for new births to the municipal government within 14 days. We were able to access microdata on the date of birth, birthweight, gestation period, gender, type of birth (single or multiple), birth order, ages of the mother and father, nationalities of the mother and father, household head's job, and parents' residential locations. The municipality that the parents resided in when they submitted a birth certificate for their newborn baby was also available. For privacy reasons, home addresses were not.

To select a control group comparable to the treatment group in terms of propensity scores based on municipality characteristics during the pre-intervention period, we collected data at the municipality level from the MIAC for population density, per capita income, the unemployment rate, vehicle (passenger + commercial vehicles) registrations per capita, the services sector of the labor force, the share of the adult population who is a university graduate, and the share of the population aged 65 years and above.

Our analysis uses data from two administrative levels: prefectures and municipalities. Prefectures are the larger geographical unit in Japan and are largely responsible for monitoring air quality, implementing LEZs, and promoting environmentally friendly vehicles. Municipalities focus on dealing with local public needs, including for example providing municipality-based programs for pregnant women. Some also undertake local air pollution measures and provide additional (typically quite limited) monetary support for vehicle replacements. Municipalities also focus on dealing with local public needs, including for example providing municipality-based programs for pregnant women.

4 Sample

4.1 Matching

Over the sample period, data are available for 158 and 281 Japanese municipalities in and outside the LEZs, respectively. The two groups differ in some underlying characteristics, such as pollution levels and socioeconomic factors during the pre-intervention period (Panel A, Appendix 3). A concern is that initial conditions may be correlated with future trends, leading to questions over the parallel trends assumption. For example, people might migrate from rural to (more polluted) urban areas to seek a better job. On the other hand, it is possible that local governments in polluted areas have undertaken local pollution measures in addition to the LEZs, such as traffic flow controls. Balancing the underlying average characteristics between the LEZs and non-LEZs is designed to help alleviate the implications of such effects on our ability to accurately identify the effects of the LEZs. Similar approaches have been employed by Smith and Todd (2005), Girma and Görg (2007), Chabé-Ferret and Subervie (2013), Hirota and Yunoue (2017), and Deryugina et al. (2020).

We selected the estimation sample via the following steps. First, we used a logit model to estimate the propensity score of being "treated" for all available municipalities based on municipality-level variables during the pre-intervention period, including the PM_{10} concentration, log population density, share of population aged 65 years and above, share of university graduates in the population, unemployment rate, share of the labor force engaged in the service sector, log income per capita, and number of vehicle registrations per capita. We used 3-year averages for 2000–2002 for PM_{10} concentration and log income per capita. The remainder of the variables were averaged for 2000 only due to data limitations. PM_{10} concentration is measured hourly while the other variables are measured yearly.

Second, we constructed a sample by using single nearest-neighbor matching within a caliper width equal to 0.2 of the propensity score without replacement. We imposed a common support condition to satisfy the overlap assumption, dropping LEZ municipalities with a propensity score higher than the maximum or lower than the minimum among non-LEZ municipalities. The single nearest-neighbor approach resulted in well-equalized means of municipality variables during the pre-intervention period between the two groups (Panel B, Appendix 3). The distributions of propensity scores are also well balanced (Panel B, Appendix 4).

The above matching approach generates treatment and control samples with similar pre-trends. Specifically, pre-intervention treatment effects are statistically indistinguishable from zero for air pollution, increasing confidence that the parallel trends assumption is met (Figure 3).

We classify the treatment and control groups as in Table 1. The treatment group includes 209 monitors in 86 municipalities in the LEZ in Greater Tokyo. The 190 monitors in the control group are in 86 municipalities that did not implement an LEZ (Fig. 1). The selected sample of municipalities is common to the analyses of LEZ effects on air pollution and birthweight. For the analysis of effects on new vehicle registrations, we use the 15

Table 1 Treatment and control groups

Prefectures	Number of municipalities	Number of air pollution monitors
Treatment group		
Tokyo	17	32
Saitama	30	49
Kanagawa	19	36
Chiba	20	92
Total	86	209
Control group		
Aichi	30	59
Fukuoka	3	8
Gunma	3	8
Hiroshima	4	7
Ibaragi	6	8
Kyoto	5	6
Mie	2	4
Miyagi	1	1
Nara	5	13
Osaka	18	51
Shimane	3	4
Tochigi	1	2
Wakayama	3	15
Yamaguchi	1	1
Yamanashi	1	3
Total	86	190

The treatment group is subject to an LEZ, while the control group is not

prefectures that have at least one selected municipality through the matching process, listed in Table 1 as the control group. This is because the vehicle registration data we have are only available at the prefecture level.

4.2 Descriptive Statistics

Table 2 shows the sample averages of outcome variables during the pre- and post-intervention periods and their differences for the treatment and control groups.[5] We see that the average hourly PM_{10} concentration fell by 7.4 μg/m^3 in the treatment group and 5 μg/m^3 in the control group. The treatment group experienced greater increases in new registrations of the regulated vehicles (trucks and buses) relative to the control group. Importantly, the treatment group also experienced greater improvements in birthweight outcomes relative to the control group. Thus, simple difference-in-differences calculations provide evidence of treatment effects.

[5] Appendix 5 reports descriptive statistics for all variables.

Table 2 Descriptive statistics for outcome variables

	Treatment group			Control group		
	Before	After	Diff	Before	After	Diff
PM_{10} concentration, μg/m^3	35.1	27.8	–7.4	34.1	29.1	–5
Birthweight, grams	3,026	3,009	–17	3,021	3,003	–18
Dummy variable if birthweight is						0
< 2,500 g	0.088	0.094	0.006	0.089	0.097	0.007
< 1,500 g	0.007	0.007	0	0.007	0.008	0.001
New registration of trucks	14,550	18,054	3,504	5,466	5,765	299
New registration of buses	357	536	179	125	145	20
New registration of passenger cars	109,641	101,351	–8,291	42,579	39,012	–3,567

This table presents the sample averages during the pre- and post-intervention periods, and their differences, for the treatment and control groups. For the pollution variable, Before is from October 2000 to September 2003, and After is from October 2003 to September 2008. For the birth variables, Before is from July 2000 to June 2004, and After is from July 2004 to June 2008. For the vehicle registration variables, Before is from 1999 to 2002, and After is from 2003 to 2008

5 Difference-in-Differences Analyses

5.1 Specifications

We estimate the following initial difference-in-differences (DD) specification:

$$PM_{i,t} = \alpha_0 + \alpha_1 \left(Treated_i \times Post_t \right) + \gamma \boldsymbol{X}_{i,t} + \varepsilon_{i,t} \tag{1}$$

where *PM* is ambient PM_{10} concentration in μ g/m^3, i is pollution monitor, and t is hour. *Treated* is a dummy taking the value one if a unit is located inside an LEZ and zero otherwise. *Post* is a dummy indicating October 2003 onwards. $\boldsymbol{X}$ is a vector of determinants of outcome variables. ε is an error term. Our interest is in identifying α_1, the effect of the treatment.

$\boldsymbol{X}$ includes hourly meteorological conditions, monitor fixed effects, month-by-year fixed effects (month fixed effects, hereafter), hour-of-day fixed effects, and national holiday and weekend dummies. The monitor fixed effects account for time-invariant factors relevant for air pollution levels such as topography. The month fixed effects control for any national-level monthly changes during the sample period such as the tightening of the national emission standard and reductions in the sulfur content of light fuel oil. The hour-of-day fixed effects capture regular within-day patterns such as due to peak and off-peak hours.

Our specification for analyzing the effect of the LEZs on new vehicle registrations (*Vehicle*) is:

$$\ln Vehicle_{p,t,s} = \alpha_0 + \alpha_1 \left(Treated_p \times Post_t \right) + \gamma \boldsymbol{X}_{p,t,s} + \varepsilon_{p,t,s} \tag{2}$$

where subscripts p, t, and s are prefecture, year, and vehicle size (standard or heavy) and ln is the natural logarithm. This three-dimensional specification is estimated separately for new registrations of trucks, buses, and passenger cars. For the latter, we expect no observable effect as passenger cars were not subject to LEZ rules. The post period in this annual specification is 2003 onwards. $\boldsymbol{X}$ includes prefecture-level controls such as population, per capita income, and the unemployment rate. Prefecture, year, and vehicle-size fixed effects are also included.

Our analysis of the effect of LEZs on birthweights uses a dataset of all births (*j*). We estimate the equation:

$$Birthweight_j = \alpha_0 + \alpha_1 \left(Treated_m \times Post_d \right) + \boldsymbol{\gamma X}_{j,m,d} + \varepsilon_j \tag{3}$$

where the dependent variable is either the log birthweight or a binary variable taking the value one for a birthweight below either 2,500 g or 1,500 g. *m* is municipality of birth and *d* is day of birth. The post-period in this analysis is July 2004 onwards. We lag the treatment variable by 9 months from the actual date of LEZ implementation to align with the approximate conception date for births. ***X*** includes the gestation period in weeks, gender, type of birth (single or multiple), the birth order, the ages of the mother and father, the nationalities of the mother and father, the household head's job, municipality fixed effects, and month fixed effects.

