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Economic Growth and Pollution in different Political Regimes

Andreas Kammerlander[*]

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Abstract

I examine the association between nighttime light luminosity and ten pollution measures (CO_2, CO, NO_x,SO_2, NMVOC, NH_3, BC, OC, PM_{10} and $PM_{2.5}$) across different political regimes at a local level. Although the effects of the political system and economic growth on pollution have been widely analyzed at the country level, this is the first study to do so at the grid level. The empirical analysis yields three major insights. First, economic growth is positively associated with a wide array of different pollution measures. Second, there are significant differences in the association between economic growth and air pollution across different political regimes. For example, the association between nighttime light luminosity and air pollution is strictly positive for autocracies. The association between nighttime luminosity and air pollution is substantially smaller but still positive for democracies. Furthermore, among democracies the relationship between nighttime light luminosity and air pollution is concave for nine out of ten pollutants; among autocracies, the relationship is either convex (five out of ten pollutants) or the squared term is insignificant. Third, the differences among political regimes is driven chiefly by pollution emissions in the industry, energy, and transport sectors; there is no difference between autocracies and democracies in terms of the effect of growth on emissions in the agricultural and residential sectors.

JEL classification: O18; Q53

Keywords: local economic growth, air pollution, nighttime lights, geo-data

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1 Introduction

Emissions of greenhouse gases and pollution are a major threat to the environment and human health. According to the fifth assessment report of the Intergovernmental Panel of Climate Change (IPCC), the vast majority of these emissions can be directly attributed to economic and population growth (IPCC, 2014). Interestingly, the extent to which economic growth increases pollution varies substantially between countries, as shown by data from the World Bank. In China, for example a one-percent increase in GDP was associated, on average, with a 0.4% increase in per capita carbon dioxide emissions on average. By comparison, this association is substantially smaller among European countries: an average one-percent increase in GDP among countries in the European Union was associated with an average 0.18% increase in per capita carbon dioxide (CO_2) emissions. These differences may be explained by environmental policy, which can substantially affect how economic growth leads to higher emission levels (Shapiro and Walker, 2018). Environmental policy, in turn, is a political choice and, as such, depends on the political system. Therefore, the political system may play a crucial role in determining environmental policy and thus how economic growth affects environmental pollution.

A democratic system allows for a free political process and consequently enables green parties and environmental interest groups to participate and influence the political process. This raises awareness among the population of environmental issues and informs voters, who freely voice their opinions and concerns to hold politicians accountable. To increase their reelection probabilities, politicians have direct incentives to establish sound environmental policies. These fundamental building blocks of democratic societies should theoretically lead to better environmental policies and regulations. Consequently, in practice, a smaller effect of economic growth on pollution is expected among democracies than among autocracies.

This paper investigates whether economic growth affects air pollution differently in democratic compared to autocratic countries. For this purpose, the study examines the relationship between economic growth, proxied by changes in nighttime light luminosity, and pollution across different political regimes at the grid level. The empirical analysis combines ten different geo-referenced air pollutants from the Emission Database for Global Atmospheric Research (EDGAR) with nighttime light satellite data at a spatial grid resolution of $\frac{1}{2}°$x $\frac{1}{2}°$ for the whole world. The final dataset is a 22-year panel from 1992 to 2013 that accounts for an extensive set of grid and country controls and uses grid, country and year fixed effects.

The results indicate that economic growth increases a wide array of air pollutants in both democracies and autocracies, albeit to significantly different degrees. In the whole sample, a one standard deviation change in nighttime luminosity is associated with an increase in carbon dioxide emissions by one-third of a standard deviation. In democracies, this effect is nearly half the global average but is more than twice as large in autocracies. The difference in the effect of economic growth on pollution is found for nine out of ten pollutants. The only exception is NH_3, for which the effect of growth is similar in democracies and autocracies. Furthermore, the analysis shows that, testing for a quadratic relationship, squared coefficients are positive and significant for five out of ten pollutants in autocracies. All other squared coefficients are insignificant. In democracies, in contrast, an inverted U-relationship between nighttime lights and pollution is found for nine out of ten pollutants.

To identify the factors driving these findings, the study further disaggregated pollution by industrial sectors. The analysis shows that the differences in the effect of economic growth on pollution in different political systems is driven by the industry, energy, and transportation sectors. In contrast, there appears to be no systematic difference in the effect of economic growth on pollution between political systems in the agricultural and residential sectors.

This paper is related to two branches of literature, investigating the effect of economic growth on pollution and the effect of democracy on pollution, respectively. Whether democracies are cleaner than other forms of government has been widely discussed (see e.g. Midlarsky, 1998; Li and Reuveny, 2006; Bättig and Bernauer, 2009; Wen et al., 2016; Fredriksson and Neumayer, 2013; Povitkina, 2018; Gassebner et al., 2011). Although a majority of publications find that democracies produce less pollution, no consensus has emerged. For a recent literature review on the effect of democracies on pollution see Kammerlander and Schulze (2020a). A large body of literature has also debated the effect of economic growth on pollution, specifically, the existence of an inverse U-shape relationship between economic growth and pollution, the so-called the environmental Kuznets-curve (EKC). Dinda (2004), Kaika and Zervas (2013), and Stern (2017) are examples of recent literature reviews on the effect of economic growth on pollution. If there is a clear consensus from these studies, it is that a universal EKC does not exist. Although there may be evidence of the EKC for single countries and specific pollutants, there is no evidence of a general EKC applicable to all types of pollution. However, the focus of this study lies on the effect of interaction of economic growth and the political system on air pollution. Few studies have specifically investigated the effect of the interaction between economic growth and the political system on pollution.

Arvin and Lew (2011) studied the impact of democracy on carbon dioxide (CO_2) emissions, water pollution, and deforestation among countries of varying wealth levels. Their results are partly inconclusive. Although democracy is not significantly associated with any environmental measure for high income countries, it is associated with higher carbon dioxide emissions and water pollution among lower middle-income and upper middle-income countries. In contrast, for deforestation, the association between deforestation and democracy is significant and negative only for low-income and upper middle-income countries and not for high-income countries.

Lv (2017) analyzes the impact of economic growth (i.e., per capita change in GDP) and democracy, measured by the indices of political rights and civil liberties from Freedom House, on carbon dioxide emissions at the country level. Lv finds a negative interaction, implying that the average effect of economic growth on carbon dioxide emissions is less pronounced among more democratic regimes. Using quantile regressions, Lv further finds that this interaction is significant only below the 75th quantile, i.e., among countries that are not among the greatest polluters.

Similarly, Farzanegan and Markwardt (2018) study the relationship between economic growth and pollution emissions among seventeen countries in the Middle East and North Africa between 1980 and 2005 in five-year intervals. They combine real per capita GDP with a rescaled version of the polity2 variable and use the logarithm of per capita sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions as the dependent variable. The impact of polity2 itself was not significant. The interaction of polity and GDP was negative and significant in all specification of sulphur dioxide, implying that economic growth causes fewer sulphur dioxide emissions in more democratic countries. For carbon dioxide, the coefficient is significant (and negative) only in the pooled OLS specification.

Using eleven different air pollutants, Kammerlander and Schulze (2020a) do not find a consistent pattern which might imply that democracies are cleaner (or dirtier) than other political regimes. The interaction term between democracy and per capita GDP is negative and significant at conventional significance levels for six of eleven pollutants and insignificant for the other five pollutants, implying that the impact of economic growth on pollution is less severe in democracies than in other political regimes.

