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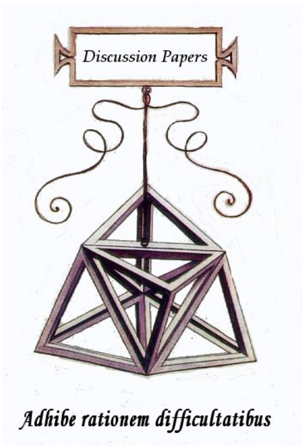

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Revealing the Link Between Air Pollution and Internal Migration: Evidence from Italy

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Abstract

People move for various reasons, including economic, social, political, demographic, and environmental factors. Environmental quality, in particular, plays a crucial role in migration decisions. This study examines the relationship between air pollution (measured as the maximum number of days in which at least one monitoring station detects an excess of 50 μg/m3 of PM10 above the established limit) and internal migration in Italy. Employing a difference-in-differences (diff-in-diff) strategy, our analysis reveals a negative relationship between air pollution and internal migration. We exploit two major legislative interventions in environmental regulation — LD 152/2006 and LD 155/2010 — as exogenous shocks affecting air pollution. We find that these environmental regulations significantly reduced the number of pollution exceeding days in municipal areas, thereby enhancing the attractiveness of those areas more committed to reducing urban emissions. Specifically, the combined effect of the two decrees led to an increase of approximately three new citizens per 1,000 inhabitants in the more committed areas, highlighting the importance of proactive environmental policies in influencing migration patterns and improving urban livability.

Keywords: Air pollution, Migration, Environmental policy.

JEL CLassification: O15, Q53, Q56, J24.

Revealing the Link Between Air Pollution and Internal Migration: Evidence from Italy

Giovanni Bernardo [*]
Pasquale Commendatore [†]
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Abstract

People move for various reasons, including economic, social, political, demographic, and environmental factors. Environmental quality, in particular, plays a crucial role in migration decisions. This study examines the relationship between air pollution (measured as the maximum number of days in which at least one monitoring station detects an excess of 50 $\mu g/m^3$ of PM10 above the established limit) and internal migration in Italy. Employing a difference-in-differences (diff-in-diff) strategy, our analysis reveals a negative relationship between air pollution and internal migration. We exploit two major legislative interventions in environmental regulation — LD 152/2006 and LD 155/2010 — as exogenous shocks affecting air pollution. We find that these environmental regulations significantly reduced the number of pollution exceeding days in municipal areas, thereby enhancing the attractiveness of those areas more committed to reducing urban emissions. Specifically, the combined effect of the two decrees led to an increase of approximately three new citizens per 1,000 inhabitants in the more committed areas, highlighting the importance of proactive environmental policies in influencing migration patterns and improving urban livability.

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1 Introduction

The incentive to migrate is usually related to adverse conditions in the place of origin or attractive conditions in the place of destination. Migrants are often attracted by the expectation of higher income, better career opportunities, better schooling for children and lower levels of taxation (Borjas, 1989, 1999, Clark et al., 2007, Gallin, 2004). Moreover, attention should be paid to environmental amenities as an important factor for public welfare (Ahmadiani and Ferreira, 2019, Bieri et al., 2023, Liu et al., 2020). Citizens more sensitive to environmental issues may decide to move to areas with better environmental conditions. An extensive body of literature has explored the link between environmental issues and migration, suggesting that changes in environmental conditions can trigger population movements (Cameron and McConnaha, 2017, Millock, 2015, Obokata et al., 2014). One strand of this literature has produced several findings demonstrating that extreme weather events or environmental disasters can lead to environmental migration (Cai et al., 2016, Feng et al., 2010, Jessoe et al., 2017).

Recently, there has been significant attention on air pollution as a primary environmental factor contributing to a significant disease burden (Giaccherini et al., 2021, Oliva, 2024, Simeonova et al., 2021). The World Health Organization estimates that 7 million premature deaths per year are currently attributable to air pollution (WHO, 2023). China and India have the highest mortality rates from air pollution. According to the European Environment Agency (EEA), despite recent improvements, air pollution caused more than 400,000 premature deaths among the European population in 2018 (Ortiz et al., 2020). PM10 concentrations are particularly high in urban areas, where vehicle congestion is a leading contributor (Dominici et al., 2014). Due to its widespread presence in the outdoor air, which can be inhaled and absorbed into the bloodstream, particulate matter represents a significant health risk factor.

In 2020, the European Court of Justice sanctioned Italy for the high number of exceedances of the concentration thresholds recommended by the World Health Organization for particulate matter. In Italy, the average annual level of PM10 is 40 micrograms per cubic metre (μg/m^3), which is higher than the level of 20 micrograms per cubic metre (μg/m^3)

recommended by the World Health Organisation[1].

Recent economic studies confirm that domestic migration flows are sensitive to air pollution (Chen et al., 2022, Germani et al., 2021, Khanna et al., 2021). Among others, Chen et al. (2022) find that a 10% increase in air pollution in China increases out-migration by 2.8%. Similarly, in the Italian context, Germani et al. (2021) find a negative correlation between migration and air pollution across different provinces[2].

The purpose of this paper is to estimate the causal relationship between air pollution and migration, namely to determine if and to what extent Italian domestic migration has been driven by people's search for better air quality. To carry out our analysis, we focus on Italian urbanized areas, i.e., provincial capital municipalities, exploiting data over the period 2003-2019. Usually, air pollution monitoring stations are located in great cities since a significant burden is placed on urban agglomerations due to intense human activity, including vehicular traffic, industries, and domestic heating, which release a large amount of pollutants into the air.

Estimating migration responses to air pollution presents some empirical challenges. Since migration involves fixed costs, it is likely to react slowly to variation of air pollution. Thus, using an exogenous medium variation in air pollution, which represents a permanent shock, allows us to disentangle unmeasured confounding factors that jointly determine air pollution and migration, as for example the volume of local economic activity (Chen et al., 2022).

The current legislation, in effect since 1999, establishes thresholds for PM10 particulate matter. Specifically, it regulates the maximum number of days that can exceed the permitted daily average limit of 50 ($\mu g/m^3$). According to this regulation, this limit cannot be exceeded for more than 35 days in a calendar year. These thresholds are set to mitigate air pollution consistently throughout the year and serve as indicators of air quality. If any monitoring station within a municipality exceeds this limit, the entire municipality is deemed non-compliant with the regulations.

[1]However, the European Union, through Directive 96/62/EC - implemented in Italy through LD 351/1999 - has mandated governments to provide adequate information to the public regarding air quality levels. Access to credible and easily accessible pollution information enables residents to better incorporate the costs of pollution into their decision-making processes, thereby increasing the responsiveness of domestic migration to pollution levels.

[2]They do not provide a compelling causal result.

Between 2003 and 2006, the average number of days on which the daily limit value for PM10 was exceeded was about twice the limit value, for a total of about 80 days. Since 2006 onward, we observe a sharp decrease in the average number of days exceeding the daily PM10 limit due to the normative process in the environmental law occurring in Europe. The two main normative interventions implemented in that period are: the legislative decree 152/2006, which elaborate further on compensatory protection against environmental damage, prescribing heavier sanctions and implementing the European directive based on the "polluter pays" principle, and the legislative decree 155/2010 that expands the allocation of a comprehensive national framework for air quality management, delegating specific powers to regions and autonomous provinces. This pertains to the adoption of plans aimed at achieving quality objectives and the implementation of additional contingency measures to mitigate the risks associated with air pollution.

In this paper, we conduct a quasi-experiment by exploiting these two decrees as permanent shocks, which helps to mitigate the endogeneity issue associated with the relationship between economic activity and air pollution. Specifically, these regulations heighten the responsibilities of local governments, compelling them to act decisively and defining their authority to intervene. Our quasi-experiment exploits the time delay between the MD 60/2002, which sets the annual parameters for maximum pollution days in Italy, and the two legislative decrees. We define provincial capitals exceeding the PM10 limit for more than 34 days between 2003-2006 (prior to LD 152/2006) in the last three years as the treatment group, and as the control group all the rest. These provincial capitals, having experienced higher pollution levels before 2006, are most impacted by the legislative interventions, motivating their local administrators to avoid sanctions and implement pollution-reduction measures. Using temporal variations in data through a difference-in-differences (diff-in-diff) design, we compare treated provincial capitals with untreated ones before and after the implementation of the LD 152/2006 (between 2003-2019), and before and after the LD 115/2010 (between 2006-2019). This strategy enables us to measure the causal effect on the net migration rate and the number of days exceeding the allowed daily limit for PM10, thereby clarifying the link between them.

The present study provides compelling evidence of the role of environmental policies on the value of local amenities, which are a significant factor in citizens' migration decision-making processes. First, the analysis indicates that the two legislative decrees effectively reduce air pollution. Specifically, the results show that these interventions lead to a reduction of about one half the average pollution levels observed in the pre-intervention period (between 2003 and 2006). This effect can be attributed to the concerted efforts of local authorities to implement measures such as traffic blocks for Euro 3 vehicles, restricted traffic zones, cycle lanes, and pedestrian areas (as shown in Table A.7 in the appendix). Second, focusing on the primary aspect of the study, we find evidence that the two environmental legislative decrees positively impact domestic migration flows in Italian provincial capitals. Specifically, there is a combined effect (of the two laws) of approximately 3 new citizens per 1,000 inhabitants in the treated provincial capital municipalities, following the enactment of these legislative measures. Furthermore, we demonstrate that municipalities implementing more environmental measures attract about two high-income individuals more per thousand inhabitants.