Birthweights are a function of both fetal growth per gestational age and gestation duration (Glinianaia et al. 2004). Gestation duration could be an outcome variable (Currie and Walker 2011). The motivation for instead controlling for this variable is that there has been an overall increase in the prevalence of cesarean sections in Japan and a decrease in gestation durations and birthweights (Kato et al. 2021). Specifically, the cesarean section rate rose from 17.4% in 1999 to 23.3% in 2008, with different growth rates by prefecture (Kawamura and Ogura 2013; Maeda et al. 2018; Yuda 2018). The data in Table 4 suggest divergent trends for the gestation period between the treatment and control groups, which may be for reasons unrelated to the LEZs themselves. This would be important to control for. Analysis of birthweights adjusted for gestation duration is common in epidemiological research, with examples including the studies of Morello-Frosch et al. (2010) and Pedersen et al. (2013).

α_1 in Eq. (3) can be interpreted as the treatment effect on birthweight per gestational age. Our approach aims to reduce omitted variable bias, but also means that the total effect of LEZs on birthweights (effect on birthweight per gestational age plus effect via influence on gestation duration) cannot be estimated. Our estimates should be regarded as a potentially lower bound of the policy effect.

To account for potential serial correlation, standard errors are clustered at the municipality level in the air quality and birthweight analyses. In the new vehicle registration regressions, clustering is at the prefecture level as this is the smallest geographical unit in this analysis (Bertrand et al. 2004).

We also estimate additional specifications to examine how treatment effects differ among prefectures and have evolved over time. For the pollution analysis, we estimate:

$$PM_{i,t} = \alpha_0 + \sum\nolimits_{p=Tokyo}^{Chiba} \alpha_1^p \left(Treated_i^p \times Post_t \right) + \boldsymbol{\gamma X}_{i,t} + \varepsilon_{i,t} \tag{4}$$

$$PM_{i,t} = \alpha_0 + \sum\nolimits_{year=-3}^{+4} \alpha_1^{year} \left(Treated_i \times Post_t^{year} \right) + \boldsymbol{\gamma X}_{i,t} + \varepsilon_{i,t} \tag{5}$$

Superscript *p* in Eq. (4) stands for the four prefectures that implemented LEZs in our sample: Tokyo, Saitama, Kanagawa, and Chiba. The other elements are identical to Eq. (1). α_1^p captures the pollution-reducing effects of the LEZs by prefecture.

Superscript *year* in Eq. (5) stands for years relative to LEZ implementation. For example year = –1 means one year prior to the intervention (October 2002–September 2003), year = 0 means the contemporaneous year of the intervention (October 2003–September 2004), and year = + 1 means one year after the intervention (October 2004–September 2005). Following the common practice in the event study literature (Schmidheiny and Siegloch 2023), we set the period one year before the treatment (year = –1) as the reference (i.e., October 2002–September 2003). α_1^{year} indicates the extent to which outcomes in treated areas differ from those of the control group relative to one year prior to the intervention. In analyzing effects on new vehicle registrations, the reference period is the year 2002. In analyzing effects on birthweights, the reference period is July 2003–June 2004.

5.2 Effects of the LEZs on Air Pollution

Table 3 reports the estimation results for Eq. (1) using a monitor-hour panel dataset. Column 1 finds an estimate for *Treated*×*Post* of –4.5, significantly different from zero at the 1% level. However this reduces to –2.3 in column 2 after controlling for monitor fixed effects, month fixed effects, and time-varying control variables, with a 95% confidence interval ranging from –3.4 to –1.2. This suggests that the interventions on average led to a reduction in hourly ambient PM_{10} concentrations of about 2.3 μg/m^3 during the post-intervention period for air pollution monitors inside the Greater Tokyo LEZ relative to other air pollution monitors. Given that the mean pre-intervention PM_{10} level for the LEZ monitors was 35.1 μg/m^3, the pollution-reducing effect of the LEZs is equivalent to about a 7% reduction on average over the post-treatment period. About 31% (≈(–2.3/–7.4)×100) of the reduced PM_{10} concentration during October 2003–September 2008 inside the LEZ in Greater Tokyo was thus attributable to the intervention.

Figure 2 presents estimation results for Eq. (4). We see that larger pollution-reducing effects were observed in Tokyo and Saitama, where hourly PM_{10} concentration was reduced by averages of 3.7 μg/m^3 (10%) and 3.8 μg/m^3 (10%) as a result of their LEZs. The smallest is found for Kanagawa, for which it is estimated that the LEZs led to an average reduction in hourly PM_{10} of only 0.6 μg/m^3 (2%), an estimate that is not statistically

Table 3 Estimated effect of the LEZs on air pollution

Dependent variable: Hourly ambient concentration of PM_{10}		
	(1)	(2)
Treated × Post	–4.461***	–2.314***
	(0.598)	(0.570)
R^2	0.008	0.177
Monitor fixed effects	No	Yes
Month fixed effects	No	Yes
Control variables	No	Yes
Monitors inside LEZs	209	
Monitors outside LEZs	190	
Observations	24,708,261	
Pre-LEZ mean	35.1	

This table shows the estimation results for Eq. (1), using an hourly panel dataset at the monitor level for 1 October 2000–30 September 2008. The control variables include hourly meteorological conditions (temperature, precipitation, wind speed, pressure, and humidity), hour-of-day fixed effects, and national holiday and weekend dummies. Standard errors are robust to heteroscedasticity and clustered at the municipality level. The pre-LEZ mean is for air pollution monitors located within LEZs

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively

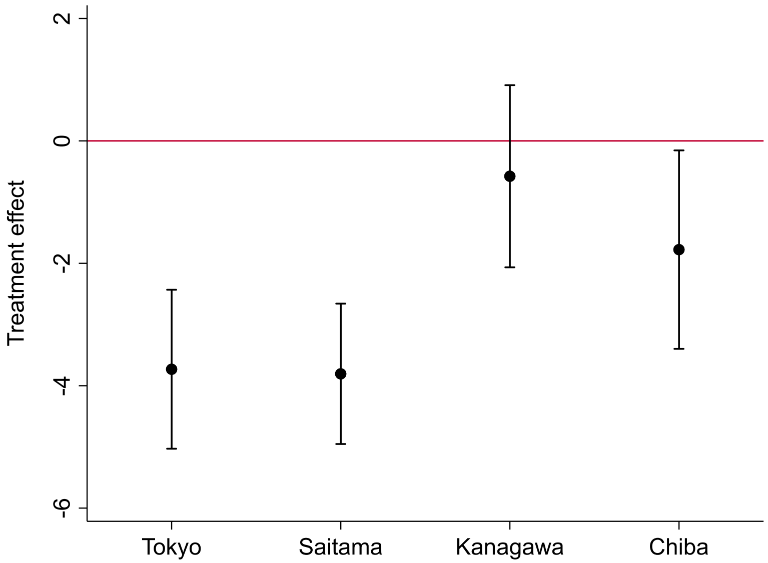


Fig. 2 Pollution-reducing effect by prefecture. Notes: The figure plots the result of estimating Eq. (4) for a monitor-hour panel dataset for 1 October 2000–30 September 2008. The circles show the point estimates and the bands represent the 95% confidence intervals. The unit of treatment effects is μg/m^3

distinguishable from zero. The pollution-reducing effect for Chiba is only a 1.8 μg/m^3 (5%) average reduction in the hourly PM_{10} level. The heterogeneous effects among LEZ prefectures are perhaps related to the fact that Tokyo and Saitama tightened their emission standards for LEZs in 2006, whereas Kanagawa and Chiba did not. It is also possible that the effects were larger in Tokyo and Saitama because the initial pollution levels were higher.

Figure 3 presents estimates of Eq. (5). We see that the time trends for the hourly average PM_{10} concentration were approximately parallel prior to the LEZs being implemented, with no significant evidence of pre-treatment effects. We see evidence of divergent trends of air pollution between the two groups during the post-intervention period. These event-study estimates suggest that the treatment effects were relatively constant over time, ranging between –2.1 and –3.3 μg/m^3 in point estimate terms.

Given the heterogeneous pollution-reducing effects presented in Fig. 2, it is interesting to investigate whether the temporal trends of treatment effects also differ among the LEZ prefectures. Figure 4 presents separate estimates of Eq. (5) by LEZ prefecture, holding the control group fixed. For example for Tokyo we estimate Eq. (5) excluding Saitama, Kanagawa, and Chiba from the sample. We see that the event-study estimates are negative and statistically significant over the post-intervention period for Tokyo and Saitama, and that the dynamics of the treatment effects are similar. The estimates are more mixed for Kanagawa and Chiba, with no clear evidence of a persistently strong effect.