The contributions of this paper are threefold. First, it investigates the relationship between economic development and air pollution for the whole world at the grid level. No previous study has investigated this relationship at the local (grid) level for a global dataset. The majority of previous studies has relied on data at the country level, which might lead to false conclusions in this context. If both entire countries and regions within countries are heterogeneous in terms of development, environmental policy, or other factors, economic growth might produce entirely different pollution outcomes. In other words, in some regions, economic growth could lead to increased pollution levels whereas in other regions, economic growth might decrease pollution. When aggregated, the effects might negate each other and lead to entirely different and misleading conclusions compared to a local analysis. This study uses localized outcomes, rather than country averages, to overcome this problem. Another approach, applied by Antweiler et al. (2001) or Grossman and Krueger (1995), is to use data from monitoring stations provided by the Global Environment Monitoring System (GEMS). However, data is available at the city level for only a few cities. Studies relying on this data lack representativeness, being restricted to a subsample of cities with no information on rural or sub-urban regions. This study is the first to overcome both the lack of representativeness and the aggregation problems created by using country averages.

Second, the study uses a wide array of air pollutants to examine the relationships among economic growth, democracy, and pollution. Although some studies measure more than one type of pollution, most studies rely solely on carbon dioxide, sulfur oxide, or particulate emissions (PM) as a proxy for environmental quality. The chief argument for using only single measures is data availability, rather than theoretical considerations. Indeed, there is no evidence that carbon dioxide levels reflect environmental quality any better than levels of any other pollutant. This study tests the relationship between air pollution and economic growth using the EDGAR dataset for a total of ten different air pollutants between 1992 and 2013.

Third, this is believed to be the first study that disaggregates air pollution by emitting sector. This allows investigation into whether the effect of economic growth on pollution is driven by specific sectors. Previous research in the growth-democracy-pollution nexus has focused only on aggregated pollution from all sources.

The remainder of the paper is structured as follows: Section 2 outlines the reasons for carrying out the analysis at the local level instead of the country-level. Section 3 describes the data. Section 4 explains the empirical approach. Section 5 presents the main findings of the empirical analysis, and section 6 extends the main results by analyzing different sectors. Section 7 conducts further robustness checks, and section 8 concludes.

2 Aggregation fallacies

This study uses grid-level data to explain the effect of economic growth on emission levels under different political systems. The vast majority of previous studies concerning the growth-environment-democracy-nexus, in contrast, relied on country-level data. There are three major arguments in favor of using local measurements instead of national aggregates.

First, environmental policy is not necessarily conducted at the national level. Many countries have smaller administrative units, such as provinces or even districts, with their own environmental policies. The differences in policies between these regions within the same nation can be tremendous. Prominent examples are California and Texas in the United States, with California having high environmental standards and Texas being famous for lighter environmental regulations. However, even if the environmental policy is set at the national level, regulations and monitoring are often localized. Chakraborti and McConnell (2012) show that the stringency of regulations under the 'Clear Water Act' in the United States depends strongly on local water quality conditions. Dion et al. (1998) find that the amount and intensity of monitoring of national environmental standards depend on local conditions. Specifically, their results suggest that plants with a higher potential for environmental damage are more likely to be monitored, meaning that not every region has, a priori, the same probability of being monitored. Additionally, economic factors play an important role. In the same study, Dion et al. find that the probability to be monitored decreases for plants located in areas with higher unemployment. Furthermore, if local environmental authorities can decide where to monitor, the bargaining power of firms might be of importance (Wang et al., 2002; Gray and Deily, 1996). Thus, environmental regulations and monitoring depend on local conditions. Consequently, firms in different locations within the same country can face different environmental policies and differences in the effectiveness of those policies, which in turn implies that economic growth can have differing effects on emissions, depending on local conditions.

Second, growth in urban areas may affect emission of pollutants differently than growth in rural areas. Growth could have positive effects due to knowledge spillovers, which in turn may lead to cleaner technologies on average. Furthermore, higher income and higher emission levels in highly populated areas may increase the demand for environmental quality. Cheng (2016) argues that geographically clustered upstream and downstream industries have positive

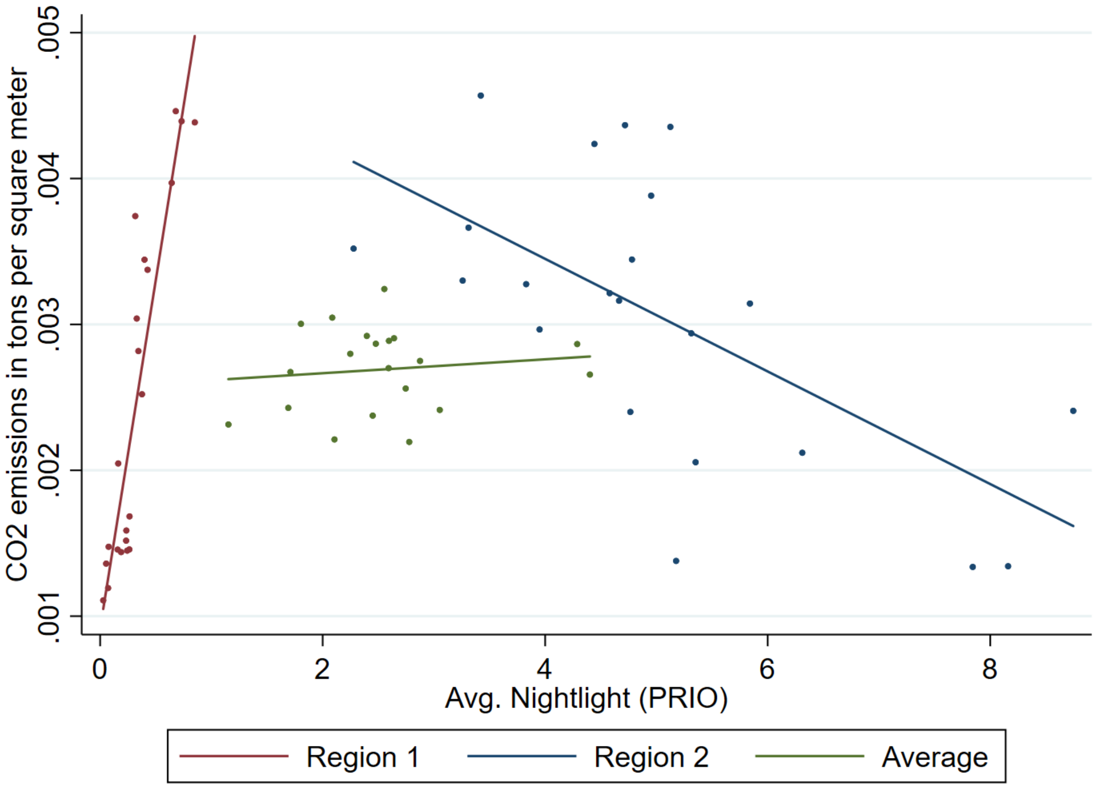

Figure 1: Example of the aggregation problematic

externalities in terms of recycling pollutants. Adverse effects are also possible. List and Co (2000) highlight that FDI and, in particular, the location of new plants by multinational firms depends on environmental regulations within a nation. Thus, to attract firms, local authorities could have incentives to lower regulations, especially in highly populated areas.

Third, aggregating regions into country averages can result in misleading conclusions. The geographical literature refers to this phenomenon as the 'modifiable areal unit problem' (MAUP). It describes the statistical bias and problems for statistical hypothesis testing that can arise from spatial data aggregation[1]. Depending on the spatial level of study observations, the results of the empirical analysis can vary or even be contradicting. In this paper, using country-level data would implicitly assume that the country's average income changes affect all regions equally. However, if the level and growth of income are not evenly distributed across space and have a different effect on pollution (as, for instance, the EKC theory would suggest), using aggregated data is problematic[2]. If regions with contrary trends are aggregated, the opposing trends might cancel each other out or produce a biased slope. Figure 1 illustrates this issue with two selected grids from the sample used in the empirical analysis. It plots average nighttime light luminosity on the abscissa and tons of carbon dioxide (CO_2) emissions per square meter on the ordinate. On average, Region 1, as shown by the red dots, has increasing levels of carbon

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[1] For a detailed definition, description and exemplification of the MAUP in general, see Grasland et al. (2006) or Jelinski and Wu (1996).

