ACNP Catalogo Italiano dei Periodici

uscite

Economia politica (Bologna. Online)

Luogo : Editore	Bologna : Il Mulino Cham : Springer
Da anno - Ad anno	1990-
Natura	Periodico
Periodicità	Quadrimestrale
Lingua	Italiano
Paese di pubblicazione	Svizzera
ISSN	1973-820X
ISSN-L	1120-2890
Codice Dewey	338.9
Codice rivista	PT02263967
Fonte	temp
Supporto	On-line (remote)
Accesso pubblico alla rivista	http://www.springer.com/economics/policy/journal/40888 http://www.rivisteweb.it/issn/1120-2890
Ha per altro supporto	Economia politica
Poss. cumulativo Acnp	**1990-**
Permalink	https://acnpsearch.unibo.it/journal/2263967
Full Text	29

Doc. Delivery   Titoli Collegati   Altri link   Cerca doni

Economia Politica
https://doi.org/10.1007/s40888-024-00348-9

ORIGINAL PAPER

Do environmental crimes contribute to air pollution? Empirical evidence and effects on health

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Received: 1 December 2023 / Accepted: 4 September 2024

Abstract

This paper investigates the effect of environmental crimes on ambient air pollution in Italy, using annual provincial data over the period 2010–2016. While the impact of ambient air pollution on health has been the focus of a significant amount of literature, a nascent body of works is focusing on the impact of illegal behavior on environmental quality. Our work is ideally divided in two steps: firstly, we identify and assess empirically the potential correlation between environmental crimes and four different kinds of ambient air pollution. Secondly, we identify the health impacts that may be triggered by environmentally harmful illegal activities, through their impact on ambient air pollution, by linking them to existing contributions. Our findings suggest that the existence of such an "indirect" link may indeed be confirmed. We find that higher levels of $PM_{2.5}$, PM_{10}, and O_3 concentration are associated with higher levels of environmental crimes related to forest fires and landscape violations (except for PM_{10} in the latter case), while NO_2 concentration is not significantly associated with any environmental crime. On the other hand, we also find non-linearities in the estimated correlations. We conclude our analysis by providing a straightforward quantification of health-related impacts of ambient air pollution changes potentially triggered by criminal environmental behaviors. We hope that our findings could contribute to a more accurate evaluation of environmental crime impacts and, subsequently, inform future criminal environmental enforcement and environmental policies.

Keywords Ambient air pollution · Environmental crime · Health · Panel data · Italy

JEL Classification I18 · Q53 · K32

Extended author information available on the last page of the article

Published online: 18 October 2024

1 Introduction

Environmental crime is one of the most profitable criminal enterprises worldwide, generating from \$110 to \$281 billion in criminal gains each year (FATF, 2021). Characterized by low risks and high profits, it affects many economic sectors, ranging from waste to agri-food, from construction to cultural heritage, from forest fires to wildlife (Europol, 2022).

According to *Legambiente*, the most prominent Italian environmental NGO, in 2023, more than 35,000 environmental crimes (including illegal trafficking and disposal of waste, biodiversity and wildlife violations, arsons, illegal constructions, fraud in the agri-food sector, etc.) were ascertained, with more than people arrested, and 60,000 administrative offenses contested, with most of the reported crimes (more than 43%) committed in Southern Italy (Legambiente, 2024). It is estimated that environmental crime businesses, also known in Italy as *ecomafie*, have had in 2023 a turnover of almost €9 billion, equal to 0.4% of GDP (Legambiente, 2024). As a result, environmental crimes have become a central issue in the agenda setting of Italian policymakers (Legambiente, 2024).

An assessment of the existing literature suggests that there are two prevalent strands focusing either on the relationship between air pollution and health or on the determinants of environmental crime. The most recent literature on environmental crime in Italy (Germani et al., 2015, 2020; Dell'Anno et al., 2020; D'Amato et al., 2015, 2018) has indeed focused on the various determinants of crime, but, nevertheless, there is a lack of empirical research on the link between environmental crime and air pollution. This link is expected to be equally relevant, since health outcomes may *indirectly* be explained by illegal environmental behaviors, leading to the potential conclusion that such behaviors could trigger harmful effects on health. Moreover, its assessment and quantification are also important for making environmental enforcement policies more effective to tackle illegal behaviors (D'Amato et al., 2018). Since a policy enforcement against environmental crimes may indirectly reduce air pollution, when the government engages in fighting illegal environmental activities (specifically wildfires and landscape crimes), it also (at least partly) indirectly combats air pollution.

To the best of our knowledge, there is no evidence on the potential effects of environmental crime on ambient air pollution, in Italy. In what follows, we aim to fill in this gap, focusing on whether, and to what extent, environmental crime affects air pollution, using annual judicial data for 110 Italian provinces, over the period 2010–2016, and employing fixed effects models. We not only present the first empirical validation of the association between environmental crime and air pollution in Italy, but we also contribute to the already established literature on the effects of exposure to elevated levels of air pollution (WHO, 2018) for a wide range of respiratory, cardiovascular and neurological diseases (GBD, 2019; Cohen et al., 2017). While the overall scope of the analysis makes this study particularly innovative, the heterogeneity of results confirms that environmental crime is a complex and multi-faceted phenomenon given that multiple types—specifically

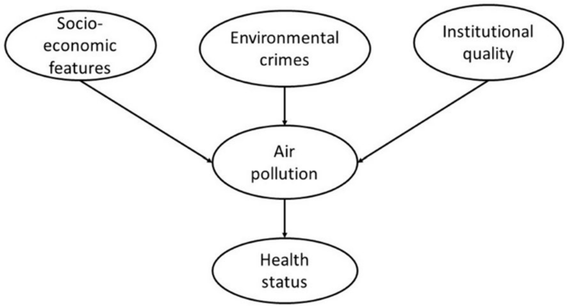


Fig. 1 Simplified conceptual framework

forest fires and landscape-related crimes—affect air pollution, thus posing serious challenges to policymakers.

More in particular, our results suggest that ignoring the link between environmental crime and air pollution would lead to an underestimation of the impacts of air pollution on human health and its societal costs.

The remainder of the manuscript is organized as follows. In Sect. 2, we illustrate a simple conceptual framework for our analysis. Section 3 introduces the data and presents the econometric methodology. Estimation results are discussed in Sect. 4. Section 5 focuses on the discussion of our results in terms of health-related impacts. Section 6 summarizes the findings and discusses some policy implications.

2 Conceptual framework

The aim of this section is to provide a conceptual background to our analysis. We assess both the main potential drivers of the link between socio-economic and judicial variables and (legal and illegal) air pollution, as well as the possible (direct and indirect) links between air pollution and health. The conceptual framework is kept as simple as possible and is reported in Fig. 1.

First, we focus on the impact of socio-economic features of the local economic system under scrutiny on the amount of air pollution. This link is expected to depend on the socio-economic variables related to total added value and its sectoral composition, education, and employment level. Better economic conditions are indeed expected to drive upward air pollution, due to a larger level of economic activity *ceteris paribus*, but a better social capital (e.g., measured by a higher level of education) can lead -to lower air pollution. This part of the analysis relates to the standard determinants of air pollution and, more generally, to its environmental impacts according to the relevant literature (e.g., Ji et al., 2018; Mazzanti & Zoboli, 2009).

Second, illegal environmental behaviors are expected to increase air pollution. This is the central part of our work: indeed, our empirical analysis aims at identifying whether, and to what extent, changes in the number of the selected environmental crimes are expected to increase air pollution and, as a result, to harm health. Clearly, the enforcement setting is expected to matter in determining environmental impacts (Almer & Goeschl, 2010; Eckert, 2004; Germani et al., 2020; Helland, 1998; Stafford, 2002) as well as the ability of institutions to cope with it. The monitoring and enforcement effort are a basic factor potentially affecting illegal behaviors; more specifically, as it is highlighted in the public enforcement of law literature (e.g. Polinsky & Shavell, 2000), the shape of monitoring and enforcement effort, determining the degree of deterrence featured in specific geographical context, will also drive the incentives of (rational) agents to engage in illegal activities, on the basis of the related costs and benefits, degree of risk aversion etc. This is a third dimension of our analysis, as we specifically control for relevant institutional and crime-related variables, including institutional quality, corruption, general crime index and entrepreneurial density.

The final part of our work is the one linking air pollution to health-related outcomes. This is done by referring to the main literature and, especially, to the contributions in relation to Italy (Giaccherini et al., 2021; Lagravinese et al., 2014; Martuzzi et al., 2006; Vigotti et al., 1996). Combining our empirical effort with the existing contributions will allow us to "quantify" the impact of environmental crimes on health, as vehiculated by the related effects on air pollution.

3 Data description and empirical strategy

3.1 Data and variables description

Our panel consists of annual data for the 110 Italian provinces (NUTS-3) over the seven-year period 2010–2016. Data on ambient air pollution (PM_{10}, $PM_{2.5}$, O_3, NO_2) were provided by the Italian Institute for Environmental Protection and Research (ISPRA), responsible for the National Emission Inventory. All the other data were obtained from the Italian Statistical Agency (ISTAT), and the Union of Italian Chambers of Commerce (*Istituto Tagliacarne*). Table 1 presents a summary of the variables that we used in our estimations. Official judicial statistics on environmental crime in Italy are only available at regional level and for the period 2006–2016. The limited availability of these data is a major problem in Italy that also undermines the effectiveness of prosecutions and enforcement actions.

By merging the above described environmental, judicial, and socio-economic data we produced a database that, as we believe, can contribute to raise some initial attention to the still unexplored nexus between environmental crime and air pollution-health in Italy. More specifically, we will focus on the largely underexplored link between environmental crimes and air pollution, while we will use the available literature to quantify the link between air pollution and health. This will allow us to provide an assessment on how environmental crime may affect health indirectly, through harming environmental quality.