5.3 Effects of the LEZs on New Vehicle Registrations

Table 4 reports estimates of Eq. (2) for a three-dimensional panel by prefecture, year, and vehicle size. Column 1 indicates that the LEZs boosted annual registrations of new diesel trucks by about 34% on average during 2003–2008 in the Greater Tokyo LEZ relative to

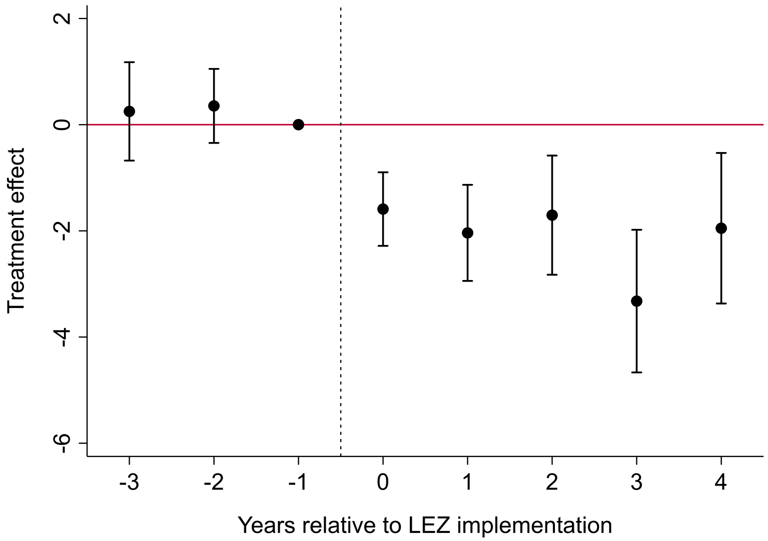


Fig. 3 Event study of air pollution. Notes: The figure plots the result for estimating Eq. (5) for a monitor-hour panel for 1 October 2000–30 September 2008. The circles show the point estimates and the vertical bands represent the 95% confidence intervals. The unit of treatment effects is μg/m^3

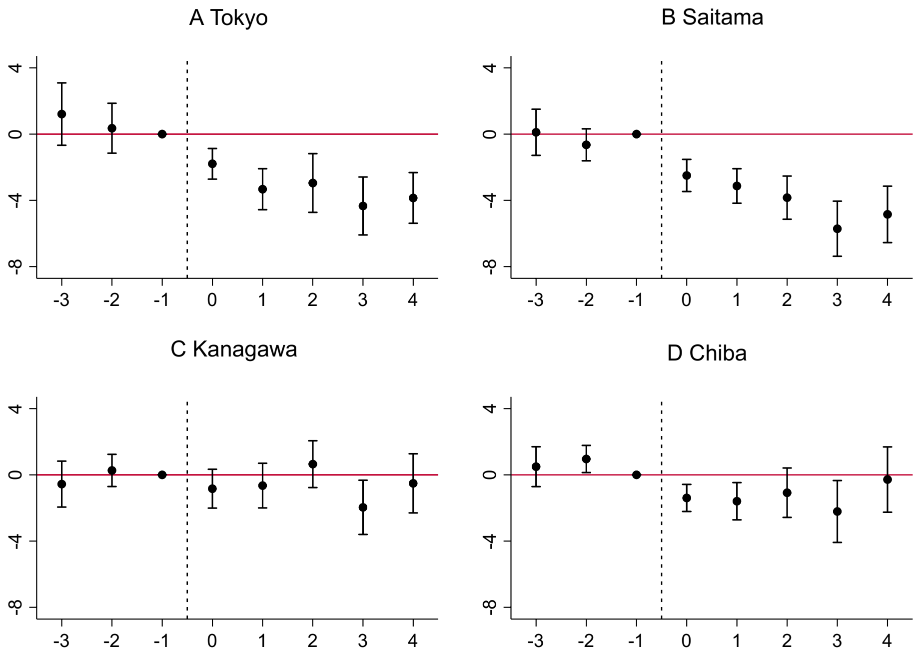


Fig. 4 Event study of air pollution by prefecture. Notes: The figures plot the result for estimating Eq. (5) for a monitor-hour panel for 1 October 2000–30 September 2008, excluding the other three LEZ prefectures, respectively. The vertical axis shows treatment effects in μg/m^3. The horizontal axis shows years relative to LEZ implementation. The circles show the point estimates and the vertical bands represent the 95% confidence intervals

Table 4 Estimated effects of LEZs on log new vehicle registrations

Dependent variables	Ln annual new vehicle registrations of:		
	Trucks	Buses	Passenger cars
	(1)	(2)	(3)
Treated × Post	0.296***	0.337***	0.011
	(0.089)	(0.088)	(0.011)
R^2	0.98	0.92	0.98
Prefecture fixed effects	Yes		
Year fixed effects	Yes		
Vehicle-size fixed effects	Yes		
Control variables	Yes		
Prefectures with LEZs	4		
Prefectures without LEZs	15		
Observations	380		
Pre-LEZ mean	14,550	357	109,641

This table shows the estimation results for Eq. (2). All specifications use a three-dimensional panel by prefecture, year, and vehicle size over 1999–2008. Control variables include population, per capita income, and the unemployment rate. Standard errors are robust to heteroscedasticity and clustered at the prefecture level. The pre-LEZ mean is for prefectures that implemented an LEZ

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively

the control prefectures.[6] Note that part of the estimated effect might emanate from government subsidies to support vehicle scrappage and retrofitting for small-and-medium enterprises. Given that the mean annual new registrations of diesel trucks in the LEZ prefectures over 1999–2002 was 14,550 per prefecture, the effects of the LEZs on new vehicle registrations amounted to about 4,950 new vehicles per prefecture per annum on average. We also find that the LEZs increased annual registrations of new diesel buses by about 40% (143 vehicles) (Column 2). The reason some truck and bus owners purchased a new vehicle rather than installing a filter is likely to be that diesel particulate filters were not installable for some old vehicles due to technical limitations.

Column 3 of Table 4 finds an effect of the LEZs on passenger car registrations that is small and statistically indistinguishable from zero. This is as expected given that cars were not targeted by the policy. The finding reduces concerns over the effects of potentially confounding trends.

Careful attention should be paid to interpreting the results in Table 4. The total number of targeted diesel trucks first registered before 1997 in the Greater Tokyo LEZ reduced from 796,000 to 217,000 over 2003–2008. Our estimates suggest that the total sum of new (and compliant) trucks as a result of the policy over 2003–2008 in the LEZ in Greater Tokyo was about 119,000 (4,950 × 6 years × 4 prefectures). This accounts for about 21% of this reduction (and does not include routine purchases that would have likely occurred at a similar rate in both the treatment and control groups). The operators of the 217,000 remaining targeted trucks likely responded by installing diesel particulate filters. Ishii

[6] The formula $100 * \left[\exp(\text{coefficient}) - 1\right]$ is applied to log-linear coefficients.

and Tsukigawa (2004) reported that around 52,000 targeted vehicles in Tokyo had indeed installed a diesel particulate filter by December 2003. Data on filter installations are not available for Saitama, Kanagawa, and Chiba.

Similarly, the total number of targeted diesel buses in the Greater Tokyo LEZ reduced from 26,000 to 7,000 over 2003–2008. Our estimates suggest that the number of new buses registered as a result of the policy was about 3,432. Routine stock turnover would also have occurred. The remaining 7,000 buses likely installed a diesel particulate filter in response to the regulations.

Figure 5 presents estimates of effects on new vehicle registrations by prefecture. We see that the positive effects of LEZs on new registrations of regulated vehicles (trucks and buses) relative to the control group are similar among LEZ prefectures (Panels A and B). Panel C indicates that effects on new registrations of passenger cars are close to zero for all LEZ prefectures, as expected.

Figure 6 presents estimates of effects on new vehicle registrations by year. Panels A–B indicate that most of the additional registrations of new trucks and buses as a response to the policy occurred during the initial post-intervention period. This is consistent with large initial adaptation efforts. In addition, a smaller surge in average treatment effects emerged three years after the intervention, perhaps reflecting the fact that Tokyo and Saitama tightened their emission standards for LEZs in 2006. The event-study coefficients for trucks turn negative in later years, implying a compensating period of demand deficit after excess demand generated by LEZ policies. No observable treatment effects occurred for passenger cars (Panel C).