[2] For a discussion of the drawbacks from using country averages in a different context see Kammerlander and Schulze (2021a).

dioxide (CO_2) emissions along with higher levels of economic activity. In contrast, Region 2 experienced decreasing levels of carbon dioxide (CO_2) emissions with rising income (blue dots). The different emission paths could, for example, be the result of different stages in development in both regions, since Region 2 has higher values of nighttime light in all years. If the two regions are aggregated, the opposing trends cancel each other out almost entirely, suggesting no clear relationship between economic activity and pollution. An analysis with aggregated data in such a case would conclude that economic growth does not affect pollution. In contrast, a local analysis could identify an inverted U-shape and a different effect of economic growth, depending on the stage of development, which would be consistent with the EKC hypothesis.

If non-linear relationships in the regions are considered, the bias becomes even more pronounced. Figure 2 plots the distribution of nighttime light luminosity and carbon dioxide (CO_2) emissions for two different regions in the larger sample. Region 1 follows a downward trend in CO_2 at increasing levels of nighttime light luminosity; region 2 follows an upward trend. The third panel shows all observations from the first and second panels. Combining all observations from both regions with the opposing trends clearly yields a convex U-shape between nighttime lights and carbon dioxide emissions (CO_2). However, when the values of the two regions are aggregated (Panel 4), the linkage between economic activity and carbon dioxide emissions (CO_2) becomes less clear. The convex shape from the third panel vanishes and the distribution no longer resembles an obvious function. If anything, the function may be described as concave, as suggested by the fitted square curve.

These examples show how an analysis that aggregates variables can be misleading and may hide underlying mechanisms. When testing for an inverted U-relationship between income and pollution, such as in the context of the environmental Kuznets curve, aggregation at the national level is highly problematic and can lead to false conclusions.

The size of the described aggregation bias depends inter alia on the amount of spatial inequality within a country. The larger the heterogeneity and spatial inequality of regions, the larger the bias can become. Thus, problems created by using data aggregated at the country level increase with higher levels of decentralization and spatial inequality, which can be especially large in a developing country (Lessmann and Seidel, 2017). To address these issues, the study uses localized data instead of country averages.

3 Data

The study employs data at the grid level to analyze the relationship between economic development and ten different air pollutants (CO_2, CO, NO_x,SO_2, NMVOC, NH_3, BC, OC, PM_{10}, and $PM_{2.5}$). The study combines EDGAR pollution data with nighttime light luminosity, population density, and other control variables at the grid level. The combined dataset consists of 1,282,616 observations covering the period between 1992 and 2013. The resolution of the grid is $\frac{1}{2}\ x\ \frac{1}{2}^{\circ}$ which is approximately 48x48 km at the equator. The size of the grid decreases with distance from the equator.

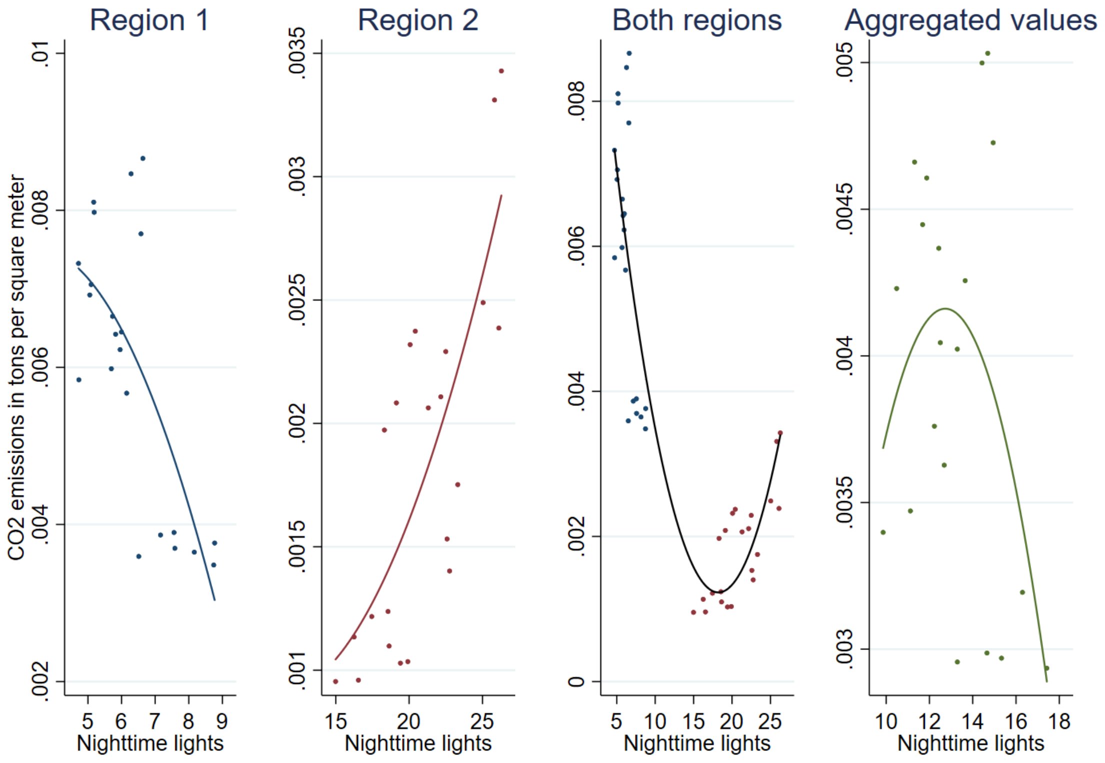

Figure 2: Aggregation problematic of regions

3.1 Air pollution

The EDGAR dataset v5 by Crippa et al. (2018) provides gridded annual data for air pollution and is available globally for the period 1970 to 2015. All pollutants are measured as emission per square meter (m^2) per year and are standardized for ease of interpretation and comparability. The most prominent emission factor is the greenhouse gas carbon dioxide. The other available air pollutants are grouped into gaseous air pollutants and aerosols containing particulate air pollutants. The gaseous air pollutants include carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), non-methane volatile organic compounds (NMVOC), and ammonia (NH_3). The aerosols in the dataset are black carbon (BC), organic carbon (OC), and particulate matter (PM). Particulate matter (PM) is further divided into particle pollution smaller than ten micrometers (PM_{10}) and fine particulates smaller than 2.5 micrometers ($PM_{2.5}$).

Most pollutants affect human health and climate change. However, the analysis of particulate matter (PM) is primarily linked to health issues, rather than to climate change.[3] For a detailed study of health impacts and the pathways of pollutants and particulate matters, in particular, see Kampa and Castanas (2008). The effects range from acute respiratory infec-

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[3] $PM_{2.5}$ and PM_{10} are a mixture of chemicals and natural components that can vary substantially depending on the local conditions and sources of emissions (Li et al., 2019). Common chemical constituents of particulate matter are "metals, organic compounds (measured as organic carbon [OC]) including materials of biological origin, inorganic carbonaceous material (including black carbon [BC] and elemental carbon [EC]), and sulfate, nitrate, ammonium, and other ions" (Adams et al., 2015, p. 545). The different compositions of matter make it difficult to evaluate their climate impact, because single components can have contrary climate impacts.

tions in children to chronic bronchitis, heart diseases, and lung cancer. Moreover, exposure to these pollutants is associated with premature mortality and reduced life expectancy (Kampa and Castanas, 2008). Although air pollution and its effects on health are mostly seen as local problems, Verstraeten et al. (2015) and Ngo et al. (2018) show that ozone (O_3) and nitrous oxide (NO_x) regularly travel from China to the west coast of the United States, where they cause severe health problems.[4] Thus, the health impacts of air pollution are a global, rather than only a local or regional, problem.