3.2 Dependent variables

Our focal indicators of local air pollution refer to the annual average mass concentration—measured at monitoring station level—of particulate matter ($PM_{2.5}$

Table 1 Variables description and data sources (years 2010–2016)

Variable	Description	Source
Dependent variable(s)		
$PM_{2.5}$	Annual average of the mass concentration (μg/m^3) of $PM_{2.5}$	ISPRA
PM_{10}	Annual average of the mass concentration (μg/m^3) of PM_{10}	ISPRA
O_3	Number of days exceeding the threshold for ozone	ISPRA
NO_2	Annual average of the mass concentration (μg/m^3) of NO_2	ISPRA
Environmental crime explanatory variables		
Wastewater violations	Ratio of wastewater criminal proceedings over population per 100,000 inhabitants	ISTAT
Waste violations	Ratio of waste criminal proceedings over population per 100,000 inhabitants	ISTAT
Forest fires violations	Ratio of forest fires criminal proceedings over population per 100,000 inhabitants	ISTAT
Landscape violations	Ratio of landscape criminal proceedings over population per 100,000 inhabitants	ISTAT
Construction violations	Ratio of construction criminal proceedings over population per 100,000 inhabitants	ISTAT
Economic explanatory variables		
Employment rate	Rate of employment	ISTAT
Total added value	Per capita added value at provincial level (in million €, at current prices)	ISTAT
Added value	Added value is broken down in the following economic sectors: (i) agriculture, forestry, and fishing, (ii) manufacturing, (iii) services	ISTAT
Other socio-economic explanatory variables		
Education	Average years of study of the population aged at least 25	ISTAT
Crime index	Number of crimes reported by the police forces to the judicial authorities	ISTAT
Corruption	Number of people convicted of corruption	ISTAT
Infrastructure index	General index of economic infrastructures	*Istituto Tagliacarne*
Entrepreneurial density	Registered firms × 100 inhabitants	*Istituto Tagliacarne*
Tourism	Attendance (Italians and foreigners) in hotels and complementary businesses (number of days)	ISTAT
Energy consumption	Consumption of energy (in MWh) in agriculture, industry, and services sectors	ISTAT

Table 1 (continued)

Variable	Description	Source
Population	Resident population as of 31 December by province	ISTAT
Area	Extension of the territory of the province in square kilometers	ISTAT

ISPRA, https://www.isprambiente.gov.it/it/banche-dati; ISTAT, http://dati.istat.it/; *Istituto Tagliacarne*, https://www.tagliacarne.it/linee_di_attivita-33/

and PM_{10}), nitrogen dioxide (NO_2) and ozone (O_3) which are considered amongst the main anthropogenic emissions responsible for detrimental air quality and the most important pollutants in terms of potential risk for human health (EEA, 2018). $PM_{2.5}$ and PM_{10} are particle air pollutants 2.5 and 10 µm, respectively, in aerodynamic diameter. In particular, for province *i* in year *t*, we take the annual average concentration of each pollutant, registered by all monitoring stations (i.e., traffic, industrial and background stations in urban, suburban and rural areas).[1],[2] Figure 2 depicts the geographical distribution of each dependent variable in terms of average values (2010–2016) of air pollutant by type for the 110 Italian provinces. The peculiarity of the Italian context in terms of economic dualism across more developed Northern/Central and less developed Southern regions seems to be confirmed with the evidence of the clear asymmetries in the geographical distribution of air pollution between Northern and Southern regions in the considered time frame.

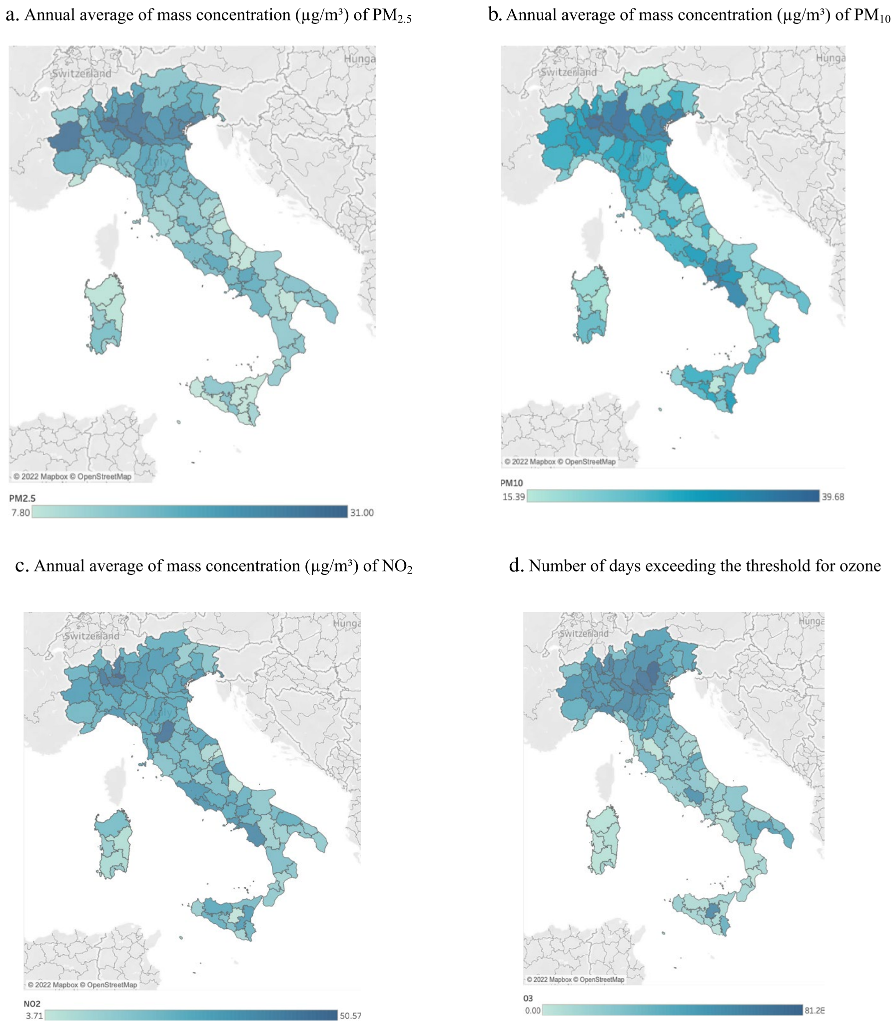
From Fig. 2, we can, in fact, observe a strong spatial heterogeneity which is fairly consistent across all the four measures of air pollution considered.

While air pollution in the Northern provinces is generally higher due to the high level of industrialization and urbanization, in the Southern provinces the presence of highly environmentally impacting industrial plants plays a very relevant role. The provinces with a darker color exhibit higher average mass concentration of pollution: in the Northern regions of Piedmont, Lombardy and Veneto, the provinces of Turin, Milan, Cremona, Monza, Lodi, Brescia, Padua and Venice show the highest concentration of $PM_{2.5}$. Similarly, the same Northern provinces exhibit the highest concentration levels of PM_{10} with the addition of some Northern provinces (Vicenza and Rovigo in the Veneto region) and some Southern provinces (Rome, Latina, Frosinone in the Lazio region, and all the provinces in the Campania region). PM_{10} and $PM_{2.5}$ often derive from different emissions sources: emissions from combustion of gasoline, oil, diesel fuel or wood produce much of the $PM_{2.5}$ pollution found in outdoor air, as well as a significant proportion of PM_{10}. PM_{10} also includes dust from construction sites, landfills and agriculture, wildfires and brush/waste burning, industrial sources, and wind-blown dust from open lands.[3] Nitrogen dioxide (NO_2) shows the highest average mass concentration in the Northern regions of Lombardy and Piedmont (provinces of Milan, Como, Monza, Novara);

[1] According to the Italian Legislative Decree 155/2010 (Annex I), for most of the pollutants, monitoring stations have to fulfill the criterion of reporting more than 75% of valid data out of all the possible data in a year. In certain years, several stations did not achieve this data quality objectives (also in terms of number) and, therefore, the respective provinces will display missing values for our index.

[2] More specifically, we aggregated data from different types of monitoring stations: traffic stations are those located in close proximity to a single major road, while industrial stations are those located in close proximity to an industrial area or an industrial source. At the background stations, pollution levels are representative of the average exposure of the general population or vegetation. The area surrounding these stations is further classified as i) urban (continuously built-up urban area), ii) suburban (largely built-up urban area), and iii) rural (all other areas). For each pollutant, we first calculated the average concentration, for each year, of the different monitoring stations; then, we calculated the average province-level indicators of pollution of the so obtained means.

[3] The description of pollutants and their sources are taken from the U.S. E.P.A. website. See https://www.epa.gov/environmental-topics/air-topics.



Source: authors' elaboration on ISPRA data (2010-2016)

Fig. 2 Territorial heterogeneity of air pollution—geographical (province-level) distribution of each type of considered air pollutant (2010–2016, average values). **a**. Annual average of mass concentration (µg/m^3) of $PM_{2.5}$. **b**. Annual average of mass concentration (µg/m^3) of PM_{10}. **c**. Annual average of mass concentration (µg/m^3) of NO_2. **d**. Number of days exceeding the threshold for ozone. *Source:* authors' elaboration on ISPRA data (2010–2016)

in the Central regions of Tuscany and Lazio (provinces of Florence, Rome, and Latina); in the Southern regions of Abruzzo and Campania (provinces of Teramo, Pescara, Naples and Salerno). The main human sources of nitrogen dioxide are related to the combustion of fossil fuels (coal, gas, and oil) especially fuel used in cars, but also from power plants, industrial emissions, and off-road sources such as construction sites. The ozone (O_3) in the atmosphere is another dangerous pollutant that can cause negative health effects even at low levels; its main sources come from pollution emitted from cars, power plants, industrial boilers, refineries, and chemical plants. Ozone pollution is very diffusely concentrated in several Northern provinces, but also in some Central (i.e., Frosinone in the Lazio region) and Southern provinces (i.e., Syracuse and Enna) in the Sicily region.

3.3 Independent variables

The main independent variables used in the regression model consists in the number of criminal proceedings for environmental crimes, at regional level, regulated by both the Environmental Code and by the Italian Penal Code,[4] which includes (i) *illegal constructions*, (ii) *illegal waste disposal*, (iii) *illegal wastewater discharges*, (iv) *offenses in terms of landscape violations*, and (v) *illegal forest fires*.[5] All the values are expressed in per capita for one hundred thousand inhabitants for each region.[6] We aim to explore whether the Italian regions that suffer higher levels of environmental illegality are also those that experience higher levels of air pollution. Our main idea behind the use of environmental crimes is that environmental violations (i.e., illicit disposal of waste, illegal constructions, forest fires, etc.) may contribute to activities that could be destructive for the environment, feeding environmental degradation through an increase of local air pollution. Figure 3 depicts the geographical distribution of each environmental crime type in terms of average values of criminal proceedings.