Our contribution to the existing literature is twofold. First, we provide additional evidence of the relevance of local amenities in migration decisions. Such empirical investigations are more common in developing countries, where environmental concerns are heightened due to their severity (Adams et al., 2018, Miller, 2019). Our study stands out as one of the few to provide causal evidence for the developed countries. In developed countries, governments typically disclose more information about air pollution levels compared to their counterparts in developing ones. The access to credible and readily available pollution information allows residents to better internalize the cost of pollution in their decision-making process increasing the sensitivity of domestic migration to pollution levels (Johnson and White, 2017, Smith, 2021). Secondly, we develop a quasi-experimental design exploiting two environmental regulations, demonstrating its effectiveness in assessing the impact of environmental legislative interventions (Chay and Greenstone, 2003, Greenstone, 2004, Greenstone and Gayer, 2009, Zhang et al., 2018). Our findings also contribute to the existing evidence on the effectiveness of decentralizing public policy (Doe, 2020, Green et al., 2016, Lee, 2018, Zhang and Mu, 2018). We show that the lowest levels of government are more responsive to social concerns and capable of implementing tailored policies to mitigate harmful health risks.

The rest of the work is organized as follows. Section 2 describes the environmental legislative framework concerning air pollution. Section 3 presents the variables of the analysis. In Section 4 illustrates the empirical strategy, and Section 5 presents the empirical evidence on the effect of the legislative decrees on the air pollution and the municipal migration rate and presents a discussion of the results, offering further estimates that support our evidence. Section 6 presents some robustness checks and Section 7 concludes.

2 Legislative Framework

In this section, we briefly outline the legislative framework that was in force before the period we examined in our study and the two most important innovations in the Italian environmental regulatory system occurring during that period: Legislative decrees 152/2006 and 155/2010. These decrees represent significant shocks that profoundly impacted pollution emissions in the urban areas under examination, as we shall observe in the data and our analysis.

2.1 Legislative background before 2006

Air quality regulations have always been numerous and heterogeneous. A significant part of recent regulations consists of standards derived from the European Union legislation and international agreements aiming to reduce the most hazardous pollutants on a global scale. In this paper, we focus primarily on regulatory developments concerning the assessment and management of outdoor air quality, particularly with regard to PM10 (i.e., particulate matter with a diameter of 10 micrometers or less). [3]

The primary legislation on air quality, Directive 96/62/EC, was enacted in Legislative Decree No. 351 of 1999, aiming to reduce the harmful effects of air pollution. Subsequent

[3] Since 1987, the high risk to human health posed by PM10 has been recognized by the World Health Organization in the European Air Quality Guidelines. The term "PM10" identifies particles suspended in outdoor air with an aerodynamic diameter equal to or less than 10 μm. Particulate matter can be originated from natural and anthropogenic sources.

daughter directives, such as 1999/30/EC and 2000/69/EC, addressed specific pollutants. These directives were consolidated in Ministerial Decree 2002 No. 60, which establishes explicit limit values and criteria for air pollutants. Specifically, it establishes daily and annual thresholds for PM10 concentrations. From 1999 to 2005, the decree imposes a daily limit of 50 $\mu g/m^3$ for PM10 which cannot be exceeded more than 35 times per year. Initially, a margin of tolerance of 50% of the limit value is allowed, permitting concentrations up to 75 $\mu g/m^3$. However, this margin decreases progressively each year until it reaches 0% in 2005. In contrast, during the subsequent period from 2005 to 2010, the daily limit remains constant at 50 $\mu g/m^3$, but must not be exceeded more than seven times per year. Regarding the annual limit values, the decree sets an annual limit of 40 $\mu g/m^3$ for PM10 for the initial period (1999-2005). A 20% margin of tolerance is allowed, permitting concentrations up to 48 $\mu g/m^3$. Similar to the daily parameter, this margin of tolerance decreases each year until it reaches 0% in 2005. For the subsequent period (2005-2010), the annual limit value is further reduced to 20 $\mu g/m^3$, with a margin of tolerance of 10 $\mu g/m^3$.

However, the various sanctions imposed on Italy by the European Court of Justice regarding the limits on the concentration of pollutant particles raise concerns about the national environmental protection system and, particularly the role of the involved local authorities. It's important to note that, according to Article 117 of the Italian Constitution, environmental protection falls under the exclusive legislative competence of the State. Consequently, the regulatory power in this field should also belong exclusively to the State, unless delegated to the Regions, as provided for in Article 117, comma 6, of the Constitution.

In general, the institutional framework for environmental issues respects the principle of vertical subsidiarity established in Articles 82-84 of Legislative Decree no. 112/1998, where the administrative functions of the State are explicitly identified, while those of the regions and local authorities are residual. Public entities and their operators already have a legal responsibility to intervene in the avoidance and elimination of severe levels of air pollution harmful to public health, according to the offences defined in articles 328 and 674 of the Penal Code.

The ineffectiveness of previous sanctions and uncertainty regarding the powers and responsibilities of local authorities in air pollution issues have led to inertia among units. Provincial capitals experienced high PM10 concentrations, exceeding the permitted threshold of 35 pollution days per year, reaching more than 100 days in some cities. Nevertheless, since 2006, a reduction in the number of days exceeding the daily PM10 limit has been observed , although not yet within the 35 days per year limit allowed by law.

2.2 Legislative decrees 152/2006 and 155/2010

In 2006, Italy enacted Legislative Decree 152/2006, also known as the Consolidated Environmental Act (TUA), to unify and address the inefficiencies of its environmental legislation. The parts of interest for our discussion regards air pollution control [4] (Part V) and environmental damage and liability (Part VI). Of primary interest are the measures to prevent and define environmental damage, which are extensively regulated by the TUA. Article 301 mandates prompt preventive action in the event of threats to human health and the environment, highlighting the responsibility of public operators to promptly report hazards to the relevant authorities. Both public and private entities potentially affected by environmental damage can initiate preventive measures through the Ministry of the Environment. Regions, local authorities, individual citizens and environmental associations have the right to request ministerial intervention and seek judicial protection against any justified inaction.

According to Paragraph 2 of Article 304 of LD 152/2006, failure to comply with the reporting or intervention obligations outlined in Paragraph 1 results in administrative fines ranging from one to three thousand euros for each day of delay. In cases of environmental damage, whether due to offences or omissions, the assessment must cover restoration costs. If a precise quantification of the irreparable damage is not feasible, a pecuniary equivalent is assumed, amounting to at least three times the sum corresponding to the administrative penalty. In the case of a criminal penalty, the pecuniary equivalent amounts to 400 euros for each day of imprisonment.

A second, even more significant, innovation in Italian environmental regulation is LD 155/2010, which transposes Directive 2008/50/EC and establishes a comprehensive national

[4] Part V of the TUA specifically targets air pollution, outlining regulations concerning emissions from industrial plants, civil thermal plants, and fuel standards.

framework for the assessment and management of air quality. This decree consolidates all pertinent pollutant concentration thresholds into a single regulatory document [5]. Furthermore, it extends the delegation of specific powers to regions and autonomous provinces for the assessment and management of air quality. These responsibilities includes the adoption of plans to achieve and sustain quality targets, as well as to address exceedances of value limits, critical levels, or alarm thresholds.

Regions, in collaboration with local authorities, formulate plans to meet quality targets and develop action plans comprising immediate measures to prevent exceeding value limits and alarm thresholds. Moreover, regions are tasked with zoning territories, classifying areas and agglomerations for the installation of monitoring stations, and forming a monitoring network subject to public management or oversight. Simultaneously, mayors have been granted interdictive powers [6], entrusted with implementing provisions outlined in regional plans for traffic restriction measures aimed at achieving quality targets or reducing the risk of surpassing pollution values detrimental to health. Traffic restrictions, enacted by ordinance, can be crucial in addressing air pollution concerns based on criteria established in regional plans.

3 Data and variables

To carry out our analysis, we gathered data from two sources both provided by the Italian National Institute of Statistics (ISTAT). Specifically, we collected data on internal migration flows from the *Annual Demographic Balance* [7] and data on air pollution from the *Environmental Data in Cities Survey*.

The main variable is the municipal net migration rate, which is defined as the difference between the number of people arriving in municipality i from other municipalities and the number of people leaving municipality i to move to other municipalities, divided by the population of municipality i at the end of the year, then multiplied by 1,000[8]. A positive

[5] A special attention is also given to addressing the population's exposure to PM2.5.

[6] Unless regional law designates a different authority.

[7] In particular, we collect data from the online section dedicated to demographics (Demo-ISTAT).

[8] this way, we have a measure expressing the number of migrants per 1000 inhabitants.

net migration rate implies that the number of immigrants exceeds the number of emigrants, indicating the attractiveness of the municipality. Conversely, a negative net migration rate, where emigrants outnumber immigrants, may indicate adversities or a lack of attractiveness in the municipality. Figure B.1 in the appendix B illustrates the annual average net migration rates for provincial capital municipalities from 2003 to 2019. The data show a negative net migration rate for the entire period between 2003-2009, reaching its lowest point in 2007. The rate becomes positive from 2012, peaking in 2013.

Air pollution data are collected by municipal statistical offices using monitoring stations situated within municipal boundaries. The territorial network of these monitoring stations was established in the early 1990s and further consolidated following the introduction of Ministerial Decree 60/2002 in the early 2000s. This decree, together with the *Criteria for EuroAirnet*, provides guidelines for selecting sampling sites. However, due to the diverse characteristics of Italian territories, the air monitoring authority opted for urban centers of significant size, mostly provincial capitals, for the installation of monitoring stations. Monitoring stations are classified into three types based on the source of pollution: background, traffic, and industrial (Barrero et al., 2015). Traffic and industrial monitoring stations are located near dominant pollution sources, while background stations are placed in areas influenced by a cumulative contribution from different sources.