Although only the health impacts of particulate matter (PM) are emphasized, the single components of particulate matter (PM) (e.g., black carbon (BC)) can also have a substantial impact on global climate change (see e.g., Myhre et al., 2014). Analyzing the health effects of single particle pollutants is complex because different pollutants may interact and often occur simultaneously. Because it is difficult to disentangle their effects, the pollutants are often grouped with particulate matter (PM) depending on their size rather than on their actual composition (Adams et al., 2015).

The major role of carbon dioxide (CO_2) as a forcing agent in global climate change is well-known. Hansen and Sato (2001) emphasize the importance of black carbon in the context of global warming. They estimate the direct impact of black carbon to be more than one-third of the impact of carbon dioxide (CO_2). This is consistent with the findings of Ramanathan and Carmichael (2008), who find that the contribution of black carbon emissions to current global warming is the second strongest after carbon dioxide. Furthermore, they stress that the lifespan of black carbon (one week) is substantially less than that of carbon dioxide (one hundred years). Reducing emissions of black carbon than therefore immediately improve the outlook with respect to global warming.

Ozone (O_3) is another major forcing agent of global warming (Hansen and Sato, 2001). It is not included in the EDGAR dataset. However, ozone forms in the atmosphere through chemical reactions between carbon monoxide, non-methane volatile organic compounds, and nitrous oxide, all of which are all available in EDGAR. Although tropospheric ozone has severe implications for global climate change, ground-level ozone can be a major health problem (WHO, 2020). Thus, carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), and nitrous oxide (NO_x) are relevant air pollutants on a global and local scale. According to the WHO, these three pollutants are a risk to health both collectively, because they combine to create ground-level ozone, and individually. Additionally, nitrous oxide and sulphur dioxide are the primary reasons for acid rain. Acid rain is well known to be responsible for severe damage to the environment, mainly to wildlife, fish, plants, and trees (see e.g. EPA, 2016). Furthermore, sulphur dioxide can negatively affect the respiratory system and form particulate matter through reaction with other compounds (EPA, 2016). The IPCC (2006) lists sulphur dioxide and ammonia (NH_3) as precursors of aerosols and thus particulate matter. Ammonia itself is a toxic gas that is highly acidic when inhaled.

Figure 3 shows the global growth in emissions from 1970 to 2015 for total pollution (left

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[4] The EDGAR dataset does not cover ozone (O_3) itself. Instead, the components NMVOC or NO_x, that form ozone (O_3), are covered.

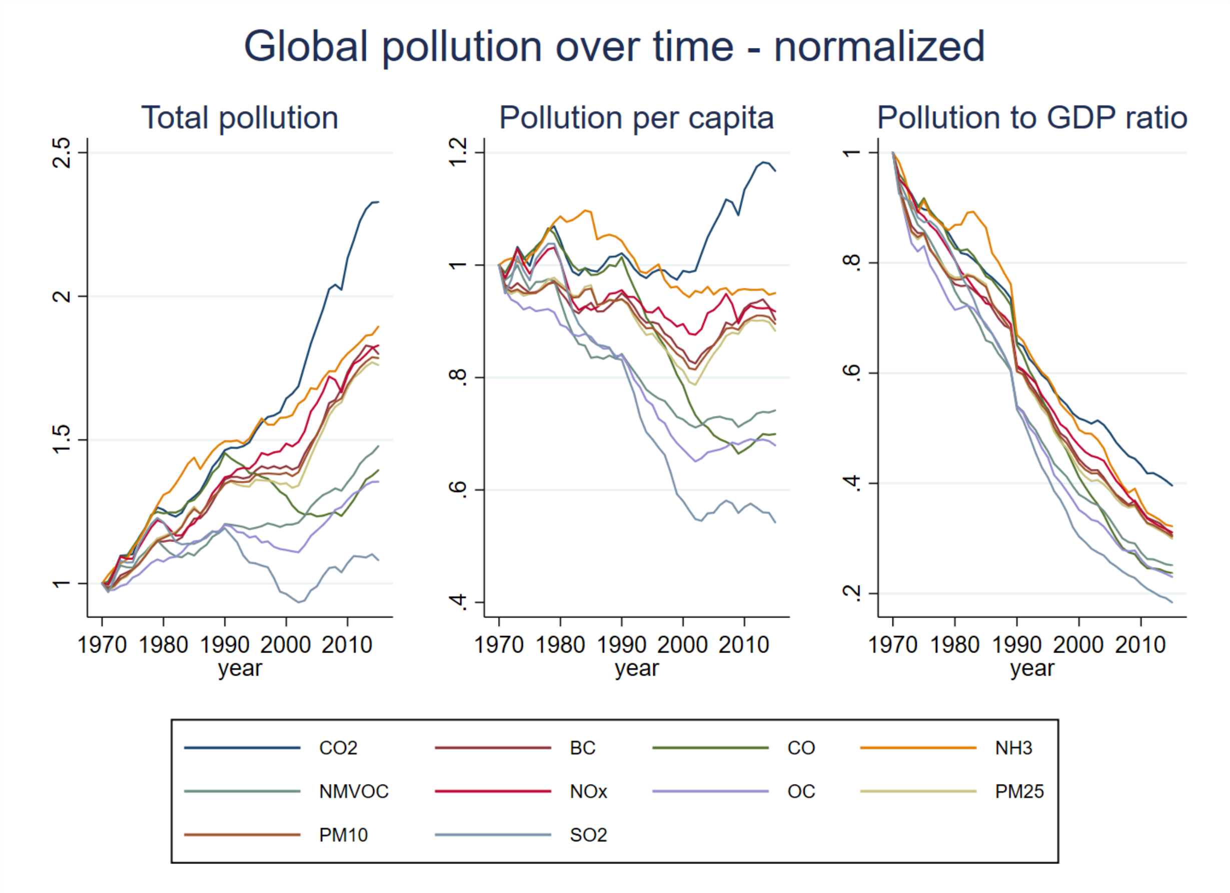

Figure 3: Development of pollutants over time

panel), per capita pollution (middle panel), and pollution as a function of gross domestic product (GDP) (right panel). All variables are normalized using 1970 as the base year. Despite certain fluctuations, emissions were greater in 2015 than in 1970 for all pollutants. Sulphur dioxide is the only pollutant that temporarily fell below its 1970 level of emissions. In contrast, 2015 carbon dioxide emissions increased by more than 230% compared to 1970 and emissions of nitrous oxide and ammonia nearly doubled. Although emissions of sulphur dioxide decreased slightly over the whole sample period and emissions of some pollutants were decreasing before 2003, the general trend of total global air pollution is strictly upward. The general direction of per capita pollution appears to be different. The middle panel shows that in per capita terms, only emissions of carbon dioxide increased overall. However, the growth was not linear. From 1970 onward, emissions of the majority of pollutants increased until shortly before 1980. Afterwards, the general trend was downward. Since 2002 and 2003, the trend seems to have reversed, and most pollutants increased again. The development of pollution per unit of GDP (real GDP at chained PPP in million 2011 $US.) shows a clear downward trend among all pollutants. This indicates a technology effect that contributed to more pollution-efficient production.

3.2 Local economic output

Nighttime light luminosity data from NOAA serves as a proxy for local economic output. Specifically, local economic output is measured using the Average Visible, Stable Lights, & Cloud Free Coverages from the Global DMSP-OLS Nighttime Lights Time Series (Version 4), which produces a consistent proxy for economic output across both developing and developed countries. Fog and cloudy weather may substantially affect the lights actually visible at night. The Average Visible, Stable Lights, & Cloud Free Coverages series ensures that this is not problematic and that we observe actual nighttime luminosity. The use of nighttime luminosity data has recently become a popular measure of local economic activity, especially in the context of developing countries (Henderson et al., 2012; Hodler and Raschky, 2014; Alesina et al., 2016; Lessmann and Seidel, 2017). Nighttime light data is globally available on an annual basis from 1992 to 2013 and measures light intensity at night on a scale from 0 to 63.