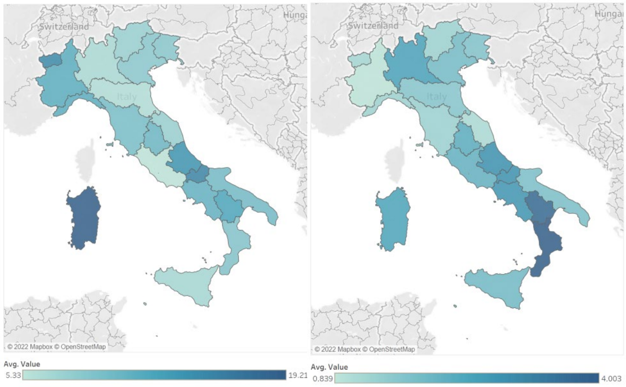
With regard to waste-related criminal proceedings, the regions with a darker colour exhibit higher average numbers of criminal proceedings. In Fig. 3a, for this specific type of crime, the cross-regional territorial heterogeneity rate (measured as the ratio of criminal proceedings over population per 100,000 inhabitants) seems to suggest that a North/Center versus South bifurcation is less pronounced. However, amongst the Southern regions, Sardinia exhibits the highest incidence of waste proceedings and, overall, the South area accounts for approximately the 44% of the total waste-related criminal proceedings in Italy, while the North and the Center account for the 33% and the 23%, respectively. Looking to wastewater-related

[4] The Environmental Code (Law Decree 152/2006) regulates several issues: environmental impact assessment, protection of soil and water, regulation of the waste and wastewater sectors, and decontamination of polluted sites. It consists of seven parts: (i) Environmental general principles, (ii) Environmental impact assessment and integrated pollution prevention and control (lPPC) permit, (iii) Water resources management and soil protection, (iv) Waste and packaging management, (v) Remediation of contaminated sites, (vi) Air protection and air emissions, (vii) Environmental Damage.

[5] In the Italian legislation, waste and wastewater violations are included in the Environmental Code (L.D. 152/2006) which defines and regulates the proceedings related to waste and water resources management (such mixing of waste, unauthorized waste management, illegal traffic of waste, discharges of wastewater from industrial plants or non-compliant behaviors with regard to maximum pollution thresholds). In the Penal Code are regulated the other types of environmental offenses considered, i.e., forest fires, violations related to construction and urban planning, and violations in the landscape sector.

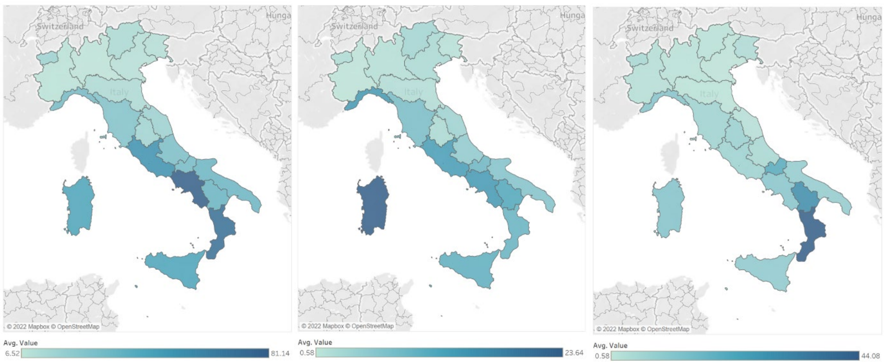
[6] The Italian territory is composed by twenty regions; a province is an administrative sub-division of a region, which is an administrative sub-division of the State. Provinces are equally distributed on the territory between northwest, northeast, center and south, even though the level of urbanization is higher in the northern area of the country.

a. **Waste**-related criminal proceedings b. **Wastewater-**related criminal proceedings



Source: authors' elaboration on ISTAT data (2010-2016)

c. **Illegal construction** criminal proceedings d. **Landscape**-related criminal proceedings e. **Forest fires** criminal proceedings



Source: authors' elaboration on ISTAT data (2010-2016)

Fig. 3 Territorial heterogeneity of environmental crime type—geographical (region-level) distribution of proceedings for each type of considered environmental crime (2006–2016, average values). **a**. Waste-related criminal proceedings. **b**. Wastewater-related criminal proceedings. **c**. Illegal construction criminal proceedings. **d**. Landscape-related criminal proceedings. **e**. Forest fires criminal proceedings. *Source:* authors' elaboration on ISTAT data (2010–2016)

criminal proceedings, in Fig. 3b, we can observe that a North/Center and South territorial divide is indeed more evident; overall, the South area accounts for the 46% of the phenomenon, against the 25% of the Center and the 41% of the North.

Considering illegal construction-related proceedings, in Fig. 3c, it is possible to observe a clear South macro-territorial prevalence (holding the 62.5% of the total criminal proceedings) compared to the North (10.3%) and to the Center (27.2%). With regard to landscape-related violations (i.e., mines and quarries), in Fig. 3d, it is possible to observe a prevalence of the South area, which accounts for the 59.1% of the total proceedings in this type of crime, compared to the North (11.1%) and the Center (29.8%). In relation to forest fires proceedings, in Fig. 3e, we can observe again a Southern prevalence. Overall, in the South area it is concentrated almost the 70% of the total number of forest fires criminal proceedings.

All the other independent variables are at provincial level. They were chosen according to the most commonly used in the economics of environmental crime literature (Almer & Goeschl, 2010; D'Amato et al., 2015; Germani et al., 2020; Helland, 1998; Stafford, 2002) and are motivated by the broad types of factors underlying Cole (2007) and Biswas et al. (2012) models, which consider the effects on air pollution not only due to conventional economic factors (i.e., income level, population, urbanization, industrialization, energy intensity, etc.) but also to the shadow economy and the level of corruption.

We control for a number of variables that proxy for the socio-economic and territorial characteristics: we use *employment rate*, *added value* as measures of economic conditions and to capture the role played by the wealth of a province.[7] The existence of a causal link between unemployment, income and air pollution has been widely investigated in the literature (Cole et al., 2005; Deily & Gray, 1991; Ferreira et al., 2013; Luechinger, 2009) since formal pollution regulation by local authorities may depend upon the social territorial problems; *ceteris paribus*, we would expect a province with a high employment rate and higher total added value to devote more resources to pollution control. In addition, the sectoral structure of the economy may influence air pollution; in our empirical specification, we also control for the share of *added valu*e at current prices of (i) *agriculture, forestry, and fishing production*, (ii) *mining, manufacturing, electricity, gas, steam and air conditioning supply, water supply, sewerage, waste treatment and remediation, construction*, and (iii) *services sector*. A higher share of added value in the agriculture/manufacturing/services sectors may be accompanied by higher air pollution emissions (Biswas et al., 2012; Dinda et al., 2000; Friedl & Getzner, 2003). *Educatio*n is also considered to be a relevant variable that can affect air pollution; a higher level of education is expected to increase awareness of environmental hazards and of the related health problems (Bimonte, 2002; Biswas et al., 2012; Farzin & Bond, 2006; Pellegrini & Gerlagh, 2006). In addition, we control for the role of *general crime* and *corruption*; research examining the relationship between corruption and pollution (Biswas et al., 2012; Goel et al., 2013) finds evidence that the presence of corruption and a strong shadow economy may indeed feed environmental degradation through increases in air pollution. This is coherent with the well-established theoretical literature on the impact of corruption on enforcement effectiveness and, therefore, on illegal behaviors (e.g., Polinsky & Shavell, 2000).

We also account for other important determinants of air pollution: the *entrepreneurial density* (number of registered firms every 100 people at the province level) and the *level of infrastructure* present in each province, measured as an

[7] We are not particularly concerned about the correlation between the total added value and the sectoral (decomposed) added value: in fact, the correlation coefficient between (i) agricultural, forestry, fishing production added value and total added value is roughly 0.15, between (ii) mining, manufacturing, electricity, etc. added value and total added value is roughly 0.43, between (iii) services sector added value and total added value is roughly 0.27.

indicator of the transportation infrastructure endowment that may play an important role within the context of the analysis; other things being equal, we would expect a positive relationship between air pollution and production/infrastructural territorial characteristics. We also account for *energy consumption* (Biswas et al., 2012) and *tourism* (Saenz-de-Miera & Rosselló, 2014); increasing energy consumption and resource exploitation in the tourism sector might lead to increased air pollution. Finally, *population* and the size of the territory of the provinces (*area* in km^2) are included as regressors to account for social pressures; arguably, resources are more intensively used in more populated and bigger provinces, with corresponding consequences for the environment. Table 2 provides an overview of the selected variables and their summary statistics: an overall look illustrates significant heterogeneity in our variables, in the time span under consideration. The standard deviation, in particular, displays higher values for NO_2 and O_3 concentration, and for the construction-related environmental crime covariate.

3.4 Identification strategy

We model the relationship between environmental crime and ambient air pollution in Italy, at provincial level over the years 2010–2016, taking into account socio-economic and territorial heterogeneity. To test our hypotheses, we use the following fixed effects panel regression model for each of the four different types of pollutants $PM_{2.5}$, PM_{10}, O_3 and NO_2:

$$y_{it} = \beta_1 EnvCrime_{it} + \beta_2 EnvCrime_{it}^2 + \beta_3 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \tag{1}$$

where subscripts i and t represent emissions for one of the provinces ($i=1, \ldots, 110$) and time period ($t=1, \ldots, 7$), respectively. Therefore, variable y_{it} represents the emissions for the four different types of pollutants $PM_{2.5}$, PM_{10}, O_3 and NO_2 at time t in province i. Variable $EnvCrime_{it}$ represents the five types of environmental crime at time t in province i: illegal constructions, illegal waste disposal, illegal wastewater discharges, landscape violations, and illegal wildfires. This variable enters the model nonlinearly. X_{it} is the set of socio-economic and territorial controls (employment rate, added value and the value added in agricultural/manufacturing/services sectors, education, corruption, crime index, entrepreneurial density, infrastructure index, tourism, energy consumption, population, area). μ_i are the regional fixed effects to control for unobserved heterogeneity and δ_t is the yearly time trend by region. Our main parameters of interest relate to *environmental crimes* (β_1 and β_2).