From the *Environmental Data in Cities Survey* conducted by ISTAT, we collect data on the **Exceeding Days** of the PM10 limit for Italian provincial capitals from 2003 to 2019. This metric is defined as the maximum number of days on which at least one type of monitoring station (among all those located within the boundaries of the provincial capital) detected PM10 exceeding the daily limit of 50 μg/m^3 (micrograms per cubic meter). For example, in 2019, the provincial capital of Naples had seven monitoring stations: two background stations and five traffic stations. Among these, the traffic station located in "Naples NA07 railway entity" recorded the highest number of days exceeding the PM10 limit in 2019, with 36 days. This value of 36 represents the proxy for air pollution in Naples for that year[9]. We use this measure of air pollution to assess the risk to human health associated with PM10

[9] A day is considered to be non-compliant if at least one monitoring station exceeds this limit.

exposure.

Graph B.2a in figure B.2 (in the appendix B) illustrates the number of days exceeding the daily PM10 threshold for various types of monitoring stations from 2003 to 2019. In addition, graph B.2b depicts the frequency of cities, categorized by type of monitoring station, that recorded the highest annual number of exceeding days for a specific pollution source during the same period. The graphs indicate that traffic sources, in particular, and background sources are the primary contributors to urban pollution, consistently showing higher frequencies over the years. In contrast, industrial stations, despite having a relatively high average number of pollution days, are less frequent due to the limited presence of industrial plants near provincial capitals. Furthermore, Figure B.3 show two sharp decreases in 2006 and 2011 [10], which, interestingly, correspond to the implementation of legislative decrees 152/2006 and 155/2010.

On the other hand, Figure B.1 also shows a similar trend corresponding to the timing of the legislative changes, particularly an increase in net migration between 2006 and 2011, changing from negative values to zero, and a further increase from 2011 onwards, becoming positive[11].

Control Variables. Our analysis includes several control variables to capture unobserved time-varying heterogeneity. To account for different levels of economic incentive, we use **Wage**, defined as the natural logarithm of the ratio between the taxable labour income of municipality i and the number of its labour taxpayers. These data are sourced from the *Ministry of Economic and Finance* (MEF) database. We expect that higher wages will be associated with greater increases in internal migration. We also control for **Pop**, the number of inhabitants (expressed in natural logarithm terms) to account for scale effects and the externalities associated with living in large communities.

We include two additional control variables to assess the role of mayoral qualities ininfluencing the effectiveness of local administrations in implementing innovative environmental

[10] LD 155/2010 became fully effective in 2013. From 2010, it started to produce partial effects due to the structural steps required, which take longer to implement.

[11] Thus, to address econometric issues concerning unobserved determinants of migration and air pollution that may lead to spurious estimates, we exploit random variation in air pollution related to normative shocks of the legislative decrees 152/2006 and 155/2010.

policies (Frederickson et al., 2004, Nelson and Svara, 2012). The first variable is **Mayor's Degree**, a binary indicator set to 1 if the mayor holds a university degree. The second variable is **Mayor's Age** at time t, which serves as an additional measure of leadership experience and perspective. These data are obtained from the *Ministry of the Interior* database.

Since municipalities with extensive public transport infrastructure tend to exhibit lower pollution levels, we control for several proxies related to public transport supply (Adler and van Ommeren, 2016, Bauernschuster et al., 2017, Dustmann and Okatenko, 2014, Yang et al., 2023). Specifically, we include the following variables: **Bus** which measures the number of bus seats per inhabitant, calculated by multiplying the total number of bus seats available by the distance travelled; **Tram**, which measures the number of tram seats per inhabitant, calculated by multiplying the total number of tram seats available by the distance travelled; **Trolleybus**, which accounts for the trolleybus seat supply per inhabitant, calculated by multiplying the total number of trolleybus seats available by the distance travelled; and **Metro**, which measures metro seat supply per inhabitant, calculated by multiplying the total number of metro seats available by the distance travelled. Additionally, we consider Public **Transport Demand**, defined as the ratio of total passengers carried for each type of public transport during the year to the population. Communities where residents prefer public transport for commuting may experience lower air pollution levels.

Finally, to address residents' private transportation behavior within the municipality, including road congestion and urban mobility, we include three variables that may negatively impact migration patterns by reducing the municipality's attractiveness and increasing air pollution (Büchs and Schnepf, 2013, Leroutier and Quirion, 2022). Specifically, we consider: **Vehicle density**, defined as the number of vehicles per square kilometer of the municipal area; **Motorisation rate**, the ratio of vehicles (including cars and motorcycles) per 1,000 inhabitants; **Euro-0123**, the percentage of vehicles falling into Euro emission classes 0, 1, 2 and 3. Data on private and public transport are sourced from *Environmental Data in Cities Survey* provided by ISTAT.

4 Empirical Strategy

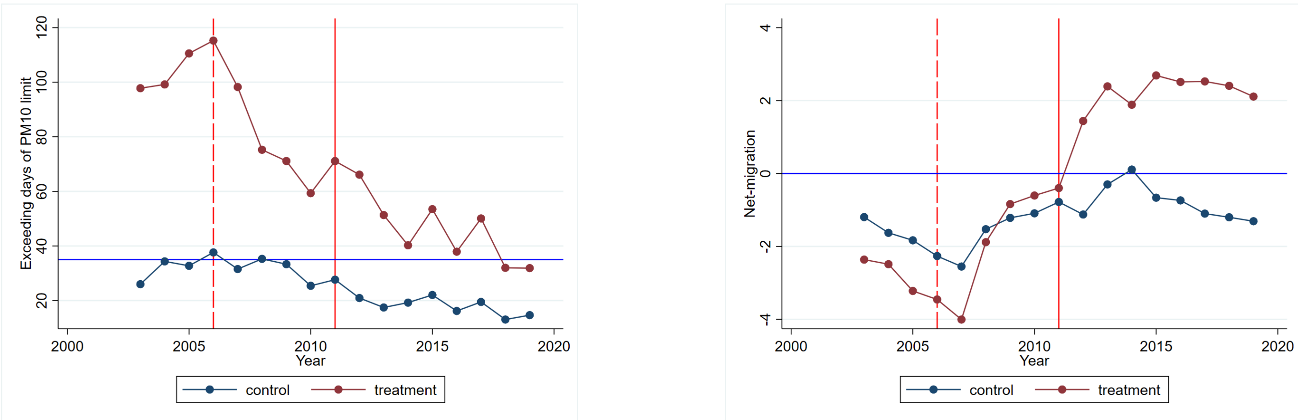
There is extensive evidence regarding the relationship between economic activity, air pollutants, and migration patterns. Cities with higher levels of economic activity typically produce more emissions from industrial sectors and commuter traffic, often associated with commercial enterprises and public facilities (Chay and Greenstone, 2003, Ebenstein, 2012, Grossman and Krueger, 1995). These areas also tend to have more dynamic labour markets with higher-paying jobs and greater employment opportunities, attracting migrants (Borjas, 2001, Todaro, 1969). Conversely, migration flows can accelerate urbanization and worsen urban pollution. The relationship between economic activity, air pollution, and migration represent an empirical challenge that may lead to incorrect conclusions if not properly addressed. Indeed, Chen et al. (2022) argue that a simple OLS estimation of migration on air pollution may yield an upwardly biased coefficient, leading to the mistaken conclusion that pollution attracts migrants. They address this issue using an IV strategy that exploits variations in meteorological thermal inversions – causing pollutants to accumulate near the ground and deteriorate air quality – representing exogenous variations in air pollution. Their findings reveal that air pollution is an important factor influencing internal migration in China.

In this paper, we propose an alternative empirical strategy to address endogeneity in our estimations. Specifically, we exploit the normative time delay between MD 60/2002, which sets the annual target for the maximum number of pollution days, and the legislative decrees 152/2006 and 155/2010 to define treatment and control groups. In particular, we define the treatment group as provincial capitals that exceeded the daily PM10 limit for more than 34 days in the last three years before the LD 152/2006 (period 2003-2006). The control group consists of all other provincial capitals

To illustrate the time trends of the treatment and control groups in relation to the implementation of the two laws. These trajectories are presented in Figure 1. Figure 1a compares the average number of PM10 exceedance days between the treatment and control groups of provincial capitals. The treatment group demonstrates a clear reduction in exceedance days following the enactment of the environmental laws. Conversely, the control group shows only slight improvements in air quality, consistently maintaining pollution levels below the annual PM10 limit of 35 days per year throughout the period. Furthermore, Figure 1b highlights an increase to a positive net migration within the treatment group after the introduction of the first decree, while the control group exhibits a persistent negative migration balance over the analysed period.

Figure 1: Average in treatment and control groups. 2003-2019

(a) Air pollution (b) Net migration



The graph depicts the annual mean of the number of days when PM10 exceeds the daily limit of 50 $\mu g/m^3$ (Graph 1a), and the annual net migration in treatment and control groups of provincial capitals (Graph 1b). Years 2003-2019.

In other words, the two figures show that the legislative measures had a more significant impact on provincial capitals that experienced higher pollution levels before 2006. Local authorities in these areas had greater incentives to implement measures to reduce air pollution and avoid penalties, thereby potentially increasing the attractiveness of these cities to potential residents. Moreover, these findings highlight the strengths and weaknesses of command and control policies already recognised in the literature. In particular, command and control policies provide clear directives and can promptly address specific environmental problems (Lamperti et al., 2020, Tuladhar et al., 2014). However, they often fail to stimulate innovation (Hepburn, 2006, Swaney, 1992). In this context, while imposing emission limits and penalties leads to significant reductions in PM10 concentrations in non-compliant areas, such policies fail to encourage continuous improvement. Municipalities that are already in compliance lack incentives to improve air quality further.