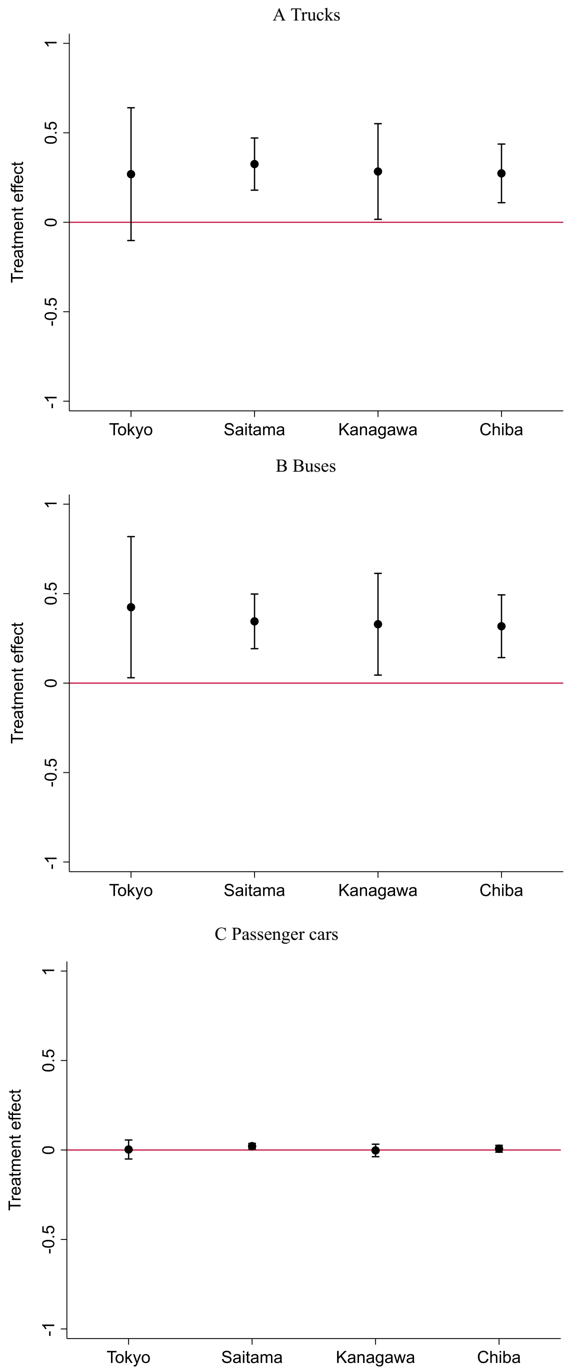
The estimates, together with the ratio of standard to heavy trucks (48:52) and the average unsubsidized prices of standard and heavy trucks (US$45,500, US$120,000 in year-2023 dollars) from the Japan Trucking Association (2007), can be used to calculate that the aggregate cost of new purchases of diesel trucks was approximately US$10 billion in year-2023 dollars relative to the counterfactual without the intervention. Likewise, the baseline estimate above, together with the ratio of standard to heavy buses (27:73) and the average unsubsidized prices of standard and heavy buses (US$181,000, US$391,000 in year-2023 dollars) from the Ministry of Land, Infrastructure, Transport and Tourism (2017), suggest that the aggregate cost of new purchases of diesel buses was about US$1.2 billion relative to the counterfactual without the intervention. Thus, additional new vehicle purchase costs were in the order of US$11.2 billion in year-2023 dollars. Note that the estimated cost associated with new vehicle purchases may be overestimated given that our post-treatment window (6 years) is not likely to be long enough to fully cover a compensating period of demand deficit after excess demand caused by LEZ policies. It should be regarded as an upper bound.

The above suggests that the total number of filters installed due to the policy in Greater Tokyo's LEZ was about 224,000. The average price for a diesel particulate filter was US$2,400 in year-2023 dollars, suggesting filter installation costs of about US$0.5 billion in year-2023 dollars. Total compliance costs associated with vehicle replacements and filter installations are thus calculated to be around US$11.7 billion in year-2023 dollars.

5.4 Effects of the LEZs on Birthweights

Table 5 reports estimates of Eq. (3) for birthweight variables. All specifications analyze a sample of 1,744,664 observations and include municipality fixed effects, month fixed effects, and control variables. Columns 1–2 present specifications using dummy variables that take the value one for birthweights below either 2,500 g or 1,500 g. The results suggest that the LEZs reduced the probability of birthweights below 2,500 g or 1,500 g by 0.27 and 0.1 percentage points

Fig. 5 Effects on log new vehicle registrations by prefecture. Notes: The figure plots results by prefecture for a three-dimensional panel by prefecture, year, and vehicle size over 1999–2008. The circles show the point estimates and the vertical bands represent the 95% confidence intervals



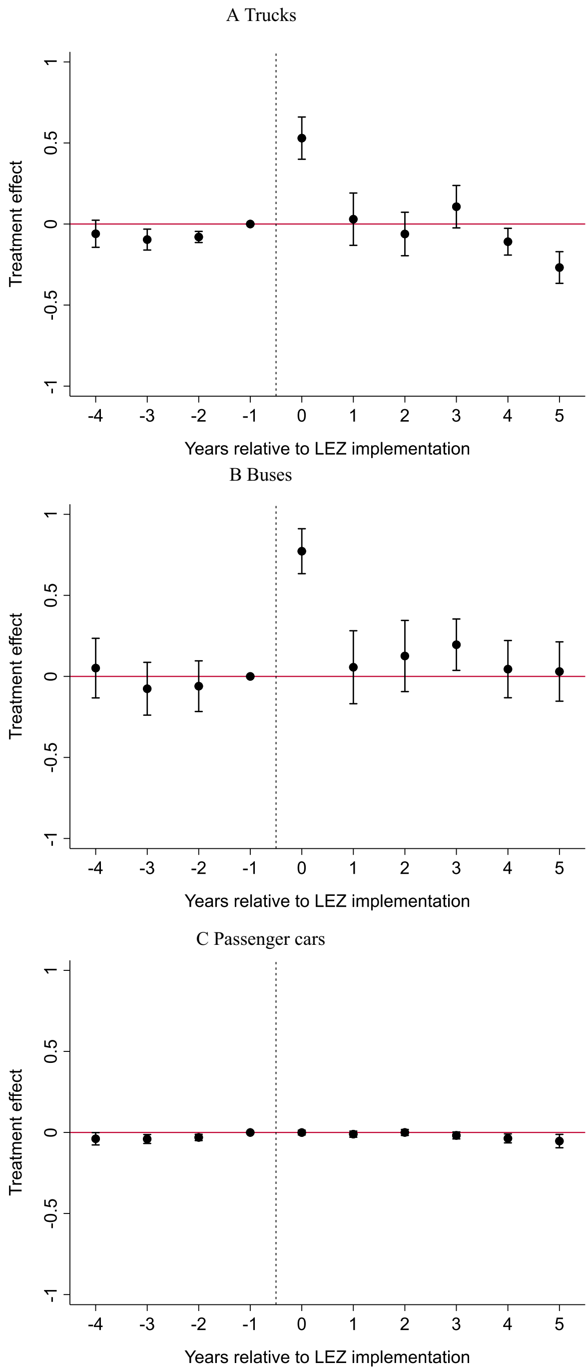


Fig. 6 Event study of log new vehicle registrations. Notes: The figure plots the result for estimating effects by year using a three-dimensional panel by prefecture, year, and vehicle size over 1999–2008. The circles show the point estimates and the bands represent the 95% confidence intervals

Table 5 Estimated effects of LEZ on birthweight outcomes

Dependent variables:	Dummy if birthweight is below:		Ln birthweight
	2,500 g	1,500 g	
	(1)	(2)	(3)
Treated × Post	–0.0027***	–0.0010***	0.0020***
	(0.0008)	(0.0003)	(0.0005)
R^2	0.28	0.25	0.49
Municipality fixed effects	Yes		
Month fixed effects	Yes		
Control variables	Yes		
Births inside LEZs	957,549		
Births outside LEZs	787,115		
Observations	1,744,664		
Pre-LEZ mean	0.088	0.007	3,026

The table shows the results for estimating Eq. (3). All specifications use birth data over 1 July 2000–30 June 2008. Control variables include the gestation period, gender, type of birth (single or multiple), birth order, ages of mother and father, nationalities of mother and father, and household head's job. Standard errors are robust to heteroscedasticity and clustered at the municipality level. The pre-LEZ mean is for births inside LEZs

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively

respectively, conditioning on the gestation period and the other controls. Taking the difference between the actual numbers of newborn babies with a birthweight below 2,500 g or 1,500 g in the treatment group and the counterfactual for each year after the policy during July 2004–June 2008 suggests that of the 471,275 births in the Greater Tokyo LEZ over July 2004–June 2008, about 1,272 births below 2,500 g and about 471 births below 1,500 g switched to being above these birthweight thresholds in the treatment group as a result of the intervention.

Column 3 of Table 5 presents a specification for the log birthweight, finding an estimate for Treated × Post of 0.002, which is significantly different from zero at the 1% level. This suggests that the implementation of the LEZs led to about a 0.2% increase in birthweights on average over the post-intervention period for the newborn babies inside the Greater Tokyo LEZ relative to outside the LEZs, conditioning on the gestation period and the other controls. Given that the mean pre-treatment birthweight inside the Greater Tokyo LEZ was 3,026 g, the LEZs thus increased birthweights by about 6 g on average relative to the control group, all else equal.

The results contrast with those of Gehrsitz (2017), Pestel and Wozny (2021), and Kang et al. (2024), who found no significant evidence of effects of LEZs on birthweights in Germany and Japan. There are at least a couple of potential reasons for this. First, they analyzed the overall effect without controlling for gestational age to take into account potentially differential trends in the rate of cesarean section deliveries due to reasons other than the LEZs.[7] Second, the treatment group used by Gehrsitz (2017) and Pestel and Wozny

[7] The number of cesarean sections per 1,000 live births in Germany increased from 263 to 309 during his sample period of 2005–2012 (Organization for Economic Co-operation and Development 2022).