4 Empirical results and discussion

Estimation results are presented in Tables 3, 4, 5, and 6. In all tables, standard estimates with robust standard errors are provided. Additionally, we provide Bayesian estimates and 90% credibility intervals, analogous to confidence intervals. We use Markov Chain Monte Carlo (MCMC) with diffuse priors on all parameters including the error variance parameter. As it is common, we use

Table 2 Descriptive statistics

Variables	Mean	Median	Std. dev.	Min	Max
Dependent variables					
$PM_{2.5}$ concentration	18.286	17.500	5.585	6.000	39.000
PM_{10} concentration	25.969	25.333	6.668	8.000	46.875
NO_2 concentration	25.125	25.000	9.576	1.000	61.125
O_3 concentration	35.235	31.083	25.891	0.000	144.333
Environmental crime explanatory variables					
Waste-related env. crime	453	374	349	25	1.816
Wastewater env. crime	95	61	85	0	374
Construction env. crime	1.918	1.337	2.100	64	12.493
Landscape env. crime	321	176	333	0	1.354
Forest fires crime	191	100	232	3	1.149
Economic explanatory variables					
Total added value (per-capita)	22,232	22,199	6,040	11,820	47,021
Added value (agriculture)	0.300	0.256	0.216	0.015	1.160
Added value (manufact.)	3.276	1.910	3.959	0.184	29.308
Added value (services)	1.026	0. 565	1.676	0.109	12.672
Other socio-economic and territorial explanatory variables					
Education	9.812	9.832	0.562	8.305	11.716
Employment	60.226	63.025	8.289	35.940	71.810
Corruption	0.863	0.909	0.145	0.000	1.000
Crime index	0.257	0.155	0.391	0.225	2.782
Entrepreneurial density	1.875	1.185	1.809	0.150	11.072
Infrastructure index	1.078	0.840	0.722	0.239	6.911
Tourism	3.497	1.706	5.520	0.649	34.978
Energy consumption	2.152	1.559	2.027	0.175	11.888
Population	547.110	371.550	598.620	57.180	4.353,738
Area	2739	2462	1573	0.212	7400

four chains of length 1000 with a 1000 burn-in samples. Trace plots for the significant *environmental crime* coefficients are located in the appendix. Also, for robustness, we employ the very recent test developed by Cinelli and Hazlett (2020) on the extent of omitted variable bias necessary to drive our coefficient of interest to zero. Ideally, in empirical analysis, one could test the robustness of their results against all known and even unknown omitted variables. Given this is not possible, Cinelli and Hazlett (2020) approach this problem in the reverse by asking how correlated would such a variable need to be with the variable of interest to drive the relevant coefficient to zero, that is, to nullify the effect of the variable of interest. We use the *R* package *sensemakr* and report the results (Cinelli-Hazlet Correlation—CHC) in our tables. To proceed conservatively and with caution, we consider only those coefficients that satisfy all three measures as different from zero; statistically significant with robust standard errors at

Table 3 Estimation results—dependent variable: $PM_{2.5}$ concentration

Variables	Estimate	Robust SE	CHC Measure	Posterior Mean	Posterior 5% quantile	Posterior 95% quantile
Waste-related env. crime	− 0.403	0.832	2.69	0.189	− 0.996	1.365
Wastewater env. crime	− 0.911	2.855	1.68	− 0.032	− 4.231	4.180
Construction env. crime	− 0.889	0.526	8.49	− 0.829	− 1.485	− 0.140
Landscape env. crime	4.228	1.403***	15.69	3.010	0.966	4.986
Forest fires crime	1.241	0.554**	11.64	1.642	0.904	2.421
Waste-related env. crime^2	0.012	0.047	1.41	− 0.020	− 0.088	0.047
Wastewater env. crime^2	0.842	1.042	4.22	0.487	− 1.171	2.193
Construction env. crime^2	0.021	0.012	7.66	0.009	− 0.003	0.021
Landscape env. crime^2	− 0.357	0.114***	13.15	− 0.189	− 0.336	− 0.050
Forest fires crime^2	− 0.101	0.052*	9.93	− 0.148	− 0.225	− 0.078
Added value (total)	0.563	0.136***	21.25	0.557	0.374	0.741
Added value (agriculture)	2.582	0.995***	12.09	2.243	0.528	4.019
Added value (manufact.)	0.275	0.108***	12.37	0.266	0.087	0.451
Added value (services)	− 0.545	0.273**	10.66	− 0.520	− 0.938	− 0.105
Education	− 0.950	0.581	8.19	− 1.089	− 1.977	− 0.195
Employment	− 0.121	0.077*	8.55	− 0.107	− 0.223	0.007
Corruption	10.997	1.995***	20.28	9.295	5.363	13.326
Crime index	3.028	1.256***	16.01	2.687	1.185	4.228
Entrepreneurial density	− 1.062	0.479**	11.64	− 0.882	− 1.630	− 0.150
Infrastructure index	− 0.348	0.251	0.69	− 0.308	− 0.784	0.180
Tourism	− 0.005	0.051	2.66	− 0.005	− 0.068	0.057
Energy consumption	0.458	0.156***	13.59	0.482	0.205	0.750
Population	0.320	0.985	0.50	0.718	− 0.185	1.774
Area	− 0.880	0.175***	24.54	− 0.849	− 1.116	− 0.578
Provincial fixed effects	Yes					
Year fixed effects	Yes					
R^2	0.774					
F-stat	19.67					

the 10% level; Bayesian significant at the 10% level; and a CHC above 10%. Of course, there is very significant overlap in all measures with but the few exceptions around the threshold value of 10%.

Table 4 Estimation results—dependent variable: PM_{10} concentration

Variables	Estimate	Robust SE	CHC Measure	Posterior Mean	Posterior 5% quantile	Posterior 95% quantile
Waste-related env. crime	1.020	0.802	5.51	0.733	-0.442	1.984
Wastewater env. crime	0.360	2.753	0.54	3.377	− 1.813	9.553
Construction env. crime	− 0.524	0.537	4.66	− 0.196	− 0.836	0.524
Landscape env. crime	3.484	1.726*	8.69	3.363	0.418	5.661
Forest fires crime	1.999	0.660***	12.72	1.824	0.894	2.772
Waste-related env. crime^2	− 0.068	0.046	6.28	− 0.056	− 0.133	0.018
Wastewater env. crime^2	0.323	1.143	1.25	− 0.944	− 3.165	1.161
Construction env. crime^2	0.014	0.015	4.15	0.004	− 0.006	0.016
Landscape env. crime^2	− 0.402	0.234*	7.98	− 0.318	− 0.523	− 0.110
Forest fires crime^2	− 0.171	0.065***	11.75	− 0.156	− 0.241	− 0.071
Added value (total)	0.666	0.182***	16.30	0.655	0.405	0.881
Added value (agriculture)	5.334	1.288***	16.52	5.140	2.967	7.312
Added value (manufact.)	0.230	0.133***	6.66	0.247	0.001	0.489
Added value (services)	− 0.385	0.293	4.91	− 0.470	− 1.024	0.085
Education	0.984	0.651	6.67	0.860	− 0.130	1.873
Employment	− 0.289	0.097***	13.98	− 0.244	− 0.387	− 0.105
Corruption	5.507	3.790	7.73	3.680	− 0.407	7.933
Crime index	− 0.568	0.907	2.51	− 0.591	− 2.245	1.013
Entrepreneurial density	0.249	0.448	2.44	0.277	− 0.439	1.028
Infrastructure index	− 0.298	0.336	3.47	− 0.289	− 0.929	0.269
Tourism	− 0.032	0.057	2.66	− 0.026	− 0.111	0.056
Energy consumption	1.089	0.183***	20.89	1.095	0.741	1.431
Population	− 0.141	1.161	0.50	0.241	− 1.052	1.358
Area	− 1.630	0.203***	31.31	− 1.609	− 1.947	− 1.302
Provincial fixed effects	Yes					
Year fixed effects	Yes					
R^2	0.652					
F-stat	14.74					

4.1 $PM_{2.5}$ as a dependent variable

Table 3 shows the results with $PM_{2.5}$ as the dependent variable. Notice that our findings show a positive and statistically significant correlation between *forest fires* and $PM_{2.5}$ emissions, and between *landscape violations* and $PM_{2.5}$ emissions. It is not surprising that forest fires and landscape violations are the only environmental crime variables that turn out to be significant for this as well as for most of the other pollution variables considered. This is definitely a relevant and novel result, which appears to suggest that both illegal wildfires and landscape activities can be crucial (albeit not unique) in driving air pollution in Italian provinces. As it has been already addressed in the literature (Karanasiou et al., 2021), annual premature

Table 5 Estimation results—dependent variable: NO_2 concentration

Variables	Estimate	Robust SE	CHC Measure	Posterior Mean	Posterior 5% quantile	Posterior 95% quantile
Waste-related env. crime	− 2.099	1.211	7.220	− 2.263	− 4.025	− 0.465
Wastewater env. crime	− 7.349	4.357	6.720	− 2.712	− 11.028	5.156
Construction env. crime	0.651	0.805	3.550	1.344	0.440	2.288
Landscape env. crime	0.129	2.409	0.210	− 0.082	− 3.534	3.301
Forest fires crime	1.113	0.961	4.520	0.976	− 0.474	2.428
Waste-related env. crime^2	0.113	0.068	6.710	0.119	0.008	0.229
Wastewater env. crime^2	3.711	1.813	8.620	1.716	− 1.418	5.009
Construction env. crime^2	− 0.020	0.029	3.240	− 0.013	− 0.027	0.000
Landscape env. crime^2	0.001	0.371	0.010	− 0.125	− 0.383	0.145
Forest fires crime^2	− 0.095	0.094	3.940	− 0.078	− 0.221	0.069
Added value (total)	0.242	0.262	4.000	0.204	− 0.191	0.600
Added value (agriculture)	2.933	2.028	6.220	2.535	− 0.982	5.931
Added value (manufact.)	0.825	0.221	14.720	0.815	0.427	1.199
Added value (services)	− 1.603	0.557	12.630	− 1.541	− 2.397	− 0.647
Education	4.152	1.141	16.520	3.435	1.752	5.059
Employment	− 0.250	0.148	8.010	− 0.229	− 0.448	− 0.006
Corruption	2.426	4.925	2.170	3.686	− 3.812	11.508
Crime index	4.938	1.608	13.160	4.883	2.017	7.646
Entrepreneurial density	− 1.502	0.738	9.080	− 1.395	− 2.622	− 0.121
Infrastructure index	1.645	0.491	11.770	1.829	0.891	2.780
Tourism	0.066	0.081	3.540	0.058	− 0.076	0.194
Energy consumption	− 0.147	0.232	2.040	− 0.129	− 0.653	0.422
Population	− 0.115	2.181	2.040	− 0.885	− 2.905	1.251
Area	− 1.180	0.308	16.190	− 1.191	− 1.695	− 0.700
Provincial fixed effects	Yes					
Year fixed effects	Yes					
R^2	0.568					
F-stat	9.995					

deaths at country level—ranging from hundreds attributable to short-term exposure to thousands attributable to long-term exposure—are indeed associated with $PM_{2.5}$ and PM_{10} pollution from wildfires, with the most significant damage to communities close to the source. Similarly, particulate matter is one of the primary pollutants produced from mining and quarry operations. Health related studies widely indicate a strong association of airborne PM with adverse impacts such as reduced lung capacity, increased cardiovascular disease, cancer and neurotoxic effects (Patra et al., 2016). Moreover, while the physical link between forest fires, landscape violations and $PM_{2.5,\ 10}$ pollution has already received careful attention from the literature (i.e., Romanov et al., 2022; Worlanyo & Jiangfeng, 2021), correlation between the other types of environmental crimes considered and air pollution is