Collecting yearly observations from 2003 to 2019 (stopping just before the pandemic crisis), we exploit the random temporal variations in the data represented by the two legislative decrees to implement a difference-in-differences (diff-in-diff) design. First, we estimate the effect of the legislative decrees on air pollution to show the significant impact of environmental regulation on reducing air pollution levels. We use the following specification:

$$P_{i,t} = \alpha_1 LD152_{i,t} + \alpha_2 LD155_{i,t} + \gamma X_{i,t} + f_i + f_t + \epsilon_{i,t} \tag{1}$$

where $P_{i,t}$ is the maximum number of days the daily limit of 50 μg/m^3 was exceeded at time t as detected by any type of monitoring station installed within the municipality. $LD152_{i,t}$ is a dummy variable equal to 1 for each treated provincial capital i from 2006 to 2019, and 0 otherwise. $LD155_{i,t}$ is a dummy variable equal to 1 for each treated provincial capital i from 2010 to 2019, and 0 otherwise. f_i is a municipality fixed effect; f_t is a time fixed effect; $\epsilon_{i,t}$ is an idiosyncratic error term. The term $X_{i,t}$ represents the set of time-varying control variables; and γ is a vector of coefficients.

The coefficients α_1 and α_2 in Eq. 1 estimate the differential change in the maximum number of PM10 limit-exceeding days between the treatment and control groups. This differential captures the contemporaneous effect of the legislative decrees on air pollution.

Individuals' migration choices typically do not respond immediately to changes in air pollution due to fixed costs (e.g., moving expenses, housing costs, and travel costs); instead, they tend to react slowly to variations in pollution levels. Therefore, we estimate this relationship by including the lagged effects of the two normative interventions on net migration. The second equation is represented by the following linear regression:

$$M_{i,t} = \beta_1 LD152_{i,t-1} + \beta_2 LD155_{i,t-1} + \gamma X_{i,t} + f_i + f_t + \epsilon_{i,t} \tag{2}$$

where $M_{i,t}$ is the net migration rate for the provincial capital i at time t. In this specification, we also consider time-varying controls, as well as municipality and time fixed effects

The estimated coefficients β_1 and β_2 in Eq. 2 capture the lagged differential change in the net migration per thousand inhabitants during the time frame of the two legislative interventions in the provincial capital municipalities that had higher pollution levels between

2003 and 2006 (treatment group) compared to other provincial capital municipalities (control group).

By including time-fixed effects, we control for the air pollution trends related to the broader economic cycle and the European legislative process on air pollution, which includes norms promoting alternative fuels and sustainable transportation methods common to all municipalities.[12] Through municipality fixed effects, we address potential issues arising from the possibility that municipality-specific characteristics may influence the formation of air pollution. Geographic features such as latitude, longitude, elevation, and proximity to other geographic locations can affect air pollution through their impact on climatic conditions, atmospheric stability, and pollutant transport.[13]

To assess the validity of the common trend assumption underlying the difference-indifferences approach (Angrist and Pischke, 2009, Imbens and Wooldridge, 2009), we employ a generalized diff-in-diff research design. This allows us to compare the time trajectories of treated and untreated provincial capitals in each year for the maximum number of PM10 exceedance days and the net-migration rate. This also allows us to assess the dynamic effect of environmental policies on these outcomes. The generalized diff-in-diff linear regression equation is

$$Y_{i,t} = \sum_{t=2003}^{2019} \theta_t D_{i,t} + \gamma X_{i,t} + f_i + f_t + \eta_{i,t} \tag{3}$$

where $Y_{i,t}$ represents the outcomes of the analysis in municipality i in year t; D_t denotes the interaction between the treatment group and the year dummies; to examine possible pre-

[12]These include: 1) regulations to promote clean transportation. For instance, Law 166/2002 allocated 800 million euros for local public infrastructure and the transition to low-emission vehicles. Law 308/2004 authorized 150 million euros for sustainable development programs, including the promotion of clean vehicles. Additionally, LD 16/2005 established a 140 million euro fund to improve air quality and reduce particulate emissions in urban areas. 2) directives for cleaner transportation and fuels. For example, Presidential Decree (PD) 84/2003 requires information on fuel efficiency and CO2 emissions for new vehicles. The Ministerial Decree (February 18, 2003) implements discharge emissions controls for gasoline and diesel engines. LD 66/2005 focuses on fuel quality standards, particularly sulphur content below 10 mg/kg from 2009. LD 128/2005 promotes the use of biofuels and renewable alternatives in the transport sector.

[13]For example, higher elevations can trap pollutants near the surface, leading to higher concentrations, especially in valleys and basins. Additionally, elevation can influence local weather patterns, such as temperature inversions, which can further exacerbate pollution episodes by trapping pollutants near the ground. Wind patterns influenced by latitude can also transport pollutants over long distances, affecting air quality in neighbouring regions. Proximity to bodies of water can impact air quality as well, by affecting local climate conditions and humidity levels, which in turn impact the dispersion and concentration of pollutants.

treatment trajectories related to unobservable covariates and anticipatory effects, we use the year 2006 as the reference period, omitting D_{2006}. The remaining θ_t coefficients measure the difference in the outcome variables in the period before and after the implementation of LD 152/2006 in the treatment group compared to the control group of municipalities. Moreover, we control for municipality fixed effects f_i and time fixed effects f_t, and account for all time-varying controls specified in other models; and, finally, $\eta_{i,t}$ represents the idiosyncratic error term.

As provincial capitals within the same region may exhibit correlated outcomes due to unobserved cluster effects, such as common regional regulations and policies, our inference could be biased. To address this issue, we compute standard errors that are robust to contemporaneous spatial correlation, accounting for 340 clusters (i.e., 17 annual observations for 20 regions).

5 Results

5.1 Effects of legislative Decrees

To assess the impact of Legislative Decrees 152/2006 (LD152) and 155/2010 (LD155), we conduct a diff-in-diff analysis on air pollution and on the net migration of the Italian provincial capitals. Table 1 displays the model estimates of the diff-in-diff analysis on air pollution, i.e. Eq. 1, they show the average difference between treated and control groups of provincial capitals regarding the exceedance days of the daily PM10 limit occurred with legislative decrees.The most compelling results are found in column (4), which present the full specification model. For LD152, the estimate in column (4) indicates a significant reduction of 30.624 days for treated municipalities, with statistical significance at the 1% level. Similarly, for LD155, the estimate in column (4) shows a significant reduction of 15.110 days for treated municipalities, with statistical significance at the 5% level.

The results are consistent across different model specifications. For LD152, the reductions range from 27.573 to 34.117 days; while for LD155, the reductions range from 13.359 to 16.374 days. The stability of these estimates across columns underscores the robustness of the legislative decrees' effects on air pollution. The combined effect of these two legislative interventions results in a significant reduction in the number of exceeding days through time, amounting to approximately 50% of the average number of exceeding days observed for the treatment group during the 2003-2006 period (i.e., 105 polluted days, see Table A.2 in the appendix). This substantial decrease underscores the effectiveness of the decrees in mitigating air pollution levels.

The significant reduction in PM10 exceedance days indicates that provincial capital municipalities, which experienced higher pollution levels during 2003-2006, were incentivized to implement and comply with air pollution reduction policies following the enactment of LD152 and LD155. Consequently, these legislative measures effectively reduced air pollution, leading to improved environmental conditions in the treated municipalities. These findings strongly suggest that the primary transmission channel for the net migration effect of the two legislative interventions is through improvements in air quality.

The results, highlighting the substantial impact of regulatory measures on environmental outcomes suggest that these reductions in exceedance days are not only statistically significant, but also economically relevant, highlighting the substantial impact of regulatory measures on environmental outcomes. This is particularly important in the context of the ongoing discussions about the efficacy of environmental regulations and their role in public health (National Research Council, 2002).

Table 1: Effect of legislative decrees LD152 and LD155 on the exceedance days

	Exceeding days					
	(1)	(2)	(3)	(4)	(5)	(6)
$LD152$	-27.573***	-30.475***	34.117***	-30.624***	-27.945***	
	[6.618]	[6.569]	[5.431]	[5.921]	[5.753]	
$LD155$	-13.359**	-16.374**	14.974***	-15.110***		-14.828***
	[5.487]	[5.446]	[3.476]	[3.622]		[3.512]
Controls		yes		yes	yes	yes
FE			yes	yes	yes	yes
Observations	1591	1520	1520	1520	738	1270

Note: The table shows the results of the diff-in-diff estimation. The dependent variable is the maximum number of days exceeding the PM10 daily limit at time t. LD152 is the interaction between a dummy equal to 1 for provincial capital municipalities that exceeded the PM10 daily limit for more than 34 days for at least three years between 2003-2006 (i.e., treated) and a dummy variable equal to 1 from 2007 onwards. LD155 is the interaction between the dummy for treated and a dummy equal to 1 from 2011 onwards. Columns (1) and (2) don not include year and provincial capital municipality fixed effects, but column (2) consider time-varying controls. Column (3) includes only fixed effects, while column (4) is the full model. Column (5) is the full model that consider the time-span between 2003 and 2010, including only LD152. While column (6) consider the time-span from 2006 to 2019, including only LD155. Clustered standard errors accounting for contemporaneous spatial correlation are in brackets. Significance is denoted as follows: * significant at the 10% level; ** significant at the 5% level; ***significant at the 1% level.

We now turn to the diff-in-diff analysis dealing with the impact of the two legislative decrees on net migration, as this metric implicitly reflects the effect of air quality on relocation decisions. Table 2 presents the estimates of Eq. 2, with the most compelling results highlighted in column (4), which details the full specification model. Our findings indicate that provincial capitals in the treatment group experienced significant changes in net migration rates following the enactment of these decrees. Specifically, LD152 is associated with an increase in net migration by 0.921 per thousand inhabitants compared to the control group, with statistical significance at the 5% level. This suggests that provincial capitals exceeding the PM10 daily limit on more than 34 days in the last three years of the period 2003-2006 saw an increase of approximately one citizen per thousand inhabitants post-implementation of LD152, *ceteris paribus*. Similarly, LD155 is associated with an increase in the net migration rate by 2.062, statistically significant at the 1% level (column 4). This indicates that treated provincial capitals experienced an average increase of two citizens per thousand inhabitants compared to untreated capitals post-LD155 enactment.