Ideally, gridded GDP data should be used to explain pollution measures. However, the only database that provides gridded GDP data is the G-Econ dataset v4.0 by Nordhaus (2006). It provides gross cell products (GCP), but it is measured at only a 1x1 degree resolution and is available in only five-year intervals. I use this variable (linearly interpolated) as a robustness check.

3.3 Democracy

The main measure of democracy comes from the PolityIV project (Marshall et al., 2019). The variables used in the baseline regressions are dummies for democracy, partial democracy, and autocracy. They are based on the polity2 variable, a continuous measure of democracy that ranges from -10 (strongly autocratic) to 10 (strongly democratic). To classify polity2 values into political regimes, the study follows the categorization of Epstein et al. (2006), who classifies countries as democratic if polity2 ≥ 7, partially democratic if $7 >$ polity2 > 0, and autocratic if polity2 ≤ 0.

The polity2 variable is a combination of two eleven-point scale variables: institutionalized autocracy (*autoc*) and institutionalized democracy (*democ*), that each range from 0 to 10. A score of 10 implies strongly democratic or strongly autocratic, respectively. The combined polity score is the difference between *democ* and *autoc*.

Political regimes are categorized because of their easy interpretation and good data availability. However, one obvious drawback of the polity data is that different combinations of *autoc* and *democ* can result in the same polity score. Further, even single subcategories are subject to this criticism. In the end, many different combinations of political variables and outcomes can result in a particular polity outcome (Cheibub et al., 2010). Furthermore, the polity variable, especially the categorization in democracy, partial democracy, and autocracy, exhibits little variation over time within a particular country, which might be a substantial caveat of a within-estimation.

The study addresses these limitations by using further measures of democracy as robustness checks. First, alternative cut-offs, as suggested by the PolityIV project, are used: countries with polity values from -10 to -6 are labeled as autocracies, countries with polity values from 6 to 10 are categorized as democracies, and all other countries are considered anocracies. Second, the study also uses the raw polity2 scores as a continuous measure. However, the main criticism of Cheibub et al. (2010) cannot be addressed with this approach.

The study thus also makes use of the Machine Learning Democracy Index by Gründler and Krieger (2021). The Grundler datasets provide a continuous measure of democracy ranging from 0 to 1. The machine learning approach incorporates ten variables and three dimensions of democracy (political participation, political competition, and freedom of opinion). Underlying this measure is the idea that democracy must account for different dimensions and aspects. A continuous measure allows for the capture of small changes towards democracy or autocracy, something not possible with a dichotomous measure.

The study also uses the Bjørnskov-Rode regime data. Contrary to Gründler and Krieger (2021) and the polity2 scores, Bjørnskov-Rode use a minimalistic approach to define democracy: "A country is defined as democratic, if elections were conducted, these were free and fair, and if there was a peaceful turnover of legislative and executive offices following those elections" (Bjørnskov and Rode, 2019). This measure has the advantage that changes in the democracy variable can be easily understood and interpreted. For a discussion of minimalistic and maximalist approaches and their advantages/drawbacks, see Gründler and Krieger (2021).

3.4 Control variables

Population density

Agglomeration can lead to economies of scale, i.e., economic growth in a region and a severe increase in pollution levels due to congestion, increased production, etc. To capture this phenomenon, population density is controlled for at the grid level, measured as the logarithm of the number of persons per square kilometer. A small constant (i.e., 0.01) is added before applying the logarithmic function to avoid losing grids that are not populated. The data is provided by the Center for International Earth Science Information Network (CIESIN). The Gridded Population of the World, Version 4 (GPWv4) from 2000 to 2012, and the Gridded Population of the World (GPW), v3 from 1992 to 2000 are both used. The data is available in five-year intervals. Data for years between the five-year intervals were linearly interpolated.

Climatic controls

The study controls for local precipitation and temperature, because they may affect economic activity as well as pollution. Temperature is measured as the average temperature in a grid throughout one year (in degrees Celsius), using data from Fan and van den Dool (2008). Precipitation is measured as the total yearly amount of rainfall, using data from Schneider et al. (2016). Both variables are provided by the PRIO GRID v2.0 in a $\frac{1}{2}$ °resolution.

Human Capital Index

The economies of different countries vary in their structures and factor endowments that affect economic growth as well as the pollution intensity of production. To account for this, the study included the human capital index from the Penn World Table 9.1. The variable weights years of schooling with marginal returns to education, following Psacharopoulos (1994). This incorporates diminishing returns to education[5]. Instead of measuring human capital using years of schooling, which implicitly assumes constant returns to education, the human capital index captures the non-linearity of returns to education and thus allows for decreasing returns to education.

Capital-labor ratio

Capital and labor-intensive industries are likely to be different in their emission levels, making the factor endowment a potential confounding factor. To control for this, the study adds the log of capital per worker from the Penn World Table 9.1 as a control variable.

Real GDP

Pollution at the local level is affected by local economic growth. A country's average economic growth can also affect local pollution, because it could bring about stricter environmental policies, changes in country wide monitoring, or a more efficient production technology, even if there is no growth at the local level. The study thus includes GDP per capita, measured using the logarithm of GDP per capita at purchasing power parity (PPP) from the Penn World Table 9.1, as a control variable.

KOF Globalization Index

Many studies have examined the effect of globalization on the environment (see e.g. Copeland and Taylor, 2004; Antweiler et al., 2001; Cherniwchan et al., 2017). Globalization might incentivize those policy makers with a pro-growth agenda to decrease environmental regulation to attract foreign investments, leading to more environmental pollution. It is also possible that globalization leads to less domestic pollution if dirty industries relocate to other countries with fewer environmental regulations. Thus it is essential to control for globalization. Instead of including different measures, such as trade flows or FDI, this study controls for one index that captures different aspects of globalization: the KOF Globalization Index, which ranges from 0 to 100. The KOF Globalization Index distinguishes between de facto and de jure globalization. It further divides these into subcategories for economic globalization, financial globalization, social globalization, and political globalization. The index takes a total of forty-three variables into account. For a detailed explanation of the procedure, weighting, and variables that were

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[5] The Human Capital Index from by Psacharopoulos (1994) weights the years of schooling t and is calculated as

$$H(t) = \begin{cases} 0.134 \cdot t & \text{if t} \leq 4 \\ 0.134 \cdot 4 + 0.0101 \cdot (t-4) & \text{if } 4 < \text{t} \leq 8 \\ 0.134 \cdot 4 + 0.0101 \cdot 4 + 0.068 \cdot (t-8) & \text{if t} > 8 \end{cases}$$

used for the index, see Gygli et al. (2019)[6].

To analyze the relationship between air pollution and nighttime lights, the study uses different specifications of the following basic regression model:

$$Pollution_{itc} = \beta_1\ Nightlight_{itc} + Grid\ controls_{itc}\zeta + Country\ controls'_{ct}\gamma + \delta_i + \delta_c + \delta_t + \epsilon_{itc} \quad (1)$$

$Pollution_{itc}$ measures emitted pollution per square meter in grid i, in year t, in country c. Pollution can either be CO_2, CO, NO_x, SO_2, NMVOC, NH_3, BC, OC, PM10, or PM2.5. The variable of interest is $Nightlight_{itc}$, measuring nighttime light luminosity at the grid level. Control variables at the grid level are the logarithm of population density and yearly averages of temperature and rainfall. At the country level, the control variables are the human capital index, capital per worker, logarithm of GDP per capita, the KOF globalization index, and dummy variables for the political regime. To account for time-invariant characteristics at the country level and common trends and developments among all observations, a set of country and year fixed effects is included. Because the study is primarily interested in changes in pollution and nighttime lights, grid-fixed effects are added to control for unobserved time-invariant heterogeneity. Standard errors are clustered at the grid level.