Table 6 Estimation results—dependent variable: O_3 concentration

Variables	Estimate	Robust SE	CHC Measure	Posterior Mean	Posterior 5% quantile	Posterior 95% quantile
Waste-related env. crime	– 7.044	3.499**	8.800	– 3.415	– 9.642	2.505
Wastewater env. crime	– 27.416	11.394*	9.240	– 9.446	– 31.802	13.171
Construction env. crime	– 3.176	2.326	6.360	– 4.846	– 7.460	– 2.486
Landscape env. crime	20.638	7.872***	11.720	14.894	2.574	27.812
Forest fires crime	11.725	2.998***	16.290	12.848	7.542	18.015
Waste-related env. crime^2	0.310	0.201	6.750	0.120	– 0.227	0.487
Wastewater env. crime^2	14.188	4.688***	12.120	8.070	– 0.551	16.944
Construction env. crime^2	0.057	0.079	4.070	0.051	0.017	0.089
Landscape env. crime^2	– 1.696	1.132	7.880	– 1.094	– 2.113	– 0.054
Forest fires crime^2	– 0.937	0.275***	14.070	– 0.991	– 1.444	– 0.545
Total added value	2.351	0.722***	13.720	2.214	1.095	3.373
Added value (agriculture)	– 10.319	6.726	7.930	– 10.910	– 20.727	– 0.995
Added value (manufact.)	0.740	0.540	5.150	0.687	– 0.342	1.739
Added value (services)	– 1.948	1.248	5.870	– 2.097	– 4.466	0.497
Education	– 1.136	3.382	1.710	1.011	– 3.903	5.993
Employment	– 0.990	0.423**	11.270	– 0.926	– 1.560	– 0.297
Corruption	59.847	12.955***	18.050	44.036	19.329	68.663
Crime index	2.839	4.040	2.840	1.200	– 6.514	8.558
Entrepreneurial density	0.192	1.538	0.410	0.684	– 2.759	4.266
Infrastructure index	– 6.015	1.491***	13.440	– 7.104	– 10.284	– 3.839
Tourism	– 0.471	0.198	9.040	– 0.428	– 0.835	– 0.031
Energy consumption	2.869	0.771***	13.710	3.070	1.595	4.564
Population	– 3.179	4.972	2.640	0.744	– 5.992	7.626
Area	– 3.333	0.897***	16.640	– 3.204	– 4.630	– 1.684
Provincial fixed effects	Yes					
Year fixed effects	Yes					
R^2	0.582					
F-stat	10.17					

tenuous and may not exist. Our estimates show that the *energy consumption* variable plays a role in exerting a positive effect on the outcome variable (as expected). Nonetheless, the positive and highly statistically significant correlation between *crime index and corruption*—as a general measure of illegal attitudes—and $PM_{2.5}$ pollution, is a very interesting result in that the higher the level of criminal activities and the number of convicted offenders for corruption, the higher the concentration of $PM_{2.5}$, therefore, suggesting that crime and corruption can affect the stringency of environmental enforcement (Polinsky & Shavell, 2001), increasing illegal economic activities and amplifying air pollution. *Total added value and added value* from *agriculture* and *manufacturing sectors* also play explanatory roles being positively linked to $PM_{2.5}$ pollution. Finally, the size of the province (*area*) decreases $PM_{2.5}$

concentrations, as we may expect less pollution density if a certain amount of pollution spreads over a wider area. Overall, we have a very good fit with an R^2 of 0.774 and an F-statistic of 19.67.

4.2 PM_{10} as a dependent variable

In line with our results for $PM_{2.5}$, our findings show a significantly positive and direct effect of *forest fires* on PM_{10}. Table 4 shows quite similar results as for $PM_{2.5}$, where however *corruption* is no longer significant, replaced (maybe as a “broad” measure of social capital) by the negative and statistically significant relationship with the *employment* variable. A possible reason for this negative correlation could be suggesting the presence of an anti-cyclical behavior of pollution levels in the Italian economic context, which implies that pollution increases when employment rate drops due to the need to rely on dirtier but less costly production and consumption choices. As for the $PM_{2.5}$ model, *total added value* and the added value from both the *agriculture sector and the manufacturing sectors* exert a positive effect on the dependent variable confirming that the corresponding economic activity increases local environmental pressures. Overall, we have a good fit with an R^2 of 0.652 and an F-statistic of 14.74.

4.3 NO_2 as a dependent variable

Moving to nitrogen dioxide (NO_2), as we can observe (Table 5), neither the environmental crime variables nor all the other control variables appear to be significant.

4.4 O_3 as a dependent variable

Results for ozone (O_3) are similar to $PM_{2.5}$ and PM_{10} in that forest fires and illegal landscape activities turn out to be relevant (Table 6). *Total added value* is confirmed as an important factor in explaining local O_3 concentrations across Italian provinces, as well as *employment*, *infrastructure index,* and *energy consumption,* whose signs and statistical significance are in line with the results above considered. In particular, the positive and statistically significant relationship of *corruption* supports the argument that higher levels of corruption contribute to environmental degradation because, by definition, it involves illegal activities that could be destructive to the environment. Overall, we have a good fit with an R^2 of 0.582 and an F-statistic of 10.17.

4.5 Summary of results

Table 7 summarizes the results across different pollutants for each type of environmental crime considered. The main purpose of this paper has been to verify the existence of an association between environmental crime and air pollution in Italy; air pollution is affected by a variety of factors and environmental crime is certainly one of the causes. As noted above, our main findings show that forest

Table 7 Summary of results (√ represents statistical significance)

	$PM_{2.5}$	PM_{10}	NO_2	O_3
Waste proceedings	x	x	x	x
Waste proceedings^2	x	x	x	x
Wastewater proceedings	x	x	x	x
Wastewater proceedings^2	x	x	x	x
Construction proceedings	x	x	x	x
Construction proceedings^2	x	x	x	x
Landscape proceedings	√	x	x	√
Landscape proceedings^2	√	x	x	x
Fires proceedings	√	√	x	√
Fires proceedings^2	x	√	x	√

fires and landscape offenses stance as a serious threat to air pollution; therefore, inappropriate enforcement of wildfire illegal activities and management of mining and quarries operations could contaminate the environment which in turn has wide-ranging effects on human health and well-being.

Our findings consistently show a statistically significant effect of forest fires on $PM_{2.5}$, PM_{10}, and O_3, and of landscape offences on $PM_{2.5}$ and O_3, implying that an increase of these illegal activities increases air pollution, also increasing the risk of generating adverse health effects. Moreover, the results support the existence of a nonlinear effect between forest fires and both PM_{10} and O_3, and between landscape-related violations and $PM_{2.5}$ concentration of emissions. In order to fight these types of environmental crimes, regulators and policy makers should enhance their respective enforcement of laws and regulations in a nuanced perspective that considers regional heterogeneity as well as the socio-economic context to support policy. Our results may, however, also have importance beyond the confines of Italy. They point to the fact that air pollution control strategies cannot be dissociated from the relationship to forest fires and landscape devastation.

5 From air pollution to health outcomes: the indirect effect of environmental crimes

Considered the fourth most important global health risk factor (Juginović et al., 2021), ambient air pollution has been identified as one of the main priority areas for public health intervention. The negative effects of living in polluted areas both on health and living standards have been increasingly attracting the attention of international organizations, researchers, and policy makers worldwide (Brunekreef & Holgate, 2002; Cohen et al., 2017; EEA, 2018; Ferreira et al., 2013). Both the epidemiological and economic literature have indeed investigated (and proved) adverse effects of air pollution on health.

Since the seminal paper by Logan (1953) on the increased number of deaths registered after the exposure to the London Great Smog, several studies have attempted to evaluate the link between air pollution and health. Excluding indoor sources of air pollution and countries with extremely high levels of pollution (such as China, India or Brazil, and developing countries in general), the epidemiological literature has generally found a negative association between ambient (outdoor or urban) air pollution and health. Results are indeed consistent among diverse health outcomes (respiratory symptoms, lung function, hospitalizations for respiratory and cardiovascular disease, respiratory morbidity, cardiopulmonary disease mortality) and different pollutants ($PM_{2.5}$, PM_{10}, nitrogen dioxide, sulfur dioxide, carbon monoxide and ozone), as reported in Filippini et al., (2019), Brunekreef and Holgate (2002), Janke et al., (2009), Anderson et al., (1996), Dab et al., (1996), Pope et al., (1995) and Dockery et al., (1993), among others.

On the other hand, the economic literature has either focused on the role of socio-economic characteristics on the link between air pollutants and life expectancy (Hill et al., 2018), hospitalizations (Giaccherini et al., 2021; Lagravinese et al., 2014; Neidell, 2004), morbidity (Currie & Walker, 2011; Di Novi, 2010) or mortality (Bell et al., 2005; Currie & Neidell, 2005; Currie et al., 2009; Jerrett et al., 2005; Martuzzi et al., 2006; Vigotti et al., 1996), or examined the impact of pollution on other aspects of human life, such as student outcomes, (Ebenstein et al., 2016), labor supply and productivity (Zivin & Neidell, 2012, 2013; Pope et al., 1995), and unemployment (Heutel & Ruhm, 2016).