(2021) included births outside LEZs but within the same city, which could potentially lead to underestimation of the within-LEZ health effect given that drivers of non-compliant vehicles might increase their driving outside LEZs but within the same city.

Figure 7 presents estimation results for birth outcomes by prefecture. The estimates indicate that Tokyo experienced a reduction in the probability of birthweights below 2,500 g or 1,500 g by 0.21 and 0.1 percentage points respectively, and about a 0.2% increase in birthweights. Similar evidence is found for Saitama. Interestingly, there is also evidence of some effects in Kanagawa and Chiba, although there is no significant effect on the probability of birthweights below 1,500 g for Kanagawa (Panel B).

Figure 8 presents estimation results for birthweight effects by year, showing consistent evidence across outcome variables. We see that the time trends of birth outcomes are generally similar between treatment and control groups during the pre-intervention period. We also see evidence of divergent trends of birth outcomes between the two groups during the post-intervention period. For example, Panel C suggests that the treatment effects on birthweight evolve, ranging from 0.14 to 0.26% during July 2004–June 2008.

Figure 9 shows separate event-study estimates for log birthweight by LEZ prefecture. Interestingly, the time patterns of the effects on birthweights mirror those for the effects on air pollution (Fig. 4). Positive and significant effects on birthweights are evident for Tokyo and Saitama, the prefectures that had the more stringent LEZ policies. Health effects are weaker and/or less consistent over time for Kanagawa and Chiba.

6 Robustness Analyses

6.1 Potentials for Spatial Spillovers

Spatial spillovers could bias our estimates. On the one hand, new low-emission vehicles that comply with LEZ standards are sometimes driven outside the LEZs, which would mean that our method could underestimate the effect of the LEZs. On the other, it is possible that truck and bus companies relocated their businesses outside the LEZs, which could mean that our method would overestimate the pollution-reducing effects of the policy. To gauge the extent and scope of potential spatial leakages to nearby areas, we estimate the following specification for a restricted sample of air pollution monitors outside the Greater Tokyo LEZ:

$$PM_{i,t} = \beta_0 + \beta_1\left(Neighbor_i \times Post_t\right) + \boldsymbol{\gamma}\boldsymbol{X}_{i,t} + \varepsilon_{i,t} \tag{6}$$

where *Neighbor* is a dummy variable taking the value one if a non-LEZ monitor is located within 20 km from a boundary of the giant Greater Tokyo LEZ and zero for the remaining non-LEZ monitors. To examine the potential for more widespread spillovers, we also examine using a buffer of 50 km from a boundary of the Greater Tokyo LEZ. Furthermore, we estimate a specification that controls for the geographical distance from Chiyoda ward in Tokyo, chosen based on the centroid of the Greater Tokyo LEZ. The other elements are identical to Eq. (1). The coefficient β_1 captures the net spillover effect.

Table 6 reports the results. Column 1 suggests that the non-LEZ monitors within a radius of 20 km of the Greater Tokyo experienced an increase in PM_{10} levels after the intervention of about 0.5 μ g/m^3 relative to the remaining non-LEZ monitors. However the estimate is statistically indistinguishable from zero. Column 2 shows that the result is similar even when the scope of the neighbor dummy is expanded to a radius of 50 km. Column 3 implies that the magnitude of the reduction in PM_{10} levels after the intervention

Fig. 7 Effects on birthweights by prefecture. Notes: The figure plots the result for birthweight outcomes by prefecture using a birth dataset for 1 July 2000–30 June 2008. The circles show the point estimates and the bands represent the 95% confidence intervals. The effects are conditional on the controls including the gestational period

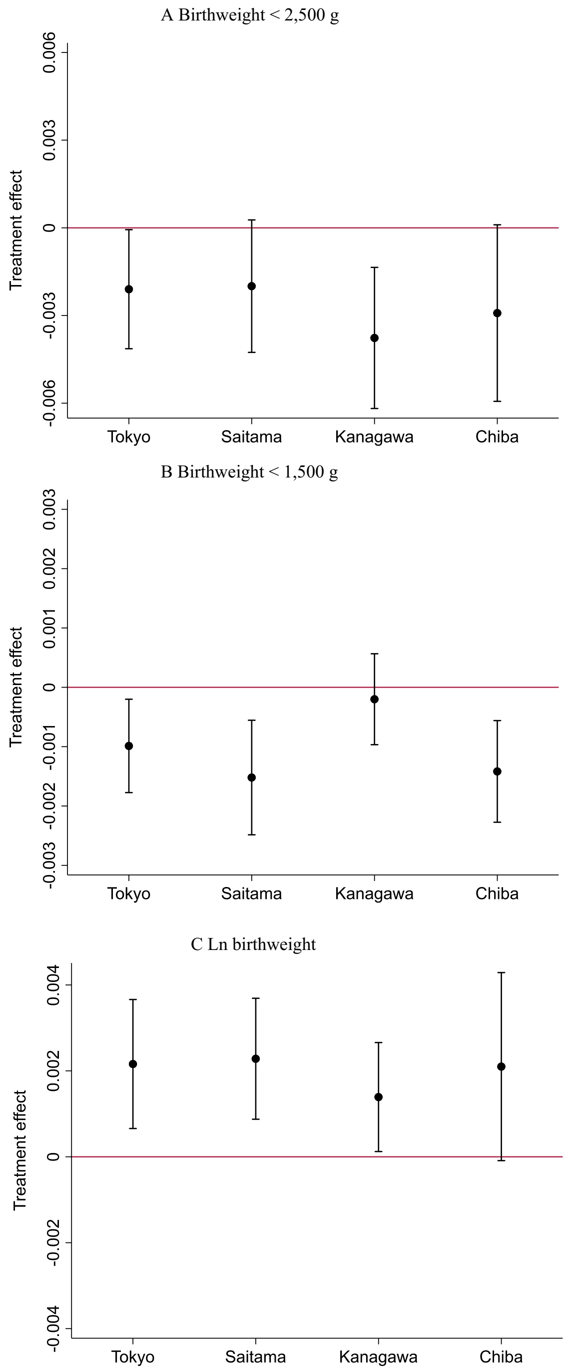
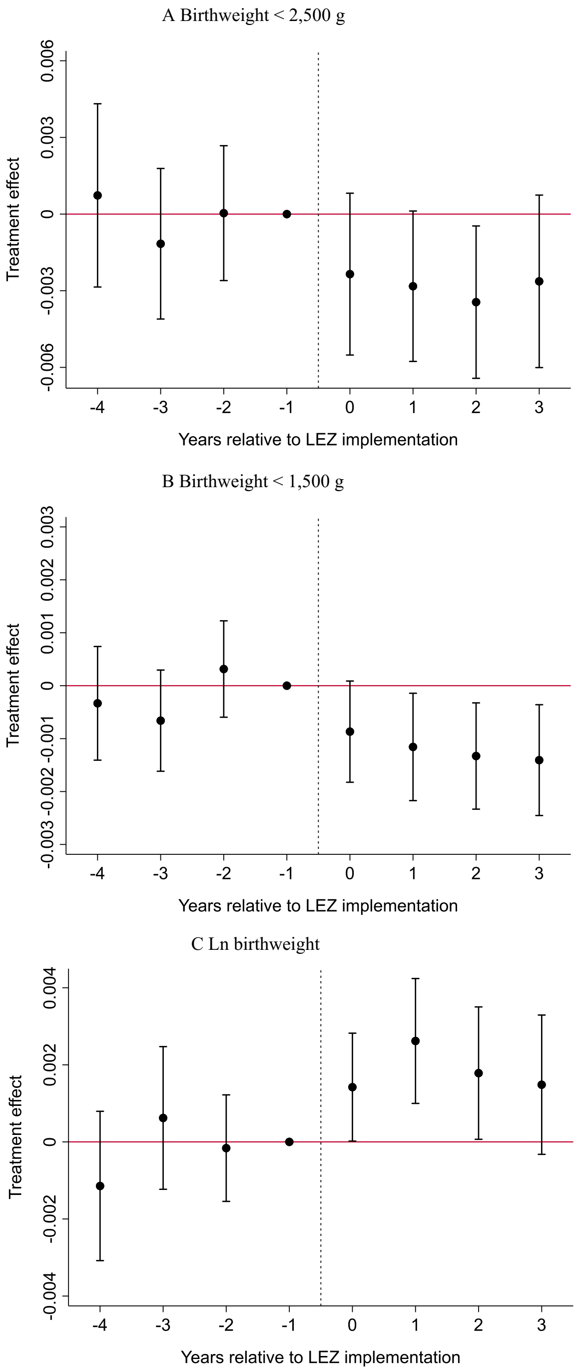


Fig. 8 Event study of birthweight outcomes. Notes: The figure plots the result for birthday outcomes using a birth dataset over 1 July 2000–30 June 2008. The circles show the point estimates and the bands represent the 95% confidence intervals. The effects are conditional on the controls including the gestational period