The main goal of this study is to investigate whether the effect of economic growth on pollution outcomes depends on the political system. To capture possible heterogeneity across political regimes with respect to local economic development, Equation (2) includes interaction terms for nighttime light and the different political regimes.

$$\begin{aligned} Pollution_{itc} = \beta_1\ Nightlight_{itc} + \beta_2\ Nightlight_{itc}\ \cdot\ Political\ regime_{ct} \\ + Grid\ controls_{itc}\ \zeta +\ Country\ controls_{ct}\ \gamma + \delta_i + \delta_c + \delta_t + \epsilon_{itc} \end{aligned} \quad (2)$$

4 Main results

Figure 4 shows the results of regressing average nighttime lights on the ten different pollution measures. For detailed results with all control variables, see table A3. The estimated linear association between nightlight and air pollution is positive and significant for all pollution measures, except for carbon monoxide (CO), whose positive coefficient is not statistically significant at conventional significance levels. Overall, these results imply that increased local economic activity is associated with higher pollution emissions throughout the vast array of the considered pollutants. An increase in nighttime light luminosity by one standard deviation (3.99) is associated with an increase in black carbon by 0.16 ($0.04 \cdot 3.99$) standard deviations. The magnitude of the coefficients differs substantially between pollutants. The smallest significant effect is found for sulphur dioxide (SO_2), where a one-standard-deviation increase in nighttime light luminosity is associated with an increase of 0.08 standard deviations in pollution. In

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[6] This index has been widely used, see e.g. Gründler and Potrafke (2019); Dreher and Langlotz (2020) or Kammerlander and Schulze (2021b)

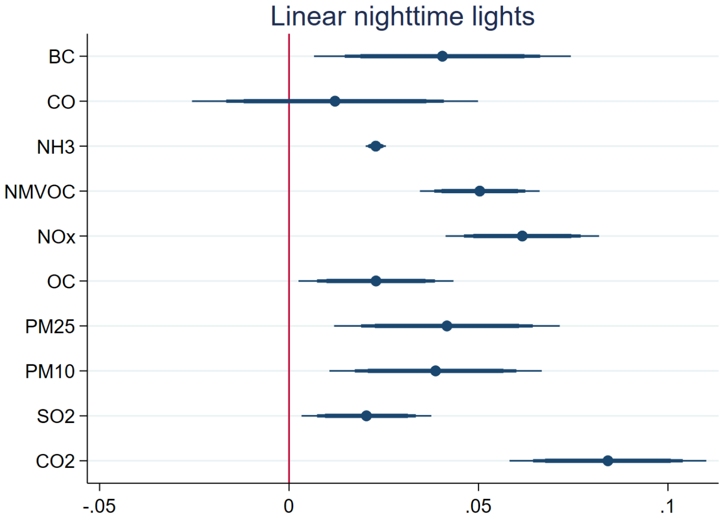

Figure 4: The effect of nighttime light luminosity on pollution

contrast, the coefficient on carbon dioxide (CO_2) is more than four times larger (0.33 standard deviations).

The evidence of the impact of the political system as such is ambiguous. The results suggest higher levels of pollution in democracies compared to autocracies for six out of ten pollutants (BC, CO, NMVOC, OC, PM2.5, and PM10). For carbon dioxide (CO_2) the association is negative and for NO_x, SO_2, and NH_3 no significant difference is found. Interestingly, partial democracies have higher levels of pollution compared to autocracies for all pollutants. Thus, there is no evidence suggesting that democracies are cleaner per se. This is in line with the findings of Gassebner et al. (2011), who find that dictatorships emit fewer pollutants per capita. The results are also comparable to Kammerlander and Schulze (2020a), who find no systematic effect of democracy on pollution per capita.

Figure 5 adds interaction terms between nighttime light luminosity and the three dummy variables for democracy, partial democracy, and autocracy. The full results are reported in table A4. It is evident that the estimated association between nighttime light and the different air pollutants differs substantially between political systems. The point estimates are smaller in democracies than in autocracies and partial democracies for all pollutants. The magnitude, however, varies between the pollutants. The effect of increased nighttime light luminosity is estimated to be more than three times larger in autocracies than in democracies for CO_2, PM2.5, PM10, and even four to five times larger for BC, NMVOC, and NOx. Nevertheless, despite differences in the magnitude between autocracies and democracies, economic growth leads, on average, to increasing levels of pollution irrespective of the political system. For carbon monoxide and sulphur dioxide, the effect of economic growth is insignificant in democracies; for all other pollutants, economic growth also leads to higher emissions. Thus, the democratic process alone is not sufficient to bring about zero-pollution growth.

The results of the study, suggesting that the marginal effect of economic activity is smaller in democracies, is in line with the results of Lv (2017). In a study of nineteen emerging countries,

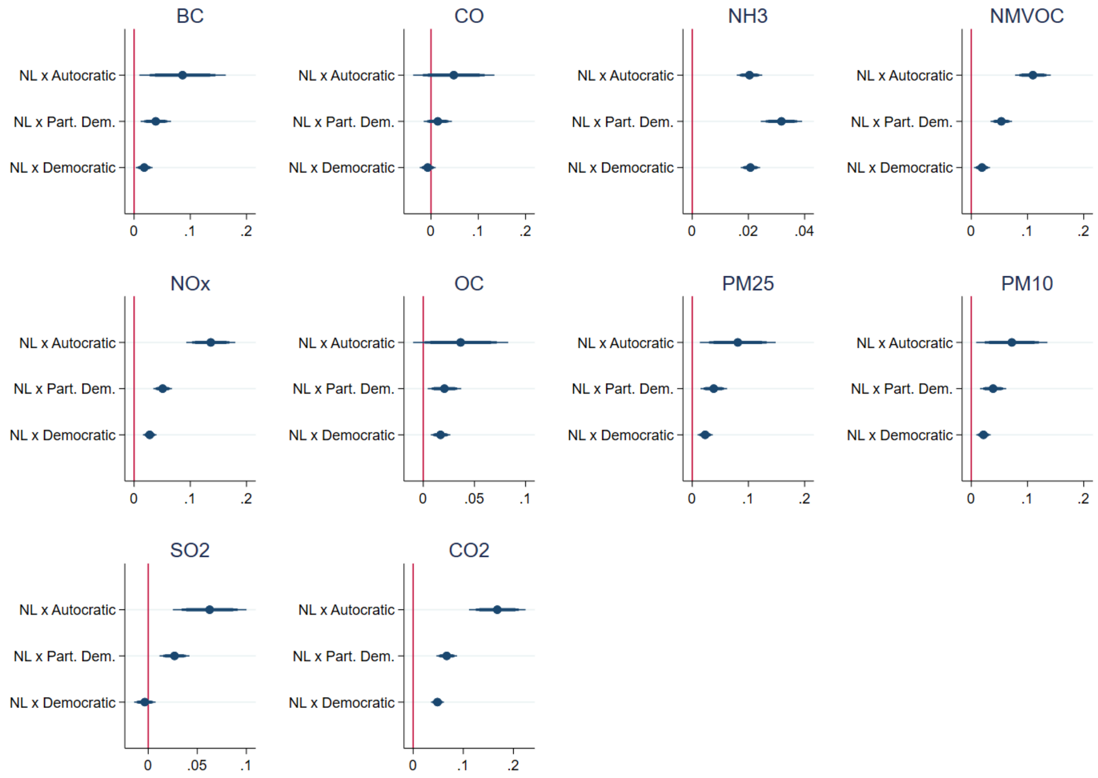

Figure 5: The effect of nighttime light on pollution in different political regimes

he finds that the pollution-increasing impact of economic growth (measured in the natural log of GDP per capita) between 1997 and 2010 was moderated by democracy. In addition to the polity2 measure, Lv also used different measures of democracy (the average of political rights and civil liberties from Freedom House) and found similar results. The results are also in line with Kammerlander and Schulze (2020a), who identify a negative interaction between democracy and per capita GDP in their fixed effects model. However, in the pooled setup, the interaction terms were positive but not always significant. Interestingly, the baseline effect of per capita GDP, i.e., economic growth, is insignificant in most settings, which is a major difference between the results of this study and the findings of Kammerlander and Schulze (2020a).