Using the estimated results in Tables 3, 4, 5, 6, we focus here on the burden of wild forest fires and landscape violations, the two environmental crimes significantly affecting the concentration of all air pollutants considered, and present back-of-the-envelope calculations of the indirect annual impact of such violations measured as both mortality and morbidity. In our analysis, mortality refers to the number of deaths that have occurred because of a specific disease or a group of diseases and it is expressed either as premature deaths or years of life lost (YLL, e.g. EEA, 2022; Kienzler et al., 2022),[8] while morbidity is the state of having a disease and it is here expressed as years lived with disability (YLD), meaning years of healthy life lost to disability for the diseases that entail the most significant health burden, as measured specifically by neoplasms (e.g., lung cancer), endocrine and metabolic diseases (e.g., diabetes mellitus in adults aged 25 and above), diseases of the circulatory system (e.g., strokes, heart attacks, cerebral hemorrhages, cerebral ischemia, coronary heart diseases), diseases of the respiratory system (e.g., asthma in children aged 15 and below, chronic obstructive pulmonary disease—COPD) resulting from exposure to $PM_{2.5}$; asthma in adults aged 15 and above, stokes, and diabetes mellitus in adults aged 35 and above resulting from exposure to NO_2 and the number of

[8] YLL is an estimate of the number of years that people in a population would have lived had there been no premature death and it is defined as the years of potential life lost because of premature death. Premature deaths are deaths that occur before a person reaches an expected age. This expected age is typically the life expectancy for a country, stratified by sex and age. Premature deaths are considered preventable if their cause can be eliminated. The YLL measure considers the age at which deaths occur; therefore, the contribution to the total number of lost life years is higher for a premature death occurring at a younger age and lower for a premature death occurring at an older age (EEA, 2022, https://www.eea.europa.eu/publications/air-quality-in-europe-2022/health-impacts-of-air-pollution).

hospital admissions due to respiratory diseases in adults aged 65 and above resulting from exposure to O_3 (EEA, 2022; Kienzler et al., 2022).[9] All outcomes for $PM_{2.5}$ and NO_2 are considered as associated with long-term exposures to those pollutants, while hospital admissions are considered as associated with short-term exposure to O_3 (Kienzler et al., 2022).

The indirect annual impact on health dimension h of a change in air pollutant p (labelled Δ_h^p), induced by a change in illegal forest fires or landscape violations (labelled Δ_v) is then calculated applying this general formula:

$$\Delta_h^p = \Delta_v \left(\beta_1^p + 2\beta_2^p \overline{V} \right) H^p$$

where β_1^p is the estimated coefficient reported in Tables 3, 4, 5, 6 for each pollutant, β_2^p is the estimated coefficient of the quadratic term; $\overline{V}$ is the mean value of the violation (either illegal forest fires or landscape violation) and equal to 191 wildfires per year and to 321 landscape violations per year, as reported in Table 2; and H^p measures the specific health burden under scrutiny, namely premature deaths, YLL, or YLD, lung cancer, diabetes mellitus in adults aged 25 and above, coronary heart diseases, asthma in children aged 15 and below, strokes and COPD for $PM_{2.5}$; asthma in adults aged 15 and above, stokes, and diabetes mellitus in adults aged 35 and above for NO_2; the number of hospital admissions due to respiratory diseases in adults aged 65 and above for O_3.

We take the estimated health burden due to air pollutants in Italy in 2020 from the EEA Report (2022), Kienzler et al. (2022) and Soares et al. (2022), i.e. the estimated number of attributable premature deaths, YLL, and YLL per 100,000 inhabitants associated with exposure to $PM_{2.5}$, NO_2, O_3; YLDs due to the above selected diseases per 100,000 inhabitants attributable to $PM_{2.5}$, NO_2 or O_3 for the age groups considered (i.e., children aged 15 and below, adults aged 25 and above or adults aged 35 and above) and hospital admissions for respiratory diseases by 100,000 inhabitants attributable to O_3 for adults aged 65 and above.

We report the health burden in Table 8, accounting for different pollutants' concentrations to assess the sensitivity of the mortality-related health outcomes. The baseline scenario is the scenario with the assumptions that have been considered from 2022 by the EEA, i.e., the latest WHO global Air Quality Guidelines (WHO,

[9] Morbidity is the state of having a disease, measured by, for instance, the prevalence of a disease in a population (EEA, 2022). More specifically, years lived with disability (YLD) are years of healthy life lost to disability. A Disability-Adjusted Life Year (DALY) is one lost year of a 'healthy' life because of a disease, injury or risk factor. DALYs are obtained by combining YLL and YLDs for the same disease or group of diseases. The burden of disease is the sum of these DALYs across the population. Therefore, DALYs standardise health effects by expressing, in one number, the number of people affected and the duration and severity of the health effects.

Table 8 Population-weighted mean concentrations of $PM_{2.5}$, NO_2 and O_3, estimated number of attributable premature deaths, YLL and the YLL per 100,000 inhabitants, associated with exposure to $PM_{2.5}$, NO_2 and O_3 in Italy, in 2020.

$PM_{2.5}$							
Annual mean concentrations	Premature deaths			YLL	YLL/100,000		
	WHO2013	WHO2021	ELAPSE		WHO2013	WHO2021	ELAPSE
15	61,200	52,300	74,300	462,300	907	775	1,101
NO_2							
Annual mean concentrations	Premature deaths			YLL	YLL/100,000		
	WHO2013	WHO2021	ELAPSE		WHO2013	WHO2021	ELAPSE
17.7	7,000	11,200	24,400	98,700	104	165	362
O_3							
SOMO35	Premature deaths			YLL	YLL/100,000		
	WHO2013	WHO2021	ELAPSE		WHO2013	WHO2021	ELAPSE
6,067	3,400	5,100	5,100	45,900	52	77	77

In scenario WHO2013 it is assumed that the counterfactual concentrations of $PM_{2.5}$ and NO_2 are respectively set to 0 and 20 μg/m^3, while the counterfactual concentration of O_3 is set to 35; in scenarios WHO2021 and ELAPSE the counterfactual concentrations are set to 5, 10 and 35, respectively. Source: EEA (2022), Kienzler et al. (2022) and Soares et al. (2022)

2021), while alternative scenarios are built on assumptions considered by previous WHO reports (WHO, 2013) and on the ELAPSE project (Brunekreef et al., 2021).[10]

We report disease specific health burden, attributable to specific pollutants and relative to specific age groups, in Table 9.

According to our back-of-the-envelope calculations, we first report in Table 10 the indirect annual impact of forest fires (panel A) and landscape violations (Panel B) on premature deaths, YLL and YLL per 100,000 inhabitants, under the three scenarios identified in the literature.

It is evident from Table 10 that different assumptions on counterfactual concentrations can yield very different numbers in terms of premature deaths and YLL, but also that by choosing the right combination of pollution constraints it is possible to positively affect the number of premature deaths and YLL, by reducing them.

We then compute the YLD associated to each disease of Table 9 and reported in Table 11 for both forest fires and landscape violations.

It is evident from Table 11 that the number of YLD per 100,000 inhabitants linked to forest fires or landscape violations is highly variable among the different diseases, also due to the specific health burden of each disease.

As we are dealing with correlations, these calculations must of course be interpreted with substantial caution. On the other hand, our attempt to quantify how environmental crimes may translate into worsening health helps explaining why, leaving out the effects of environmental crimes on ambient air pollution from the general picture, is equivalent to underestimating the effects of ambient air pollution on health outcomes.

[10] The ELAPSE study evaluated health outcomes related to variation in exposures to low ambient air pollution concentrations,

below current international guidelines. Brunekreef and colleagues developed new exposure models for all of Europe for four pollutants ($PM_{2.5}$, black carbon, NO_2, and O_3), as well as $PM_{2.5}$ particle composition and found evidence of associations between long-term exposures to relatively low concentrations of ambient air pollution and several important health endpoints. For further details, please refer to Brunekreef et al. (2021).

Table 9 Disease burdens (morbidity) by age groups and pollutants in Italy in 2020

Disease	Age	Pollutant	Disease burden
Asthma	≤15	$PM_{2.5}$	38.3
COPD	25+	$PM_{2.5}$	74.3
IHD	25+	$PM_{2.5}$	2.3
Lung cancer	25+	$PM_{2.5}$	1.8
Stroke	25+	$PM_{2.5}$	43.5
Diabetes mellitus	25+	$PM_{2.5}$	46.8
Asthma	15+	NO_2	24.9
Stroke	25+	NO_2	19.9
Diabetes mellitus	35+	NO_2	51.7
Hospital admissions due to respiratory diseases	65+	O_3	22

The disease burden is the number of years lived with disability (YLD) per 100,000 inhabitants attributable to a specific disease, except for hospital admissions due to respiratory diseases for which we report the number of hospitalisations attributable to respiratory diseases per 100,000 inhabitants. Source: EEA (2022) and Kienzler et al. (2022)

Table 10 Indirect annual burden of environmental crimes

Premature deaths			YLL	YLL/100,000		
Panel A. Indirect impact of illegal wildfires						
$PM_{2.5}$						
WHO2013	**WHO2021**	**ELAPSE**		**WHO2013**	**WHO2021**	**ELAPSE**
798	682	968	6,025	11.821	10.101	14.350
O_3						
WHO2013	**WHO2021**	**ELAPSE**		**WHO2013**	**WHO2021**	**ELAPSE**
1	2	2	14	0.016	0.023	0.023
Panel B. Indirect impact of illegal landscape violations.						
$PM_{2.5}$						
WHO2013	**WHO2021**	**ELAPSE**		**WHO2013**	**WHO2021**	**ELAPSE**
2,859	2,444	3,471	21,600	42.377	36.209	51.441
O_3						
WHO2013	**WHO2021**	**ELAPSE**		**WHO2013**	**WHO2021**	**ELAPSE**
2	3	3	25	0.029	0.042	0.042

Calculations on NO_2 are not reported as coefficients relative to both forest fires and landscape violations are not significant (see Table 5)

Table 11 YLD per 100,000 inhabitants in Italy in 2020

Disease	Disease burden	Illegal wildfires	Illegal landscape violations
Asthma (age ≤ 15; $PM_{2.5}$)	38.3	0.499	1.789
COPD (age 25 +; $PM_{2.5}$)	74.3	0.968	3.471
IHD (age 25 +; $PM_{2.5}$)	2.3	0.030	0.107
Lung cancer (age 25 +; $PM_{2.5}$)	1.8	0.023	0.084
Stroke (age 25 +; $PM_{2.5}$)	43.5	0.567	2.032
Diabetes mellitus (age 25 +; $PM_{2.5}$)	46.8	0.610	2.187
Hospital admissions due to respiratory diseases (age 65 +; O_3)	22	0.007	0.012

Calculations on NO_2 are not reported as coefficients relative to both forest fires and landscape violations are not significant in Table 5

6 Policy implications and concluding remarks

In this paper we assess and quantify the correlation between environmental crime and air pollution with the aim to contribute to the existing literature on air pollution and health outcomes. Indeed, overlooking the link between environmental crime and ambient air pollution would lead to underestimating the effect of environmental crimes on health outcomes (through air pollution), as we can indeed expect health outcomes to be indirectly affected by illegal environmental behaviors.