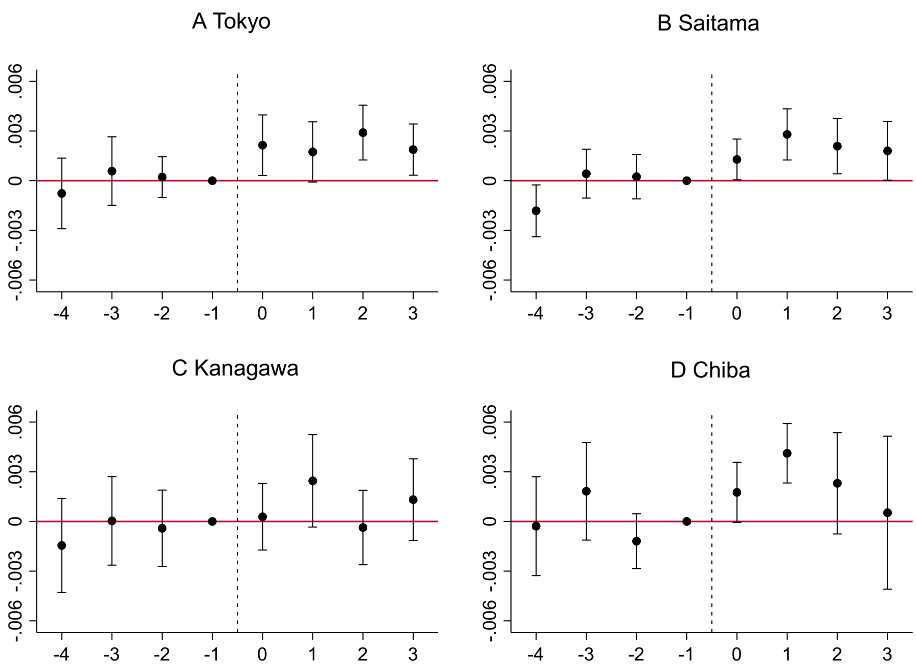


Fig. 9 Event study of log birthweight by prefecture. Notes: The figure plots the result for log birthweights using a birth dataset over 1 July 2000–30 June 2008. The circles show the point estimates and the bands represent the 95% confidence intervals. The vertical axis shows treatment effects. The horizontal axis shows years relative to LEZ implementation

is disproportional to the geographical distance from the Greater Tokyo LEZ. Again, the estimate is not statistically significant. These results reassure us that our baseline estimates are not suffering from a violation of the stable unit treatment value assumption.

6.2 Potential for Sorting

The validity of our DD research design for the analysis of birthweights relies on the assumption that parents did not move to the LEZ in Greater Tokyo to seek better birth outcomes. To examine this, we estimate the following specification for parental characteristics (*Parent_Char*):

$$Parent\_Char_j = \varphi_0 + \varphi_1 \left(Treated_m \times Post_d \right) + \delta_m + \rho_d + \varepsilon_j \tag{7}$$

where δ_m and ρ_d are municipality fixed effects and month fixed effects, respectively. Parental characteristics include the ages of the mother and father, nationalities of the mother and father, and the household head's job. We run a separate regression based on Eq. (7) for each characteristic. Table 7 reports the results. We find no evidence of compositional changes for most of the observable parental characteristics after the implementation of LEZs.[8] Although some coefficients on parents' nationality dummies are statistically significant, their magnitudes are negligibly small. This alleviates concerns over estimation bias due to residential sorting.

[8] The results are consistent when the 9-month lagged treatment variable is applied.

Table 6 Examination of spillover effects

Dependent variable: Hourly ambient concentration of PM_{10}			
	(1)	(2)	(3)
Neighbor × Post	0.486	0.419	
	(1.022)	(1.103)	
Ln distance × Post			0.032
			(0.337)
R^2	0.20	0.20	0.18
Observations	11,113,117		

The table shows estimation results for Eq. (6) using different measures of proximity to the giant LEZ in Greater Tokyo for a sample of air pollution monitors outside LEZs. All specifications use hourly panel data at the monitor level for 1 October 2000–30 September 2008 and control for hourly meteorological conditions, monitor fixed effects, month fixed effects, hour-of-day fixed effects, and national holiday and weekend dummies. Column 1 uses a dummy variable for if a non-LEZ monitor is located within 20 km from an LEZ boundary. Column 2 uses a dummy variable for if a non-LEZ monitor is located within 50 km from a boundary of the LEZ in Greater Tokyo. Column 3 uses the geographical distance from the center of the LEZ in Greater Tokyo in the interaction term. Standard errors are robust to heteroscedasticity and clustered at the municipality level

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively

6.3 Alternative Specifications and Samples

Table 8 reports results for alternative specifications for both the air pollution and birthweight analyses. Column 1 repeats our baseline estimates. Column 2 incorporates anticipation effects. There were lags between the enactments and implementations of the LEZs: 33 months for Tokyo, 19 months for Chiba, 18 months for Saitama, and 12 months for Kanagawa. Owners of non-compliant vehicles may have responded in advance of implementation by either switching to a complaint vehicle or installing a diesel particulate filter. If such anticipatory actions are not taken into account, our DD estimates could be biased upward.

Following Malani and Reif (2015), we construct a finite dummy variable to capture anticipation effects during the 12 months before the LEZs were implemented, $\sum_{j=1}^{12} \delta_k D_{p,t-k}$. k is a monthly leading indicator, p is prefecture, and t is the implementation date of the LEZ. In the case where $k=1$, for example, the dummy variable takes the value 1 if the month of the year is September 2003. Twelve months was chosen because (i) owners of non-compliant vehicles had little incentive to replace their polluting cars during the early period of the ordinance, and (ii) the Tokyo government undertook a "Diesel Vehicle Cleanup Project" to prepare for the implementation of its LEZ during the year prior to implementation.

Column 3 of Table 8 shows the results with day fixed effects (i.e., day-by-month-by-year fixed effects) instead of month fixed effects to account for additional unobservable factors at the daily frequency. Column 4 displays results with standard errors clustered at the prefecture rather than the municipality level. Our concern is that model errors for air pollution

Table 7 Estimated effects of LEZ on parental characteristics

	Coefficient	Standard error	R^2
Ln father's age	0.0010	(0.0008)	0.0171
Ln mother's age	0.0006	(0.0008)	0.0223
Father's nationality dummies			
Japan	–0.0011	(0.0007)	0.0094
South Korea	0.0007***	(0.0002)	0.0040
China	0.0004	(0.0004)	0.0056
Philippines	0.0001	(0.0001)	0.0008
Thailand	0.0001***	(0.0000)	0.0003
United States	0.0003	(0.0002)	0.0125
United Kingdom	0.0000	(0.0001)	0.0007
Brazil	–0.0005*	(0.0003)	0.0134
Peru	0.0000	(0.0001)	0.0040
Others	–0.0000	(0.0004)	0.0025
Mother's nationality dummies			
Japan	–0.0006	(0.0008)	0.0096
South Korea	0.0005*	(0.0003)	0.0036
China	0.0010*	(0.0006)	0.0062
Philippines	–0.0006	(0.0004)	0.0033
Thailand	–0.0000	(0.0001)	0.0012
United States	0.0001*	(0.0001)	0.0011
United Kingdom	–0.0000	(0.0000)	0.0004
Brazil	–0.0006**	(0.0003)	0.0127
Peru	0.0000	(0.0001)	0.0043
Others	0.0003	(0.0005)	0.0030
Household head's job dummies			
Farmer	–0.0001	(0.0005)	0.0158
Self-employed	–0.0012	(0.0014)	0.0045
Employed	0.0008	(0.0033)	0.0115
Others	–0.0011	(0.0023)	0.0044
Unemployed	–0.0008*	(0.0005)	0.0018

The table shows the results for estimating Eq. (7) for each parental characteristic, separately. All estimations are based on birth data for 1 July 2000–30 June 2008. Observations = 1,744,664. Municipality fixed effects and month fixed effects are controlled for. Standard errors are robust to heteroscedasticity and clustered at the municipality level

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively

and birthweight in the same prefecture might be correlated due to common shocks such as prefectural government policies, resulting in misleadingly smaller standard errors.