The EKC hypothesis suggests that pollution follows an inverted U-shape function with increasing income[7]. Following this hypothesis, Figure 6 tests for non-linearity by adding a squared term of nighttime light luminosity. Table A5 shows the respective estimated coefficients. For ease of interpretation and presentability, results are not shown for partial democracies, which are basically always between democracies and autocracies. The results for the whole sample in the left part of Figure 6 suggest there is no general quadratic relationship between economic activity and pollution: the squared coefficients are statistically insignificant. Exceptions are

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[7] Usually, the EKC hypothesis assumes that pollution per capita is a function of income per capita. Because this chapter is using regional data instead of country data, and uses per area instead of per capita values for pollution and economic growth, the study refrains from using the term ”environmental Kuznets-curve” when talking about an inverted U-shape relationship between pollution and economic growth.

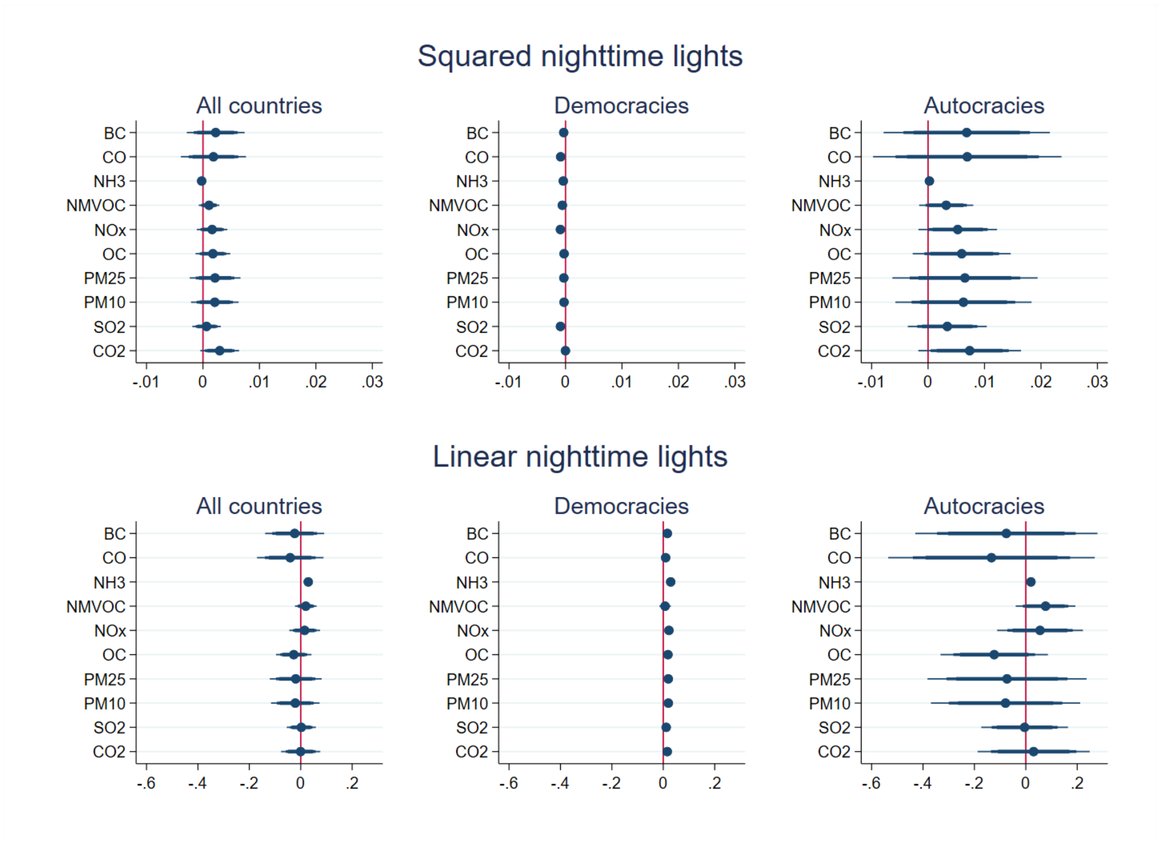

Figure 6: The effect of nighttime light luminosity squared on pollution

ammonia, with a negative squared coefficient, and carbon dioxide, with a positive squared coefficient.

The analysis using sub-samples for democracies and autocracies shows a striking heterogeneity of the effect of economic growth on pollution. In the sub-sample with only autocratic countries, the estimated relationship between pollution and economic growth is convex for all pollutants but statistically significant only for NMVOC, NOx, OC, NH_3, and CO_2. Thus, for five out of ten pollutants, the effect of economic growth on pollution is larger with higher levels of economic activity in autocracies. A concave relationship, i.e., a decreasing effect of economic growth on pollution with higher levels of economic activity, cannot be found for a single pollutant in autocracies.

In contrast, the point estimates of squared coefficients among democracies are negative and significant, suggesting a concave relationship for all pollutants. Carbon dioxide (CO_2) is the only pollutant with an insignificant coefficient on the squared nighttime lights. Instead, the estimated coefficients suggest a positive and linear relationship. The turning points, beyond which a further increase in economic growth is estimated to decrease pollution, range from 5.4 (CO) to 38.4 (PM10). To illustrate the difference in trajectories between democracies and autocracies, Figure 7 plots the function of nighttime lights and pollution according to the linear and squared terms of nighttime lights from Figure 6.[8] Figure 7 clearly shows that the effect of economic growth on pollution is larger in autocracies than in democracies. Furthermore,

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[8] Note that the coefficients are plotted irrespective of their significance.

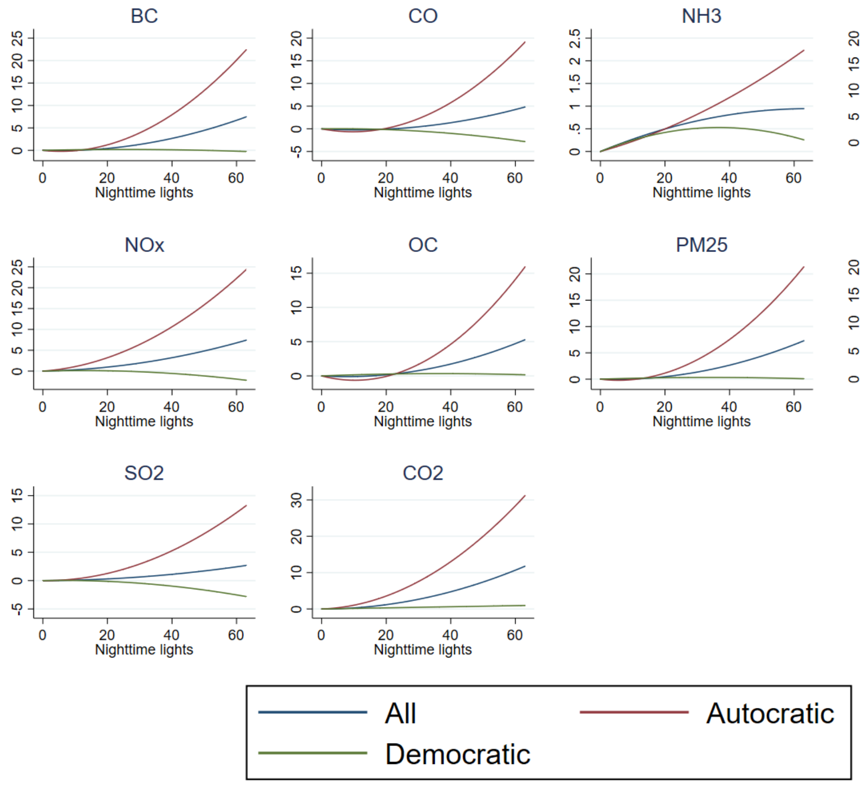

Figure 7: Plotted coefficients of nighttime light luminosity from Figure 6

this effect diminishes or even becomes negative in democracies, while in autocracies, the effect becomes larger with higher levels of nighttime light luminosity.