Columns (1) and (2), which do not consider fixed effects, include a dummy variable equal to one for the entire period, indicating whether a provincial capital is treated, to control for differences between the two groups. They also include two post-treatment dummies: one from 2006 and another from 2010, to account for temporal differences. The introduction of fixed effects for municipalities and years in columns (3) and (4) further refines the estimates by controlling for additional unobservable heterogeneity. This adjustment is particularly noteworthy for LD152, where the estimate decreases from column (2) to column (3), indicating an initial upward bias without fixed effects. Conversely, the estimates for LD155 remain stable across specifications, underscoring their robustness.

Additionally, we consider different time spans: column (5) narrows the period to 2003-2010, focusing solely on LD152, while column (6) examines the period 2006-2019, focusing exclusively on LD155. Column (5) shows that the estimate for LD152 remains stable, indicating its effect on net migration is robust even before the introduction of LD155. In column (6), the estimate for LD155 also remains consistent with previous results, underscoring the robustness of both legislative decrees' effects.

Overall, our analysis reveals that Legislative Decrees 152/2006 and 155/2010 had significant positive impacts on the net migration rates of Italian provincial capitals, with a combined effect of approximately 3 new citizens per 1,000 inhabitants. To understand the magnitude of this effect, consider the average population of provincial capitals in the treated group before the introduction of the first legislative decree, which was approximately 227,000. This implies an increase of about 680 residents (i.e., 3 inhabitants per 1,000) attributable to these legislative measures.

In conclusion, Legislative Decrees 152/2006 and 155/2010 have proven effective in significantly reducing the number of PM10 exceeding days, thereby contributing to an increase in in-migration flows in the treated provincial capital municipalities.

Table 2: Effect of legislative decrees LD152 and LD155 on net-migration

	Net-migration					
	(1)	(2)	(3)	(4)	(5)	(6)
$LD152_{(t-1)}$	2.161***	1.669**	1.229***	0.921**	1.122***	
	[0.648]	[0.660]	[0.422]	[0.467]	[0.388]	
$LD155_{(t-1)}$	2.417***	2.385***	2.435***	2.062***		2.452***
	[0.478]	[0.464]	[0.389]	[0.365]		[0.412]
Controls		yes		yes	yes	yes
FE			yes	yes	yes	yes
Observations	1591	1520	1520	1520	738	1270

Note: The table shows the results of the diff-in-diff estimation. The dependent variable is the net migration rate at time t. LD152 is the interaction between a dummy variable equal to 1 for provincial capital municipalities that exceeded the PM10 daily limit for more than 34 days for at least three years between 2003-2006 (i.e., treated) and a dummy equal to 1 from 2007 onwards. LD155 is the interaction between the dummy for treated and a dummy equal to 1 from 2011. Columns (1) and (2) don not include year and provincial capital municipality fixed effects, but column (2) consider time-varying controls. Column (3) includes only fixed effects, while column (4) is the full model. Column (5) is the full model that considers the time span between 2003 and 2010, including only LD152. Column (6) considers the time span from 2006 to 2019, including only LD155. Clustered standard errors accounting for contemporaneous spatial correlation are in brackets. Significance is denoted as follows: * significant at the 10% level; ** significant at the 5% level; ***significant at the 1% level.

5.1.1 Parallel trend assumption

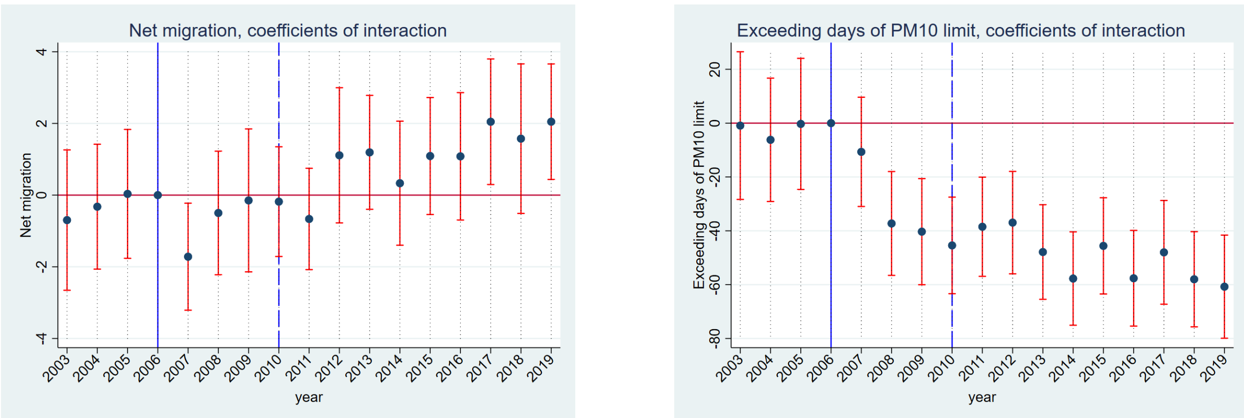
In this subsection, to check for the exogeneity of the quasi-experiment design, we provide evidence regarding the parallel trend assumption for the diff-in-diff analysis of the two legislative decrees, LD 152/2006 and LD 155/2010, on net migration and the number of PM10 limit-exceedance days.

Figure 2 depicts the estimation results of Eq. 3 using the generalized diff-in-diff approach for the net migration rate (graph 2a) and the number of PM10 limit-exceedance days (graph 2b). In both figures, the coefficients for the pre-treatment period are not significantly different from zero, suggesting the absence of any anticipation effects or unobservable covariates between the two groups of municipalities before the treatment (i.e., the enforcement of LD 152/2006). Therefore, empirical evidence supports the assumptions of a common trend and the exogeneity of the environmental reform, corroborated by the F-test results indicating that all pre-treatment coefficients are jointly equal to zero (p-value = 0.85 for net migration and 0.95 for the number of exceedance days).

The treatment dynamics for the net migration rate become effective from 2010 onwards, showing an increasing trend. Similarly, the coefficients for the number of PM10 limit-exceedance days post-2007 are significantly different from zero, displaying a stable decreasing trend from 2010 onwards. For both dependent variables, all post-treatment coefficients (after 2006) are jointly different from zero (p-value of the F-test = 0.0001), confirming the significant impact of the legislative decrees on the treated municipalities.

Figure 2: Treatment dynamics

(a) Net migration (b) Air pollution



Note. The graph reports coefficients and confidence intervals estimated according to Eq. 3. The dependent variables are the net migration rate and the number of PM10 limit-exceedance days. Standard errors are clustered at the municipality level. Dots refer to point estimates, spikes to 95% confidence intervals. All regressions include municipality fixed effects (FE), year fixed effects (FE), and additional time-varying controls. Period: 2006-2019.

5.2 Further evidence

5.2.1 Addressing Air Pollution: Environmental Measures and Strategies

The instruments for planning and programming the restoration and protection of air quality, which operate at different levels of territorial governance, from national to municipal, are complex and fragmented. In this subsection, we outline the main measures available to municipalities to reduce and mitigate air pollution. We consider the following variables: *Traffic E.*, which is the number of emergency traffic blockage days per EURO 3 vehicle; *Traffic P.*, which is the number of programmed traffic blockage days per EURO 3 vehicle;

Ltz, a dummy variable equal to one if there are limited traffic zones in the municipality; *Pedestrian*, the availability of pedestrian areas in the municipality measured in square meters per 100 inhabitants; and Bicycle-lane, the density of bicycle lanes measured in kilometers per 100 square kilometers. The data on *Traffic E.*, *Traffic P.* and *Ltz* are available from 2013, while the data on pedestrian areas and bicycle lanes are available for the entire period analyzed, although we only consider data from 2006 onwards.

Emergency traffic blockage involves restricting vehicle use on days when air pollution levels are critically high, providing immediate reductions in pollutant emissions during severe pollution events. Programmed traffic blockage involves scheduled restrictions on vehicle use, reducing overall traffic and emissions on a regular basis, thereby contributing to long-term air quality improvement. Limited traffic zone restricts vehicle access in certain areas, reducing traffic congestion and emissions in densely populated or polluted zones. Increasing pedestrian areas reduces vehicle use by encouraging walking, thus lowering emissions from traffic and improving air quality. A higher density of bicycle lanes encourages cycling as an alternative to driving, leading to reduced vehicle emissions and promoting cleaner air. These last three measures are structural and tend to change the urban structure of the municipality, providing a long-run effect on air pollution. Conversely, the first two measures produce a short-term effect on air pollution, which is very useful for combating unexpected increases in air pollution.

In Table A.7 presented in the appendix, we implement a difference in mean analysis between treated and untreated municipalities, controlling for year and municipality fixed effects. The results show that municipalities that exceeded the daily PM10 limit value on more than 34 days per year in the last three years prior to 2006 implement, on average, more environmental measures to reduce particulate matter. Therefore, it is confirmed that municipalities in the treatment group are more engaged in environmental policies against air pollution.

5.2.2 Net migration and income classes

Our evidence indicates that the effect of the environmental laws on the net migration rate and air pollution is not due to systematic differences among provincial capitals. The results suggest that people are more likely to migrate to areas where air quality is enhanced. This effect could be explained by the different trade-offs that individuals may have between perceived harms from air pollution and economic opportunities. Several studies show that air pollution alters the socioeconomic composition of neighborhoods (Banzhaf and Walsh, 2008, Hanlon, 2020, Heblich et al., 2021). This suggests that individuals with higher levels of human capital are more willing to pay a premium to live in neighborhoods with greater amenities.