Another issue is that other vehicular control policies may have also affected pollution levels. One concern is the potential impact of the expansion of the ANPC to some municipalities in Aichi and Mie and additional municipalities in Saitama in June 2001. In our sample, there are two and 30 ANPC municipalities in the treatment and control groups, respectively. Our DD estimates could be biased upward if the pollution-reducing effects of the ANPC are not considered. Column 5 of Table 8 shows results controlling

Table 8 Alternative specifications and samples

	Baseline estimates	Anticipation effects	Day fixed effects	Clustering at the prefecture level	ANPL effects	With replacement	Kernel matching
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. Dependent variable: Hourly ambient concentration of PM_{10}							
Treated × Post	–2.314***	–2.432***	–2.070***	–2.314**	–2.503***	–2.005***	–3.260***
	(0.570)	(0.642)	(0.571)	(1.087)	(0.554)	(0.576)	(0.361)
R^2	0.18	0.18	0.40	0.18	0.18	0.18	0.17
Observations	24,708,261					30,658,355	59,976,011
B. Dependent variable: Dummy if birthweight is below 2,500 g							
Treated × Post	–0.0027***	–0.0026***	–0.0027***	–0.0027***	–0.0027***	–0.0032***	–0.0027***
	(0.0008)	(0.0009)	(0.0008)	(0.0009)	(0.0009)	(0.0009)	(0.0008)
R^2	0.28	0.28	0.28	0.28	0.28	0.27	0.27
Observations	1,744,664					1,808,091	1,968,563
C. Dependent variable: Dummy if birthweight is below 1,500 g							
Treated × Post	–0.0010***	–0.0009***	–0.0010***	–0.0010***	–0.0010***	–0.0008***	–0.0009***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
R^2	0.25	0.25	0.25	0.25	0.25	0.24	0.24
Observations	1,744,664					1,808,091	1,968,563
D. Dependent variable: Ln birthweight							
Treated × Post	0.0020***	0.0020***	0.0020***	0.0020***	0.0019***	0.0022***	0.0019***
	(0.0005)	(0.0006)	(0.0005)	(0.0005)	(0.0005)	(0.0006)	(0.0006)
R^2	0.49	0.49	0.49	0.49	0.49	0.48	0.48
Observations	1,744,664					1,808,091	1,968,563

Column 1 re-presents our baseline estimates from Tables 3 and 5. Columns 2–5 show the estimation results for Eqs. (1) and (3) with alternative specifications. Columns 6 and 7 show the estimation results for Eqs. (1) and (3) with alternative samples. Standard errors are robust to heteroscedasticity and clustered at the municipality level for all columns except for Column 4 where standard errors are clustered at the prefecture level

***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively for the interaction term of a dummy for the affected municipalities with a dummy for June 2001 onwards.

Columns 6–7 of Table 8 show the results for the alternative samples using nearest-neighbor matching within a caliper width equal to 0.2 with replacement and kernel matching. In kernel matching, each treated municipality is matched with a weighted average of all control municipalities, with the weights inversely proportional to the distance between the propensity scores of the treated and control groups. We use the Epanechnikov kernel function with a bandwidth parameter of 0.06. A common support condition is imposed in both methods.[9]

Overall, the baseline estimates are robust to alternative specifications and samples. Contrary to expectations, columns 2 and 5 of Table 8 suggest that the PM_{10} point estimates become larger when anticipation effects and ANPL effects are controlled for.

7 Conclusion

In October 2003 four contiguous prefectures in Greater Tokyo introduced Low Emission Zones (LEZs) from which diesel trucks and buses without particulate filters have been banned from entering. This paper has analyzed the effects of this large-scale intervention on air quality, new vehicle registrations, and birthweights. We used a matching approach to construct a control group comparable to the designated areas in terms of propensity scores based on municipality characteristics during the pre-intervention period and applied a difference-in-differences design.

This paper has provided the first evidence of a significant link between LEZs and reduced incidence of low birthweights. The results suggest that in the absence of the LEZs, about 1,272 additional babies would have been born below 2,500 g in the Greater Tokyo LEZ over July 2004–June 2008. Japan's experience of introducing a supersized LEZ through cooperation among neighboring geographical areas serves as a relevant example of an approach of potential use elsewhere.

This paper has also found robust evidence of treatment effects on air pollution and birthweights for Tokyo and Saitama, in which emission standards for the LEZ were tightened over time. Smaller and less robust effects were found for the other prefectures in the giant LEZ, Kanagawa and Chiba. The findings highlight that tightening emission standards can be a powerful approach to enhance the benefits from LEZ policies.

The implementation of LEZs is costly. Our study found that in the case of Japan the compliance costs of new vehicle purchases and installing diesel particulate filters amounted to around US$12 billion in year-2023 dollars. We have also identified benefits in terms of birthweights from the intervention. While it is known that higher birthweights are linked to long-run health and other benefits, it is challenging to quantify these long-run effects. The LEZs may also have had other effects on health outcomes for children, adults, and the elderly and on non-health outcomes that are not explored here.

[9] Appendices 3 and 4 report the means of pre-treatment variables and the distribution of propensity scores.

Appendix 1

Table 9 Previous research on low emission zones

Authors	Locations	Targeted vehicles	Effects	Data	Methods	Selection of control groups
Wolff (2014)	German cities	All vehicles (except emergency and other work-related vehicles)	PM concentration fell by 9%	Daily panel at the monitor level for 2005–2008	DD	Similar pre-pollution levels
			Share of clean vehicles increased more in cities with LEZ or near LEZ	Cross-section at the county level for 2010	OLS	
Gehrsitz (2017)	German cities	All vehicles	PM concentration fell by 8%	Daily panel at the monitor level for 2005–2012	DD	Non-LEZ cities but introduced LEZ during the sample period
			Stillbirth reduced by 16%, but no effect is found for birthweights	Daily pooled cross section at the birth level for 2005–2012		
Rohlf et al. (2020)	German cities	All vehicles	PM concentration fell by 6%	Quarterly panel at the county level for 2006–2013	DD	Similar pre-trends
			Pharmaceutical expenditure for asthma and heart diseases by 3–4%			
Klauber et al. (2021)	German cities	All vehicles	PM concentrations fell by 5%	Quarterly panel at the county level for 2006–2012	DD	Similar pre-trends
			A LEZ-caused decrease in PM concentration reduced the number of medical prescriptions and the costs of prescriptions for children		IV	

Table 9 (continued)

Authors	Locations	Targeted vehicles	Effects	Data	Methods	Selection of control groups
Margaryan (2021)	German cities	All vehicles	PM concentration fell by 3%	Monthly panel at the monitor level for 2004–2016	DD	Similar pre-trends
			Share of high emission vehicles in car fleet fell by 0.3 percentage points	Yearly panel at the city level for 2007–2016		
			Number of patients with cardiovascular disease decreased by 3% with the larger effects for the elder	Yearly panel at the area level for 2004–2017		
Pestel and Wozny (2021)	German cities	All vehicles	PM and NO_2 concentrations fell by 6%	Yearly panel at the monitor level for 2006–2016	DD	Similar pre-trends
			Hospital's share of diagnosed ischemic heart diseases and chronic lower respiratory diseases decreased by 0.2–0.5 percentage points	Yearly panel at the hospital level for 2006–2016		
			No effect is found for low birthweights			
Zhai and Wolff (2021)	Greater London	Light/heavy goods vehicles, trucks, and buses	PM concentration increased during the initial phase by 15% and fell by 6% during the later phase	Daily panel at the monitor level for 2005–2010	DD	Over 180 miles away from London

Table 9 (continued)

Authors	Locations	Targeted vehicles	Effects	Data	Methods	Selection of control groups
Kang et al (2024)	Greater Tokyo	Diesel trucks and buses	PM concentration fell by 0.061 μg/m^3	Yearly panel at the monitor level for 1990–2010	CTE	-
			Land price increased by 0.16%	Yearly panel at the property level for 1990–2009		
			Infant deaths under 1 year of age reduced, but no effect is found for birth-weights	Yearly panel at the municipality level for 1990–2020		

DD, IV, and CTE stand for difference-in-difference design, instrumental variable approach and continuous treatment effect model, respectively

Appendix 2

Table 10 Previous research on other-traffic-related policy interventions

Authors	Interventions	Targeted vehicles	Effects	Data	Methods	Selection of control groups
Currie and Walker (2011)	E-Zpass in Pennsylvania and New Jersey	All vehicles	NO_2 concentration fell by 11%	Daily panel at the monitor level for 1994–2003	DD	Close to highway, but between 2 and 10 km of a toll plaza
			Incidences of prematurity and low birthweight decreased by 7–11%	Daily pooled cross section at the birth level for 1994–2003		
He et al. (2019)	Newly-built beltway in Sao Paulo	Heavy diesel trucks	Congestions near the original truck route fell	Hourly panel at the segment level for 2008–2013	DD	Far from the original truck route
			NO_2 concentration near the original truck route fell	Daily panel at the monitor level for 2008–2013		
			Cardiovascular and respiratory admission rates near the original truck route decreased	Monthly panel at the zip code area level for 2008–2013		
Simeonova et al. (2019)	Congestion Pricing Zone (CPZ) in Stockholm	All vehicles, but emergency vehicles, buses, hybrid or electric cars, and motorcycles	PM and NO_2 concentrations fell by 14–19%	Monthly panel at the municipality level for 2004–2010	DD	Similar pre-trends
			Acute asthma episodes per 10,000 children younger than 5 years old fell by 9.6	Monthly panel at the municipality level for 2004–2010		
Green et al. (2020)	CPZ in London	All vehicles, but motorcycles, bicycles, buses, and taxi	PM and CO concentrations fell by 8–20%	Hourly panel at the monitor level for 2000–2007	DD	Propensity scores calculated based on socioeconomic characteristics at the local authority level
			Total miles driven for cars/taxi, light/heavy goods vehicles fell, and those for bicycles, motor cycles and buses increased	Yearly panel at the county level for 2000–2007		