Using a FE model on a panel of 110 Italian regions observed for 7 years (2010–2016) to explain variation in ambient air pollution due to environmental crime with a large number of explanatory variables, we focus on five different types of environmental crimes (waste-related environmental crime, wastewater environmental crime, construction environmental crime, landscape environmental crime and forest fires crime) and estimate their effect on four major air pollutants measures ($PM_{2.5}$, PM_{10}, NO_2 and O_3). We find strong significant correlations with respect to forest fires and landscape violations, after controlling for various socio-economic and territorial characteristics; on the other hand, we also show the existence of possible non-linearities. When significant, corruption and broad general crime index also matter for the selected pollutants. Energy consumption plays an important role, too, together with the other territorial explanatory variables (added value, infrastructures index, employment, area). Our findings, therefore, confirm that non-economic factors, alongside traditional economic factors, are both relevant in determining air pollution concentration that could reshape the societal understanding of air pollution distribution across the territory. In terms of indirect health effects and relative costs, our analysis shows how important is to fight environmental crimes: every fire burns millions of euros every year, causing several premature deaths in addition to severe air pollution.

Our findings potentially lead to important recommendations concerning the effectiveness of enforcement policy: the most important general conclusion is that the multi-dimensional nature of environmental crimes requires innovative means and a strategic vision for making real progress. It is, therefore, suggested that enforcement authorities and policy makers, within a multi-agency collaboration approach, focus on increasing the efficacy of their strategies to deal effectively with the risks that environmental crime brings to the environmental welfare of societies.

Our findings might also have important implications in terms of public health and future environmental policies aimed at fighting environmental crimes, in order to give greater weight to the unintended health consequences that may follow. Governments should adopt policies targeted at protecting the population not only by promoting policies directly targeted at improving health outcomes, but also by reinforcing environmental policies targeted at improving air quality through fighting environmental crimes (in order to indirectly improve health outcomes). Strengthening the enforcement of environmental laws through adequate resource allocation, specialized training, and effective cooperation mechanisms across Italian provinces is crucial, therefore, to enhance the effectiveness of the Italian enforcement chain at national level (police forces, prosecution, and criminal courts) and to combat environmental crimes (illegal dumping of waste, use of fuel oil mixed with waste oil, air pollution, etc.) in order to ultimately control and limit serious harms for the environment and human health, including but not limited to biodiversity loss, pollution of water and consequent public health problems, air pollution and the resulting increase in respiratory diseases. This latter respect will be further refined in subsequent research. Of course, our calculations must be handled with extra care as they are based on correlations. We are, therefore, aware that estimates of the indirect health impact might be underestimated. Nonetheless, they give us an order of magnitude of the phenomenon which cannot be ignored and deserves further attention in the future.

Appendix

As earlier discussed, we undertook the fixed effects panel model estimation using Bayesian methods. Doing so, in Figs. 4, 5 and 6 we provide evidence of stability, or lack thereof, for our *forest fires* and *landscape violations* parameter estimates across the Markov Chains. Plotted below are the trace plots for the significant parameters (*environmental crime*) of interest by pollutant: *forest fires* and *landscape violations*. The three plots illustrate fairly stable parameter estimates across the four chains with linear terms of both *forest fires and landscape violations* tending to be positive

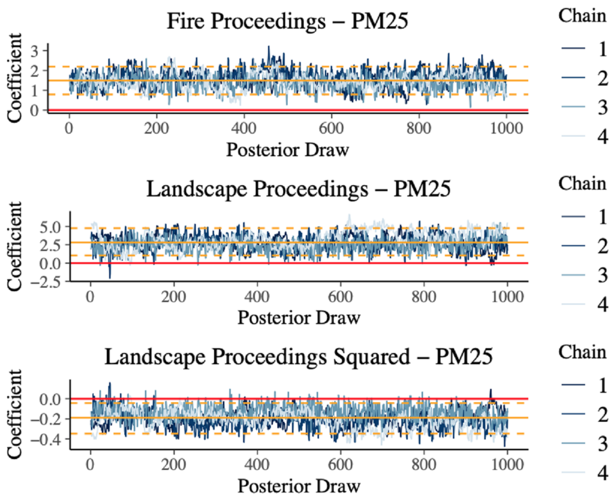


Fig. 4 Trace plots from Markov Chain Monte Carlo simulation—$PM_{2.5}$

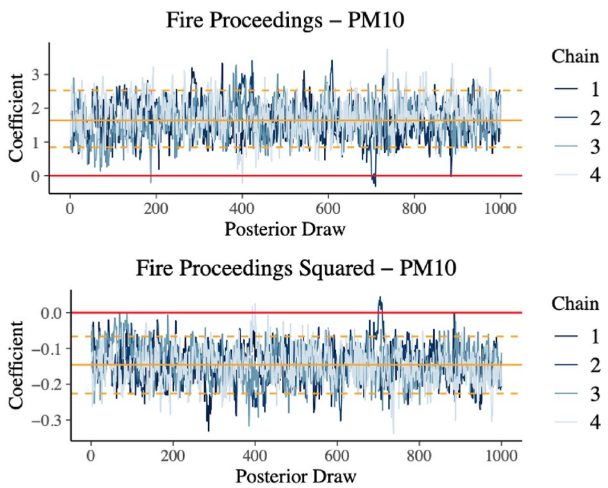


Fig. 5 Trace plots from Markov Chain Monte Carlo simulation—PM_{10}

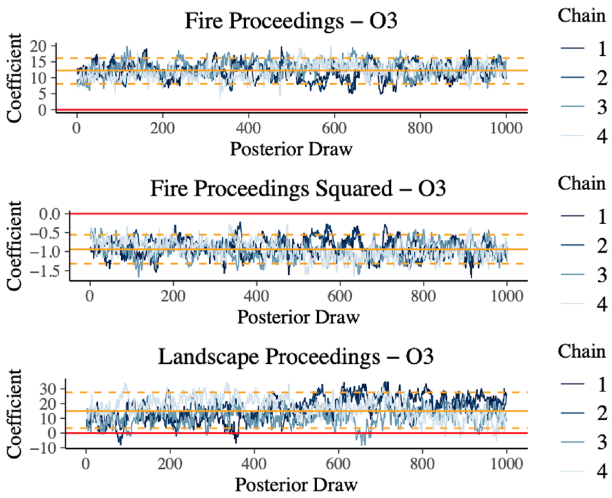


Fig. 6 Trace plots from Markov Chain Monte Carlo simulation—O_3

and quadratic terms tending to be negative. There is no apparent trend in the trace plots and therefore no autocorrelation, suggesting that we do not have a reason to suspect non convergence for either *forest fires* or *landscape violations*, confirming the robustness of the parameter and standard error estimates reported in Tables 3, 4, 5 and 6.

Acknowledgements We would like to thank the participants of the 2022 IAERE Annual Conference in Cagliari, of the 2022 International Workshop on Computational Economics and Econometrics in Rome, of the 2022 SIEP Annual Conference in L'Aquila, and the participants of the 2023 SIE Annual Conference in L'Aquila and of the 2024 Spanish-Portuguese AERNA Annual Conference in Portugal, for all their valuable feedbacks. All mistakes are obviously ours. The views expressed are those of the authors and do not necessarily reflect those of the institutions to which they belong. We are also grateful to the anonymous reviewers for their helpful and constructive comments and suggestions.

Funding Open access funding provided by Università degli Studi di Roma Tor Vergata within the CRUI-CARE Agreement.

Data availability The data used for this research are available on request.

References

Almer, C., & Goeschl, T. (2010). Environmental crime and punishment: Empirical evidence from the German Penal Code. *Land Economics, 86*(4), 707–726.

Anderson, H. R., Ponce de Leon, A., Bland, J. M., Bower, J. S., & Strachan, D. P. (1996). Air pollution and daily mortality in London: 1987–92. *British Medical Journal, 312*, 665–669.

Bell, M. L., O'Neill, M. S., Cifuentes, L. A., Braga, A. L. F., Green, C., Nweke, A., Rogat, J., & Sibold, K. (2005). Challenges and recommendations for the study of socioeconomic factors and air pollution health effects. *Environmental Science & Policy, 8*(5), 525–533.

Bimonte, S. (2002). Information access, income distribution, and the environmental Kuznets curve. *Ecological Economics, 41*, 145–156.

Biswas, A. K., Farzanegan, M. R., & Thum, M. (2012). Pollution, shadow economy and corruption: Theory and evidence. *Ecological Economics, 75*, 114–125.

Brunekreef, B., & Holgate, S. T. (2002). Air pollution and health. *Lancet, 360*, 1233–1242.

Brunekreef, B., Strak, M., Chen, J., Andersen, Z. J., Atkinson, R., et al. (2021). Mortality and morbidity effects of long-term exposure to low-level $PM_{2.5}$, BC, NO_2, and O_3: An analysis of European cohorts in the ELAPSE Project. *Research Reports: Health Effects Institute, 208*, 1–127.

Cinelli, C., & Hazlett, C. (2020). Making sense of sensitivity: Extending omitted variable bias. *Journal of the Royal Statistical Society Series B-Statistical Methodology, 82*(1), 39–67.

Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H. K., et al. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. *The Lancet, 389*(10082), 1907–1918.

Cole, M. A., Elliott, R. J. R., & Shimamoto, K. (2005). Industrial characteristics, environmental regulations and air pollution: An analysis of the UK manufacturing sector. *Journal of Environmental Economics and Management, 50*(1), 121–143.

Cole, M. A. (2007). Corruption, income and the environment: An empirical analysis. *Ecological Economics, 62*(3–4), 637–647.

Currie, J., & Neidell, M. (2005). Air pollution and infant health: what can we learn from California's recent experience? *Quarterly Journal of Economics, 120*(3), 1003–1030.

Currie, J., Neidell, M., & Schmieder, J. F. (2009). Air pollution and infant health: Lessons from New Jersey. *Journal of Health Economics, 28*(3), 688–703.

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

D'Amato, A., Mazzanti, M., & Nicolli, eF. (2015). Waste and organized crime in regional environments. *Resource and Energy Economics, 41*, 185–201.

D'Amato, A., Mazzanti, M., Nicolli, F., & e Zoli, M. (2018). Illegal waste disposal: Enforcement actions and decentralised environmental policy. *Socio Economic Planning Sciences, 64*, 56–65.