To assess this statement, in what follows, we take on board the idea that income can provide a measure of human capital (Abraham and Mallatt, 2022). Indeed, several studies provide cross-sectional evidence of household stratification by income (Bayer et al., 2007, Epple and Sieg, 1999, Sieg et al., 2004, Smith et al., 2004). Thus, we exploit the Italian Ministry of Economy and Finance (MEF) income data to provide evidence on socioeconomic compositions between treated and untreated provincial capitals. Using the MEF database, we have collected data on the number of citizens by income class at the municipal level. We grouped the income classes into three categories: Low Income (income between 0 and 15,000), Middle Income (income between 15,000 and 55,000), and High Income (income of 55,000 and above). Then, we computed three shares for each class by dividing the number of citizens belonging to a specific class by the total number of taxpayers in a municipality, multiplied by 1,000 inhabitants.

We run the same diff-in-diff specification as in Eq. 1, where the dependent variables are the shares listed above. Column (3) in Table 3 indicates that the two legislative decrees positively affect the share of high income citizens. Estimates are around 0.7 per thousand inhabitants (for LD152) at the 10% level of statistical significance, and 1 (for LD155) at the 1% level of statistical significance, respectively. These point estimates suggest that municipalities in the treatment group have, on average, approximately two high-income citizens per thousand inhabitants more than municipalities in the control group. To understand the magnitude of this effect, consider that a municipality with 150,000 inhabitants (i.e., the mean) would have 300 more high-income people. Conversely, columns (1) and (2) show that environmental legislative decrees do not affect the provincial capital composition of low and middles individuals, as the coefficients are not statistically significant. Furthermore, each column in Table 3 validates the parallel trend assumption, corroborated by the F-test results indicating that all pre-treatment coefficients are jointly equal to zero (the p-value of the F-test for each of them is around to 0.9).

In summary, environmental policies positively affect air quality, which in turn positively impacts net-migration. Moreover, our results indicate that better air quality is positively correlated with the presence of high-socioeconomic individuals. According to the literature, this evidence has several economic implications. First, it relates to housing prices. Several studies show that amenities are capitalized in housing prices (Bishop et al., 2020, 2024, Chay and Greenstone, 2005, Kuminoff et al., 2013). Our results suggest that high-income individuals are more environmentally conscious and thus more willing to pay a higher housing price for better air quality. Meanwhile, middle- and low-income individuals are less sensitive to pollution issues. Therefore, if air pollution reduces housing prices, they have a greater incentive to live in more polluted places. Second, air quality can be considered a luxury good, with demand rising more than proportionally with income (Baumgärtner et al., 2017, Deschenes et al., 2017, Ebert, 2003, Flores and Carson, 1997, He et al., 2024, Zhang and Mu, 2018). High-income individuals tend to prioritize air quality and are willing to forgo some economic opportunities to live in areas with better air quality standards. This means that they are less likely to migrate to polluted areas, even if these areas offer economic advantages such as lower housing costs or better job opportunities.

Table 3: Effect of the two legislative decrees on income shares

	Low	Middle	High
	(1)	(2)	(3)
$LD152_{(t-1)}$	-0.264	0.112	0.649*
	[1.102]	[1.176]	[0.360]
$LD155_{(t-1)}$	-1.283	0.283	0.972***
	[0.862]	[0.812]	[0.256]
Controls	yes	yes	yes
FE	yes	yes	yes
Observations	1523	1523	1523

Note: The table shows the results of the diff-in-diff of the two legislative decrees on the share of low-income citizens in column (1), the share of middle-income citizens in column (2), and the share of high-income citizens in column (3). All columns include year and municipality fixed effects, and time-varying controls. Clustered standard errors accounting for contemporaneous spatial correlation are in brackets. Significance is denoted as follows: * significant at the 10% level; ** significant at the 5% level; ***significant at the 1% level.

6 Robustness

Here we discuss the results of several robustness checks on the main estimates. We proceed as follows: First, we examine the homogeneity of the control group for all the variables used in the analysis to ensure that the treatment and control groups are comparable. Second, we test the relevance of the two legislative interventions, specifically checking if the effect of the second intervention (LD 155/2010) is driven by the first one (LD 152/2006). Third, we assess whether the results are influenced by regional-specific trends, ensuring that any regional heterogeneity does not bias our estimates. Fourth, we evaluate whether the most urbanized provincial capitals exert a disproportionate influence on the estimates, addressing potential biases from highly urbanized areas. Finally, we assess whether our estimates are impacted by serial correlation.

6.1 Homogeneity of the control group

In this section, we demonstrate that the average differences between the treatment and control groups are not driven by systematic heterogeneity in the average net migration rate and the number of PM10 exceeding days among provincial capital municipalities that did or did not experience annual PM10 limit violations.

Tables A.5 and A.6 in the appendix report the results for the net migration rate and the number of PM10 exceedance days, respectively. In column (1) of each table, we compare our treatment group (municipalities that exceeded the PM10 daily limit for more than 34 days in the last three years between 2003 and 2006) with those that never violated the annual air pollution limit. This ensures that any observed effects are attributable to differences between these two groups.

To further validate our findings, we conduct a placebo exercise by excluding municipalities in the treatment group from the diff-in-diff analysis. In column (2), we compare only those municipalities that exceeded the limits in the last year (2006) with those that never violated the annual PM10 limit between 2003 and 2006. In column (3), we compare municipalities that exceeded the PM10 limits in the last two years with those that never violated the annual limit. Finally, in column (4), we compare municipalities that exceeded the limits in the last two years with those that only exceeded the limit in the last year.

The estimates presented in column (1) of both tables maintain the same values as those shown in the main results discussed earlier. This consistency reinforces the reliability of our findings and indicates that the observed effects are robust to various checks for heterogeneity.

Table A.5, throughout columns (2)-(4), shows results regarding the placebo exercise for the net migration rate. These specifications indicate that the net migration rate is not statistically different across the two control groups, supporting the assumption that the treatment and control groups are homogeneous except for their treatment status. In contrast, columns (2)-(4) of Table A.6 show results for the placebo exercise for the number of PM10 exceedance days. Column (2) of Table A.6 indicates that those violating the annual PM10 limit only in the last year have about 28 exceedance days more than those that never violated the annual limit following the enactment of LD 152/2006. This result presents an effect with an opposite sign to the main effect, which does not change the conclusion about the difference between the treatment and control groups. Whereas, columns (3) and (4) of Table A.6 show no differences among the other control group specifications, further validating the robustness of our findings.

6.2 Effectiveness of both legislative decrees

The effect of LD 155/2010 on the net migration rate and air pollution could be correlated with the effect imposed by the earlier LD 152/206. Our coding of the two treatment variables, however, enables us to control for potential covariation between them, disentangling possible overlapping effects in the period between 2010 and 2019 that might be attributable to the earlier intervention.

Nevertheless, to show the effectiveness of both laws on our dependent variables, we run a hypothesis test to assess whether the combined impact of the laws LD 152/2006 and LD 155/2010 is equivalent to the impact of the earlier LD 152/2006 alone. This test is critical to determining whether it is necessary to consider both decrees in our model.

To address this issue, we estimate two models. The first model includes both legislative interventions, while the second model includes only the earlier intervention, i.e. LD 152/2006, as follows:

Model 1:

$$Y_{i,t} = \alpha_1 LD152_{i,t-1} + \alpha_2 LD155_{i,t-1} + \gamma X_{i,t} + f_i + f_t + \eta_{i,t} \quad (4)$$

Model 2:

$$Y_{i,t} = c_1 LD152_{i,t-1} + \gamma X_{i,t} + f_i + f_t + \eta_{i,t} \quad (5)$$

To compare these estimates, we test the null hypothesis that the sum of the effects of the two legislative decrees equals the effect of the first intervention. The null hypothesis to be tested is:

Null Hypothesis

$$H_0 : \alpha_1 + \alpha_2 = c_1 \tag{6}$$

The test results reject the null hypothesis at the 0.01% level of statistical significance for both dependent variables, indicating that both interventions have distinct and significant effects on net migration and air pollution and should both be considered in the analysis.

6.3 Regional-specific trend

Here we examine the possibility that Italian regions may have developed different environmental plans, with the general framework first introduced by LD 351/1999 and later by LD 155/2010. This could lead to common trends among municipalities within the same region, but varying trends between those in different regions. To account for this potential heterogeneity, in Table A.8 in the appendix, columns (1) and (4), includes region-specific trends. Our results remain consistent with those in Tables 2 and 1, thereby confirming their robustness.

6.4 Influences of most urbanized provincial capitals

The most urbanized provincial capital municipalities may exert a disproportionate influence on our estimates. To address this issue, we analyze the extent to which our main evidence is sensitive to the exclusion of the four largest provincial capital municipalities in terms of population. In Table A.8 in the appendix, columns (2) and (5), we report results excluding the following municipalities: Milan, Rome, Naples and Turin. Our analysis shows that the most urbanized municipalities do not appear to be crucial drivers of our estimates. The diff-in-diff estimates do not change, and their statistical significance remains stable.

6.5 Serial Correlation

It is well known that inference in panel data estimation can be significantly biased by the presence of serial correlation (Baltagi, 2005; Wooldridge, 2010). Given that both the net migration rate and air pollution levels at time t may be affected by lagged variables, we account for potential serial correlation by including up to two lags of the time-varying controls in our model. The results presented in columns (3) and (6) of Table A.8 confirm that the inclusion of lagged controls does not alter the primary results, thereby demonstrating the robustness of our main findings.

7 Conclusions

This study provides compelling evidence on the significant impact of air pollution on migration decisions within Italy. Utilizing data from 2003 to 2019 and focusing on provincial capital municipalities, we demonstrate that reductions in PM10 pollution levels significantly enhance the attractiveness of these areas to potential migrants.

Our analysis examines the effectiveness of environmental regulation in Italy in reducing pollution levels, focusing in particular on the legislative decrees LD 152/2006 and LD 155/2010. Municipalities that implemented environmental measures to comply with these regulations, such as traffic restrictions, the creation of pedestrian areas, and other environmental measures, saw significant improvements in air quality. The results indicate that these interventions reduced air pollution by about half, compared to the pre-intervention period.