DD stands for difference-in-difference design

Appendix 3

Table 11 Matched samples

	A. No matching			B. Nearest-neighbor without replacement		
	Inside LEZ	Outside LEZ	Diff	Inside LEZ	Outside LEZ	Diff
PM_{10} concentration	37.70	32.41	5.29***	35.17	35.36	–0.19
Ln population density	3.62	2.55	1.07***	3.17	3.01	0.16
Share of population aged 65 years	0.15	0.18	–0.03***	0.15	0.15	0
Share of university graduates	0.16	0.11	0.05***	0.13	0.13	0
Unemployment rate	0.05	0.05	0	0.05	0.05	0
Share of service sectors	0.69	0.62	0.07***	0.65	0.64	0.01
Ln income per capita	8.31	8.17	0.14***	8.23	8.24	0
Vehicle registration per capita	0.37	0.41	–0.04***	0.40	0.41	0
Propensity score	0.57	0.24	0.33***	0.41	0.42	–0.01
Number of municipalities	158	281		86	86	
	C. Nearest-neighbor with replacement			D. Kernel matching		
	Inside LEZ	Outside LEZ	Diff	Inside LEZ	Outside LEZ	Diff
PM_{10} concentration	36.65	34.76	1.90*	36.65	32.41	4.24***
Ln population density	3.46	2.92	0.54***	3.46	2.55	0.90***
Share of population aged 65 years	0.15	0.16	–0.01*	0.15	0.18	–0.03***
Share of university graduates	0.15	0.12	0.02***	0.15	0.11	0.04***
Unemployment rate	0.05	0.05	0	0.05	0.05	0
Share of service sectors	0.68	0.64	0.04***	0.68	0.62	0.06***
Ln income per capita	8.28	8.23	0.04***	8.28	8.17	0.11***
Vehicle registration per capita	0.38	0.40	–0.02	0.38	0.41	–0.03***
Propensity score	0.54	0.40	0.14***	0.54	0.23	0.31***
Number of municipalities	136	66		136	281	

This table reports the results of balancing tests. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively. Averages across municipalities. PM_{10} concentration and the log income per capita are averaged for 2000–2002. The rest of variables are averaged for 2000 only. PM_{10} concentration is measured hourly. The rest of variables are measured yearly

Appendix 4

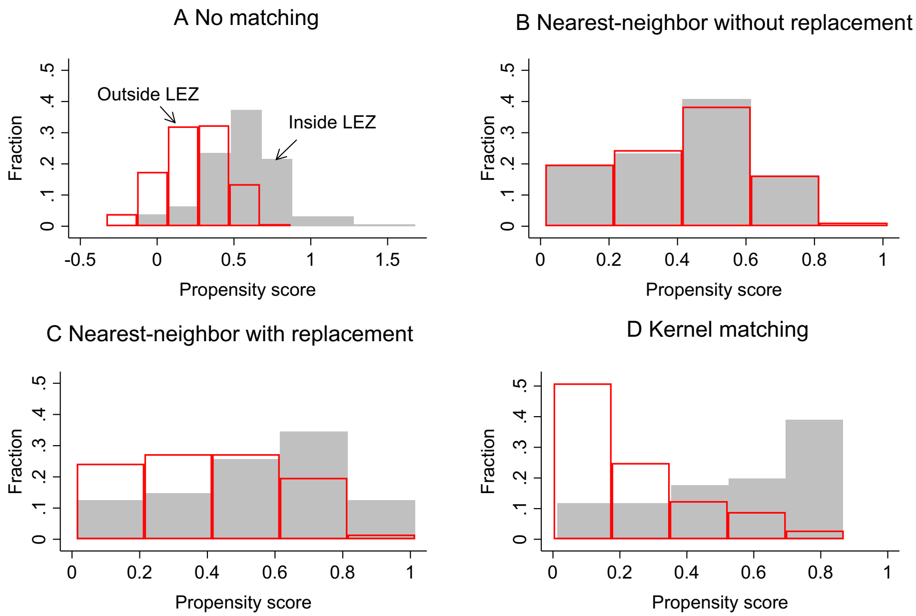


Fig. 10 Distribution of propensity score. Notes: The histogram shows the distribution of propensity score for outside and inside LEZs

Appendix 5

Table 12 Descriptive statistics for all variables

	Treatment group			Control group		
	Before	After	Diff	Before	After	Diff
A. Monitor-hour data						
PM_{10} concentration, μg/m^3	35.1	27.8	–7.4	34.1	29.1	–5
Temperature, degrees Celsius	15.4	15.7	0.3	16.2	16.4	0.2
Precipitation, millimeters	0.2	0.2	0	0.2	0.2	0
Wind speed, meters per second	3.3	3.2	–0.1	2.8	2.7	–0.1
Pressure, hectopascal	1,005	1,005	–0.3	1,007	1,007	–0.1
Humidity, %	68.9	67.4	–1.5	65.8	65.1	–0.8
B. Birth data						
Birthweight, grams	3,026	3,009	–17	3,021	3,003	–18
Dummy variable if birthweight is						
< 2,500 g	0.088	0.094	0.006	0.089	0.097	0.007
< 1,500 g	0.007	0.007	0	0.007	0.008	0.001
Gestation period, weeks	275.1	274.7	–0.5	275.0	274.7	–0.3
Single birth	0.98	0.98	0	0.98	0.98	0
Male	0.51	0.51	0	0.51	0.51	0
Birth order	1.7	1.7	0	1.7	1.7	0
Father's age	31.9	32.5	0.7	31.5	32.2	0.6
Mother's age	29.7	30.5	0.8	29.5	30.2	0.7
Father's nationality						
Japan	0.9787	0.9753	–0.0034	0.9813	0.9791	–0.0023
South Korea	0.0046	0.0043	–0.0003	0.0061	0.0049	–0.0012
China	0.0048	0.0064	0.0016	0.0031	0.0041	0.0011
Philippines	0.0006	0.0009	0.0003	0.0002	0.0005	0.0003
Thailand	0.0002	0.0002	0.0001	0.0001	0.0001	0
United States	0.0027	0.0031	0.0003	0.0007	0.0008	0.0001
United Kingdom	0.0004	0.0004	0.0001	0.0003	0.0003	0
Brazil	0.0014	0.0014	0	0.0035	0.0041	0.0006
Peru	0.0009	0.0010	0.0001	0.0007	0.0007	0.0001
Other	0.0059	0.0071	0.0013	0.0041	0.0054	0.0013
Mother's nationality						
Japan	0.9727	0.9756	0.0030	0.9786	0.9758	–0.0028
South Korea	0.0050	0.0034	–0.0016	0.0060	0.0048	–0.0012
China	0.0082	0.0086	0.0005	0.0043	0.0060	0.0016
Philippines	0.0073	0.0062	–0.0011	0.0037	0.0049	0.0012
Thailand	0.0011	0.0008	–0.0003	0.0004	0.0004	–0.0001
United States	0.0003	0.0003	0	0.0001	0.0002	0
United Kingdom	0.0001	0.0001	0	0.0001	0.0001	0
Brazil	0.0014	0.0010	–0.0004	0.0034	0.0037	0.0003
Peru	0.0009	0.0006	–0.0002	0.0007	0.0007	0

Table 12 (continued)

	Treatment group			Control group		
	Before	After	Diff	Before	After	Diff
Other	0.0032	0.0034	0.0003	0.0027	0.0036	0.0009
Household head's job						
Farmer	0.0056	0.0048	–0.0007	0.0053	0.0051	–0.0002
Self-employed	0.0767	0.0732	–0.0035	0.0799	0.0775	–0.0024
Employed	0.7834	0.7831	–0.0003	0.7857	0.7867	0.0010
Others	0.0902	0.0837	–0.0065	0.0861	0.0812	–0.0049
Unemployed	0.0130	0.0108	–0.0022	0.0155	0.0140	–0.0015
C. Prefecture-year data						
New registration of trucks	14,550	18,054	3,504	5,466	5,765	299
New registration of buses	357	536	179	125	145	20
New registration of passenger cars	109,641	101,351	–8,291	42,579	39,012	–3,567
Population, million	8.4	8.7	0.3	2.9	2.9	0
Per capita income, million yen	4.1	3.9	–0.2	3.5	3.3	–0.2
Unemployment rate, %	4.9	5.6	0.7	4.7	5.8	1.1

This table presents the sample averages during the pre- and post-intervention periods, and their differences, for the treatment and control groups. For monitor-hour data, Before is from October 2000 to September 2003, and After is from October 2003 to December 2008. For birth data, Before is from July 2000 to June 2004, and After is from July 2004 to June 2008. For prefecture-year data, Before is from 1999 to 2002, and After is from 2003 to 2008

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Declarations

Conflicts of Interest The authors have no financial conflicts of interest to disclose for this paper.

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