Dab, W., Medina, S., Quénel, P., Le Moullec, Y., Le Tertre, A., Thelot, B., Monteil, C., Lameloise, P., Pirard, P., Momas, I., Ferry, R., & Festy, B. (1996). Short term respiratory health effects of ambient air pollution: results of the APHEA project in Paris. *Journal of Epidemiology and Community Health, 50*(Suppl 1), s42–s46. https://doi.org/10.1136/jech.50.suppl_1.s42. PMID: 8758223; PMCID: PMC1060887.

Deily, M. E., & Gray, W. B. (1991). Enforcement of pollution regulations in a declining industry. *Journal of Environmental Economics and Management, 21*, 260–274.

Dell'Anno, R., Pergolizzi, A., Pittiglio, R., & Reganati, F. (2020). Waste crime in Italian regions: A structural equation approach, socio-economic planning sciences, 71. https://doi.org/10.1016/j.seps.2019.100751.

Di Novi, C. (2010). The influence of traffic-related pollution on individuals' life-style: Results from the BRFSS. *Health Economics, 19*, 1318–1344. https://doi.org/10.1002/hec.1550

Dinda, S., Coondoo, D., & Pal, M. (2000). Air quality and economic growth: An empirical study. *Ecological Economics, 34*, 409–423.

Dockery, D. W., Arden Pope, C., Xiping, Xu., Spengler, J. D., Ware, J. H., Fay, M. E., Ferris Jr, B. G., & Speizer, F. E. (1993). An association between air pollution and mortality in six US cities. *New England Journal of Medicine, 329*(24), 1753–1759.

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

Eckert, H. (2004). Inspections, warnings and compliance: The case of petroleum storage regulation. *Journal of Environmental Economics and Management, 47*, 232–259.

European Environment Agency (EEA). (2018). *Air quality in Europe—2018 report*, EEA Report No 12/2018, Copenhagen. https://www.eea.europa.eu/publications/air-quality-in-europe-2018.

European Environment Agency. (EEA). 2022. *Air quality in Europe—2022 report,* https://www.eea.europa.eu/publications/air-quality-in-europe-2022/health-impacts-of-air-pollution.

Europol. (2022). *Environmental crime in the age of climate change—threat assessment 2022*. Publications Office of the European Union.

Farzin, Y. H., & Bond, C. A. (2006). Democracy and environmental quality. *Journal of Development Economics, 81*, 213–235.

FATF. (2021). Money Laundering from Environmental Crimes, FATF, Paris, France. https://www.fatf-gafi.org/publications/methodsandtrends/documents/money-laundering-environmental-crime.html.

Ferreira, S., Akay, A., Brereton, F., Cuñado, J., Martinsson, P., Moro, M., & Ningal, T. F. (2013). Life satisfaction and air quality in Europe. *Ecological Economics, 88*, 1–10.

Filippini, M., Masiero, G., & Steinbach, S. (2019). The impact of ambient air pollution on hospital admissions. *The European Journal of Health Economics, 20*(6), 919–931. https://doi.org/10.1007/s10198-019-01049-y. Epub 2019 Apr 22. PMID: 31011845.

Friedl, B., & Getzner, M. (2003). Determinants of CO2 emissions in a small open economy. *Ecological Economics, 45*, 133–148.

Germani, A. R., Pergolizzi, A., & Reganati, F. (2015). Illegal trafficking and unsustainable waste management in Italy: Evidence at the regional level. *Journal of Security and Sustainability Issues, 4*(4), 369–389.

Germani, A. R., Ker, A., & Castaldo, A. (2020). On the existence and shape of an environmental crime Kuznets Curve: A case study of Italian provinces. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2019.105685

Giaccherini, M., Kopinska, J., & Palma, A. (2021). When particulate matter strikes cities: Social disparities and health costs of air pollution. *Journal of Health Economics, 78*, 1–23.

Global Burden Disease (GBD) (2019) Risk Factors Collaborators. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: A systematic analysis for the global burden of disease study 2019. *The Lancet, 396*(10258), 1223–1249.

Goel, R. K., Herrala, R., & Mazhar, U. (2013). Institutional quality and environmental pollution: MENA countries versus the rest of the world. *Economic Systems, 37*, 508–521.

Joshua, G. Z., & Neidell, M. (2012). The Impact of Pollution on Worker Productivity. *American Economic Review, 102*(7), 3652–3673.

Joshua, G. Z., & Neidell, M. (2013). Environment, health, and human capital. *Journal of Economic Literature, 51*(3), 689–730.

Helland, E. (1998). The revealed preferences of state EPAs: stringency, enforcement, and substitution. *Journal of Environmental Economics and Management, 35*, 242–261.

Heutel, G., & Ruhm, C. J. (2016). Air pollution and procyclical mortality. *Journal of the Association of Environmental and Resource Economists, 3*(3), 667–706.

Hill, T. D., Jorgenson, A. K., Ore, P., Balistreri, K. S., & Clark, B. (2018). Air quality and life expectancy in the United States: An analysis of the moderating effect of income inequality. *SSM - Population Health, 27*(7), 100346.

Istituto Nazionale di Statistica (ISTAT). (2021). Health for All Italia - Sistema informativo territoriale su sanità e salute. https://www.istat.it/it/archivio/14562.

Janke, K., Propper, C., & Henderson, J. (2009). Do current levels of air pollution kill? The impact of air pollution on population mortality in England. *Health Economics, 18*, 1031–1055.

Jerrett, M., Buzzelli, M., Burnett, R. T., & DeLuca, P. F. (2005). Particulate air pollution, social confounders, and mortality in small areas of an industrial city. *Social Science & Medicine, 60*(12), 2845–2863. https://doi.org/10.1016/j.socscimed.2004.11.006

Ji, X., Yao, Y., & Long, X. (2018). What causes PM2.5 pollution? Cross-economy empirical analysis from socioeconomic perspective. *Energy Policy, 119*, 458–472.

Juginović, A., Vuković, M., Aranza, I., & V. Biloš. (2021). Health impacts of air pollution exposure from 1990 to 2019 in 43 European countries. *Scientific Reports, 11*, 22516. https://doi.org/10.1038/s41598-021-01802-5

Karanasiou, A., Alastuey, A., Amato, F., Renzi, M., Stafoggia, M., Tobias, A., Reche, C., Forastiere, F., Gumy, S., Mudu, P., & Querol, X. (2021). Short-term health effects from outdoor exposure to biomass burning emissions: A review. *Science of the Total Environment, 781*, 146739.

Kienzler, S., Soares, J., González Ortiz, & A., Plass, D. (2022). Estimating the morbidity related environmental burden of disease due to exposure to PM2.5, NO2 and O3 in outdoor ambient air. (Eionet Report—ETC HE 2022/11). European Topic Centre on Human Health and the Environment.

Lagravinese, R. F., Moscone, E., & Tosetti, H. L. (2014). The impact of air pollution on hospital admissions: Evidence from Italy. *Regional Science and Urban Economics, 49*, 278–285.

Legambiente. (2024). Ecomafia 2023 - Le storie e i numeri della criminalità ambientale in Italia, Osservatorio nazionale ambiente e legalità, Edizioni Ambiente, Milano.

Logan, W. P. D. (1953). Mortality in the London fog incident, 1952. *Lancet, 261*(6755), 336–338.

Luechinger, S. (2009). Valuing air quality using the life satisfaction approach. *The Economic Journal, 119*(536), 482–515.

Martuzzi, M., Mitis, F., Iavarone, I., & Serinelli, M. (2006). Health impact of PM10 and ozone in 13 Italian cities. WHO Europe. ISBN 92 890 2293 0 WHOLIS number E88700.

Mazzanti, M., & Zoboli, R. (2009). Municipal waste Kuznets curves: Evidence on socio-economic drivers and policy effectiveness from the EU. *Environmental and Resource Economics, 44*(2), 203–230.

Neidell, M. (2004). Air pollution, health, and socio-economic status: The effect of outdoor air quality on childhood asthma. *Journal of Health Economics, 23*, 1209–1236.

Patra, A. K., Gautam, S., & Kumar, P. (2016). Emissions and human health impact of particulate matter from surface mining operation—a review. *Environmental Technology & Innovation, 5*, 233–249.

Pellegrini, L., & Gerlagh, R. (2006). Corruption, democracy and environmental policy: An empirical contribution to the debate. *Journal of Environment and Development, 15*, 332–354.

Polinsky, A. M., & Shavell, S. (2001). Corruption and optimal law enforcement. *Journal of Public Economics, 81*(1), 1–24.

Polinsky, A. M., & Shavell, S. (2000). The economic theory of public enforcement of law. *Journal of Economic Literature, 38*(1), 45–76.

Pope, C. A., III., Bates, D. V., & Raizenne, M. E. (1995). Health effects of particulate air pollution: Time for reassessment? *Environmental Health Perspectives, 103*(5), 472.

Romanov A.A., A.N. Tamarovskaya, B.A. Gusev, E.V. Leonenko, A.S. Vasiliev, E.E. Krikunov. (2022). Catastrophic $PM_{2.5}$ emissions from Siberian forest fires: Impacting factors analysis. *Environmental Pollution*, *306*: 119324.

Saenz-de-Miera, O., & Rosselló, J. (2014). Modeling tourism impacts on air pollution: The case study of PM_{10} in Mallorca. *Tourism ManagEment, 40*, 273–281.

Soares, J., González Ortiz, A., Gsella, A., Horálek, J., Plass, D., & Kienzler, S. (2022). Health risk assessment of air pollution and the impact of the new WHO guidelines (Eionet Report—ETC HE 2022/10). European Topic Centre on Human Health and the Environment.

Stafford, S. (2002). The effect of punishment on firm compliance with hazardous waste regulations. *Journal of Environmental Economics and Management, 44*(2), 290–308.

Vigotti, M. A., Rossi, G., Bisanti, L., Zanobetti, A., & Schwartz, J. (1996). Short term effects of urban air pollution on respiratory health in Milan, Italy, 1980–89. *Journal of Epidemiology and Community Health, 50*(Suppl 1), s71–s75. https://doi.org/10.1136/jech.50.suppl1.s71. PMID: 8758228; PMCID: PMC1060893.

Worlanyo, A. S., & Jiangfeng, L. (2021). Evaluating the environmental and economic impact of mining for post-mined land restoration and land-use: A review. *Journal of Environmental Management, 279*, 111623.

World Health Organization (WHO) (2013). *Health risks of air pollution in Europe—HRAPIE project recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide. Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide*. World Health Organization, Regional Office for Europe, Copenhagen.

World Health Organization (WHO). (2018). *Burden of disease from ambient air pollution for 2016*. World Health Organization.

World Health Organization (WHO). (2021). *WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide: executive summary*. World Health Organization, Geneva.

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