Specifically, our results show that the combined effect of the two legislative decrees led to an increase of approximately three new citizens per 1,000 inhabitants in the treated municipalities after the legislative measures were enacted. This demonstrates a clear link between improved air quality due to legislative intervention and increased attractiveness of these areas for potential migrants.

From an environmental policy design perspective, our analysis highlights both the effectiveness and limitations of a command-and-control policy paradigm. While this type of policy proves effective in reducing the frequency of PM10 exceedances, particularly in communities with higher levels of pollution, it does not appear as effective in areas that are already in compliance. Conversely, our empirical research finds that communities implementing more comprehensive environmental policies not only experience reductions in pollution, but also become more attractive to individuals, including high-income residents.

Furthermore, our research contributes to the existing literature by providing robust evidence of the role of environmental quality in migration decisions within a developed country context. By demonstrating the positive impact of targeted legislative interventions on local air quality and migration patterns, our findings underscore the importance of proactive environmental policies in enhancing the attractiveness and livability of municipalities. These findings highlight the need for continued efforts by local governments to prioritize environmental sustainability and improve the quality of life for their residents.

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A *Tables*

Table A.1: Descriptive statistics

	2003-2006		2007-2010		2011-2019	
	mean	sd	mean	sd	mean	sd
Net-migration	-2.478	5.141	-1.644	4.23	.804	4.11
Low-income	318.638	49.421	300.254	49.424	283.214	53.707
Middle-income	639.034	40.966	649.964	40.372	660.754	44.037
High-income	42.328	14.447	49.781	16.742	56.032	19.848
Exceeding days	80.808	53.576	56.171	45.218	34.817	31.925
Traffic e. EU3	.	.	.	.	4.191	17.502
Traffic p. EU3	.	.	.	.	45.288	92.913
Ztl	.	.	.	.	.264	.441
Pedestrian	29.072	57.327	31.385	58.212	38.142	70.625
Bike-lane	18.16	23.245	23.94	30.611	33.821	41.05
Ln(wage)	9.891	.114	9.949	.117	9.964	.13
Ln(pop)	11.597	.887	11.503	.864	11.494	.871
eu0123	92.889	7.965	66.116	9.148	25.01	19.187
Trasp. Demand	98.579	116.71	93.552	116.149	83.159	110.385
Motorisation rate	631.167	144.541	633.734	153.582	654.434	179.249
Vehicle density	1113.80	1173.60	1030.64	1140.60	1034.57	1132.09
Bus	672.014	1.691.775	580.45	1.541.172	476.067	1.246.709
Tram	64.908	388.089	58.964	372.905	60.434	300.945
Trolleybus	12.963	65.031	13.346	65.355	11.933	57.873
Metro	202.58	1.219.895	192.115	1.205.885	214.902	1.362.241
Mayor's Degree	.737	.441	.762	.426	.716	.451
Mayor's Age	52.842	7.381	54.419	8.388	53.195	9.187

Note: Descriptive statistics of all variable in the analysis. Sample of provincial capital municipalities. Period: 2003-2019.

Table A.2: Descriptive statistics for treatment and control groups (2003-2006)

	Control			Treatment		
	mean	sd	N	mean	sd	N
Net-migration	-1.714	5.058	117	-2.88	5.15	222
Low-income	500.44	60.341	117	467.315	42.099	222
Middle-income	459.406	51.245	117	483.895	34.697	222
High-income	36.653	13.973	117	45.318	13.81	222
Exceeding days	33.453	27.136	117	105.766	46.803	222
Traffic e. EU3	.	.	0	.	.	0
Traffic p. EU3	.	.	0	.	.	0
Ztl	.	.	0	.	.	0
Pedestrian	37.774	90.069	117	24.314	24.681	214
Bike-lane	11.834	21.486	117	21.619	23.488	214
Ln(wage)	9.848	.121	117	9.914	.104	222
Ln(pop)	11.344	.704	117	11.73	.944	222
eu0123	92.894	7.083	117	92.886	8.404	222
Trasp. Demand	81.853	124.35	117	107.394	111.759	222
Motorisation rate	612.463	68.642	117	641.025	170.871	222
Vehicle density	718.555	572.181	117	1.322.107	1.344.761	222
Bus	326.078	436.942	117	857.677	2.050.379	218
Tram	.396	1.959	117	98.908	476.428	222
Trolleybus	0	0	117	19.795	79.575	222
Metro	1.891	10.097	117	308.349	1.497.789	222
Mayor's Degree	.701	.46	117	.757	.43	222
Mayor's Age	53.937	8.254	111	52.284	6.847	218

Note: Descriptive statistics of all variable in the analysis by treatment and control groups. Sample of provincial capital municipalities. Period: 2003-2006.

Table A.3: Descriptive statistics for treatment and control groups (2007-2010)

	Control			Treatment		
	mean	sd	N	mean	sd	N
Net-migration	-1.405	4.394	177	-1.832	4.095	224
Low-income	464.877	57.479	180	418.198	38.445	224
Middle-income	488.436	47.878	180	523.021	30.294	224
High-income	42.67	14.646	180	55.496	16.148	224
Exceeding days	31.511	27.646	180	75.987	46.864	224
Traffic e. EU3	.	.	0	.	.	0
Traffic p. EU3	.	.	0	.	.	0
Ztl	.	.	0	.	.	0
Pedestrian	36.087	81.606	180	27.521	26.177	219
Bike-lane	14.397	27.963	180	31.784	30.523	219
Ln(wage)	9.9	.114	180	9.989	.105	224
Ln(pop)	11.212	.655	180	11.738	.938	224
eu0123	69.72	7.363	178	63.226	9.423	224
Trasp. Demand	67.983	103.242	180	114.099	121.952	224
Motorisation rate	630.636	65.798	180	636.224	197.831	224
Vehicle density	639.091	558.869	180	1.345.283	1.370.113	224
Bus	254.944	364.316	180	843.19	2.009.673	223
Tram	2.496	13.598	180	104.341	496.5	224
Trolleybus	0	0	180	24.071	86.369	224
Metro	1.192	7.93	180	345.535	1.604.619	224
Mayor's Degree	.75	.434	180	.772	.42	224
Mayor's Age	55.291	8.597	175	53.721	8.17	219

Note: Descriptive statistics of all variable in the analysis by treatment and control groups. Sample of provincial capital municipalities. Period: 2007-2010.

Table A.4: Descriptive statistics for treatment and control groups (2011-2019)

	Control			Treatment		
	mean	sd	N	mean	sd	N
Net-migration	-.524	3.967	427	1.937	3.888	500
Low-income	438.112	63.253	421	381.231	44.65	500
Middle-income	510.081	53.225	421	551.776	38.319	500
High-income	47.272	17.689	421	63.409	18.539	500
Exceeding days	19.047	23.561	427	48.284	31.982	500
Traffic e. EU3	1.494	12.146	328	6.472	20.734	388
Traffic p. EU3	11.223	41.404	328	74.085	112.633	388
Ztl	.168	.374	328	.345	.476	388
Pedestrian	35.337	77.229	427	40.576	64.329	492
Bike-lane	18.901	33.73	415	46.406	42.465	492
Ln(wage)	9.9	.121	421	10.019	.111	500
Ln(pop)	11.185	.652	427	11.757	.945	500
eu0123	27.748	20.978	427	22.672	17.192	500
Trasp. Demand	61.319	116.518	427	101.809	101.315	500
Motorisation rate	657.545	126.424	427	651.777	214.392	500
Vehicle density	665.622	658.386	427	1349.66	1.338.785	500
Bus	207.788	288.085	427	705.177	1.642.944	500
Tram	19.088	104.181	427	95.743	395.082	500
Trolleybus	.619	4.284	427	21.595	77.437	500
Metro	2.272	18.084	427	396.488	1.836.201	500
Mayor's Degree	.693	.462	427	.736	.441	500
Mayor's Age	55.42	9.155	395	51.405	8.823	491

Note: Descriptive statistics of all variable in the analysis by treatment and control groups. Sample of provincial capital municipalities. Period: 2011-2019.

Table A.5: Net migration rate - comparison between different control groups

	Net-migration			
	(1)	(2)	(3)	(4)
$LD152_{(t-1)}$	1.141*	-0.025	-0.219	0.984
	[0.515]	[1.322]	[1.004]	[1.125]
$LD155_{(t-1)}$	2.644***	1.214	0.160	0.321
	[0.461]	[1.210]	[0.630]	[0.811]
Controls	yes	yes	yes	yes
FE	yes	yes	yes	yes
Observations	1278	605	607	242

Note: The table shows the results of the diff-in-diff estimation comparing different control groups. The dependent variable is the net migration rate. Column (1) compares the treatment group with never exceeded the annual PM10 limit between 2003-2006. Columns (2)-(4) excludes the treatment group. Column (2) compares those that exceeded the PM10 daily limit for more than 34 days only in the last years (i.e., fake treated) with those never exceeded. Column (3) compares those that exceeded the annual PM10 limit for more than 34 days in the last two years (i.e., fake treated) with those never exceeded. Column (4) compares those that exceeded the PM10 daily limit for more than 34 days in the last two years (i.e., fake treated) with those exceeded the annual limit only in the last years. $LD152$ is the interaction between a dummy equal to 1 for fake treated provincial capital municipalities and a dummy equal to 1 from 2007 onwards. $LD155$ is the interaction between the dummy for fake treated and a dummy equal to 1 from 2011. All columns include year and provincial capital municipality fixed effects, and time-varying controls. Clustered standard errors accounting for contemporaneous spatial correlation are in brackets. Significance is denoted as follows: * significant at the 10% level; ** significant at the 5% level; ***significant at the 1% level.

Table A.6: Exceeding days - comparison between different control groups

	Exceeding days			
	(1)	(2)	(3)	(4)
$LD152_{(t-1)}$	-35.542***	28.133***	8.701	2.898
	[7.906]	[6.629]	[7.784]	[10.520]
$LD155_{(t-1)}$	-16.741***	5.267	1.848	11.342
	[4.001]	[5.472]	[4.758]	[7.675]
Controls	yes	yes	yes	yes
FE	yes	yes	yes	yes
Observations	1338	625	627	258

Note: The table shows the results of the diff-in-diff estimation comparing different control groups. The dependent variable is the maximum number of days exceeding the PM10 daily limit. Column (1) compares the treatment group with never exceeded the annual PM10 limit between 2003-2006. Columns (2)-(4) excludes the treatment group. Column (2) compares those that exceeded the PM10 daily limit for more than 34 days only in the last years (i.e., fake treated) with those never exceeded. Column (3) compares those that exceeded the annual PM10 limit for more than 34 days in the last two years (i.e., fake treated) with those never exceeded. Column (4) compares those that exceeded the PM10 daily limit for more than 34 days in the last two years (i.e., fake treated) with those exceeded the annual limit only in the last years. $LD152$ is the interaction between a dummy equal to 1 for fake treated provincial capital municipalities and a dummy equal to 1 from 2007 onwards. $LD155$ is the interaction between the dummy for fake treated and a dummy equal to 1 from 2011. All columns include year and provincial capital municipality fixed effects, and time-varying controls. Clustered standard errors accounting for contemporaneous spatial correlation are in brackets. Significance is denoted as follows: * significant at the 10% level; ** significant at the 5% level; ***significant at the 1% level.

Table A.7: Enviromental interventions

	Traffic E.	Traffic P.	Ltz	Pedestrian	Bicycle-lane
	(1)	(2)	(3)	(4)	(5)
Over 34 ex. days	56.143***	129.286***	0.286***	9.678***	37.922***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Muncipality FE	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes
Observations	791	791	791	1612	1591

Note: The table presents results for regressing the dummy treatment over 34 exceeding days of PM10 limit between 2003-2006 on a number of covariates related to enviromental measures to reduce air pollution. *Traffic E.* is the number of emergency traffic blocking days per EURO 3 vehicle. *Traffic P.* is the number of programmed traffic blocking days per EURO 3 vehicle. *Ltz* is a dummy equal to one if there is the presence of limited traffic zones in the municipality. *Pedestrian* is the availability of pedestrian areas in the municipality measured as m^2 per 100 inhabitants. *Bicycle-lane* is the bicycle lane density measured as km per 100 km^2) . Clustered t-statistics accounting for within-municipality correlation are in parentheses. Significance is denoted as follows: * significant at the 10% level; ** significant at the 5% level;***significant at the 1% level.

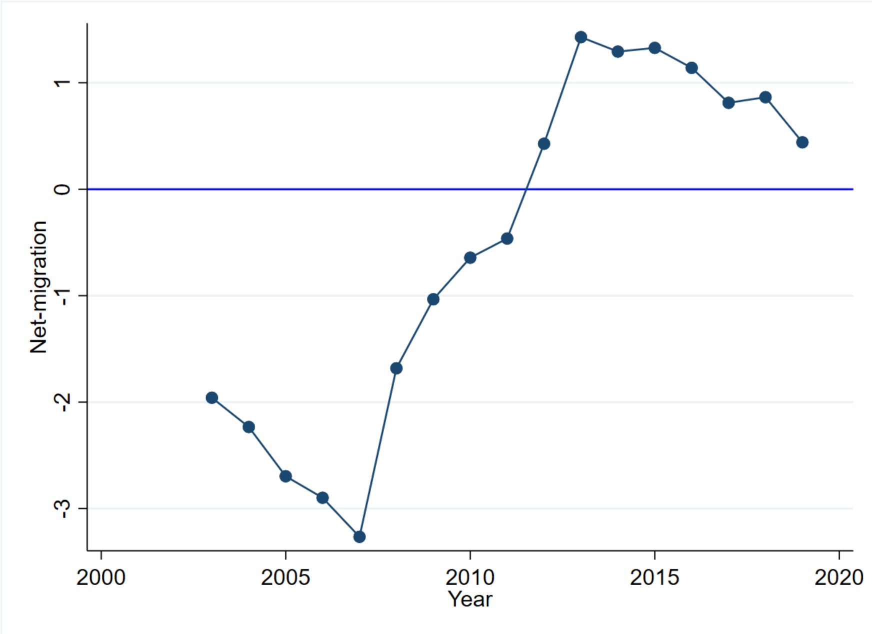
Table A.8: Further robustness

	Net-migration			Exceeding days		
	(1)	(2)	(3)	(4)	(5)	(6)
$LD152_{(t-1)}$	0.940*	1.049*	0.988*			
	[0.434]	[0.421]	[0.478]			
$LD155_{(t-1)}$	2.000***	2.265***	1.878***			
	[0.393]	[0.395]	[0.420]			
$LD152_t$				-31.484***	-33.247***	-32.379***
				[5.809]	[6.025]	[7.870]
$LD155_t$				-17.654***	-13.984***	-13.446***
				[4.132]	[3.768]	[3.533]
Controls	yes	yes	yes	yes	yes	yes
Lagged controls			yes			yes
FE	yes	yes	yes	yes	yes	yes
Region trend	yes			yes		
Observations	1520	1623	1337	1596	1529	1340

Note: The table show the results for the diff-in-diff for both Eq.1 and 2. The dependent variable is the net migration rate (for Eq. 1) and the number of PM10 limit exceeding days (for Eq. 2). Columns (1) and (4) includes 20 region-specific trends. Columns (2) and (5) exclude Milano, Roma, Napoli and Torino from the sample. Columns (3) and (6) includes two lags for each time-varying control. All Columns include contemporaneous time-varying controls, provincial capital municipality fixed effects and year fixed effects. Clustered standard errors accounting for within-municipality correlation are in parentheses. Significance is denoted as follows: * significant at the 10% level; ** significant at the 5% level;***significant at the 1% level.

B *Figures*

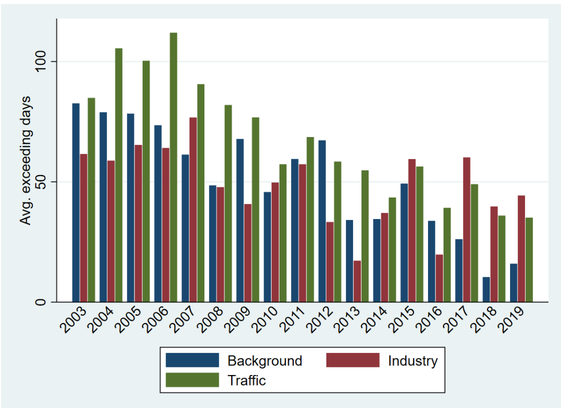
Figure B.1: Municipal net migration rate. 2003-2019



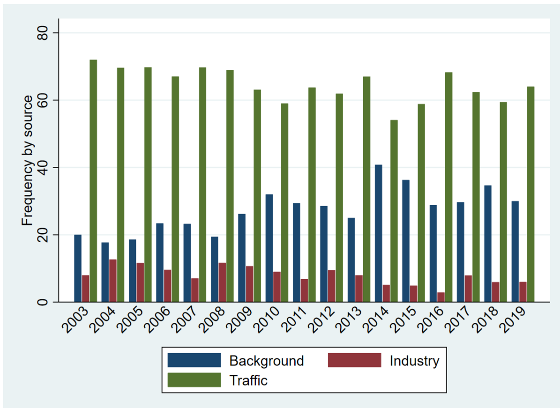
Notes. The Figure shows the average net migration rate for each year in provincial capital municipalities, i.e, the difference between people registered in municipality i from other municipalities and those deleted from municipality i to migrate toward other municipalities per 1000 inhabitants, 2003-2019.

Figure B.2: Average of exceeding days of PM10 limit and Relative frequency per type of monitoring stations over years.

(a) Average of exceeding days

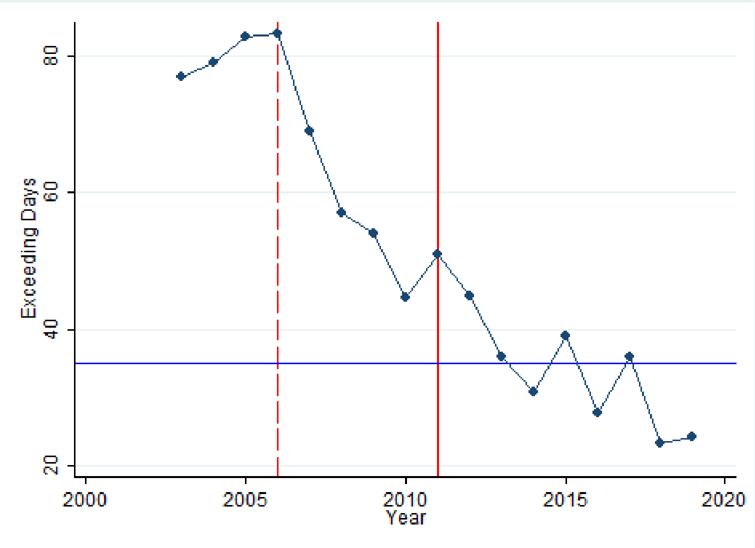


(b) Relative frequency



Note. The graph depicts the annual mean of the number of days when PM10 exceeds the daily limit of $50\mu g/m^3$ per type of monitoring station (Graph B.2a) and the annual relative frequencies of cities that have reached the maximum number of exceedances for a specific type of monitoring station (Graph B.2b). The types of monitoring stations are background, industry, and traffic. Years 2003-2019.

Figure B.3: Average exceeding days of PM10 limit. 2003-2019



Notes. The figure shows the yearly average number of exceeding days when PM10 exceeds the daily limit of $50\mu g/m^3$ in provincial capital municipalities . Years 2003-2019.