Overall, in democracies there is a turning point for most air pollutants, up to which economic growth decreases air pollution. However, the results imply that economic growth increases carbon dioxide emissions irrespective of the level of economic activity. Because the impact of carbon dioxide on climate change is larger than any other air pollutant (see Myhre et al., 2014), hopes that climate change can be ’outgrown’ are not supported by this evidence, not even in democracies. Figures 6 and Figure7 suggest that the relationship between economic activity and pollution is non-linear for the majority of pollutants. Keeping in mind the aggregation fallacies noted in section 2, this is a strong argument in favor of using gridded data, rather than country aggregates, for such an analysis.

5 Sector analysis

The availability of data on pollutants per sector allows further investigation of the effect of political regimes on the association between economic development and pollution. The EDGAR dataset provides pollution measures for forty-one different sectors. The study follows Crippa et al. (2018) and aggregates sectors into five broader categories: energy, industry, transport, residence, and agriculture. Table A2 gives a detailed overview of the sector classification.

Figure 8 shows the main sectors for each pollutant. Carbon dioxide and non-methane

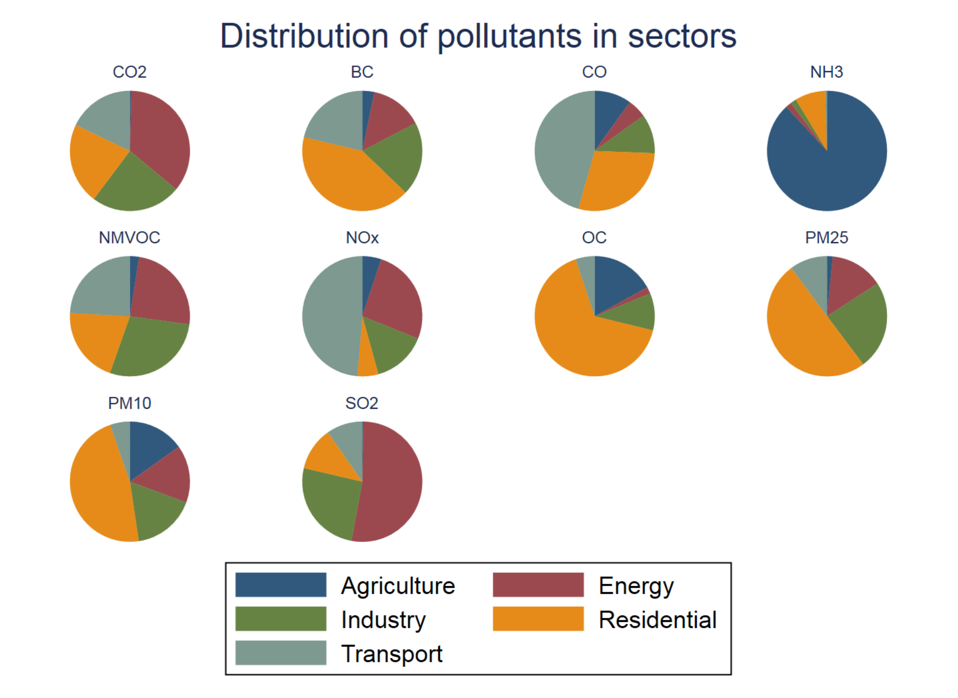

Figure 8: Distribution of pollutants in sectors

volatile organic compounds are nearly evenly distributed across the transport, industry, energy, and residential sectors. All aerosols, namely BC, OC, PM2.5 and PM10, occur for the most part in the residential sector, due to heating. The primary producer of NO_x and carbon monoxide is transport. NH_3 is predominantly emitted in the agricultural sector. The leading emitter of SO_2 is the energy sector.

Figure 9 portrays the difference in coefficients of nighttime lights from the baseline specification on pollutions emitted only in the energy sector, which is the sector with the highest CO_2 and SO_2 emissions (see Figure 8). As in Figure 6, Figure 9 displays all countries, democracies, and autocracies. Similar to the previous results, the coefficients on nightlight in partial democracies are smaller, for the most part, than those for autocracies but larger than those for democracies. The results for the entire sample (see Figure 9) show that most coefficients are relatively close to zero. Carbon dioxide (CO_2) stands out from the other pollutants with a value close to 0.1, implying a nearly 0.4 (i.e. $0.1 \cdot 3.99$) standard deviation change if nighttime lights increase by one standard deviation. Furthermore, the graph shows a substantially different pattern between democracies and autocracies. Although the estimated magnitude of all pollutants is close to zero in democracies, the picture that emerges for autocracies is entirely different: the coefficients on BC, CO, NO_x and CO_2 are more than twice the size of the full sample and more than ten times the size of the coefficients on democracies. This implies that part of the difference in the effects of growth on pollution between democracies and autocracies originates in the energy sector.

The difference between democracies and autocracies is even more pronounced for the industrial sector. Although the effect of economic growth on pollution in democracies is estimated to be zero for most pollutants, the association appears entirely different in autocracies. Most of the

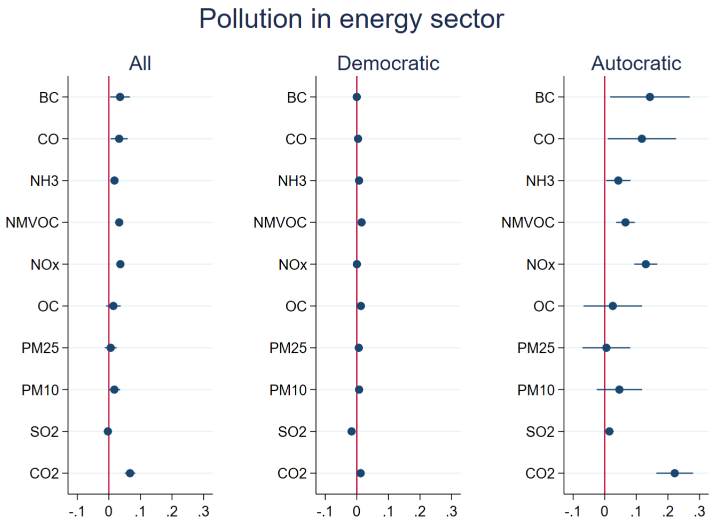

Figure 9: Estimates for nighttime lights on pollution in the energy sector

estimated coefficients imply a significant increase in air pollution, between 0.2 and 0.3 standard deviations. Transport-related emissions suggest a negative correlation between nighttime lights and pollution for eight of ten pollutants among democracies. In contrast, among autocracies only one coefficient, namely carbon monoxide is negative, whereas the other nine coefficients are all positive and highly significant. The effect of economic growth on carbon dioxide emissions is estimated to positively affect transport-related emissions in both democracies and autocracies.

In contrast to the energy, industry, and transport sectors, there is no unambiguous difference between democracies and autocracies in the residential sector. The effect of economic growth on nitrous oxide emissions is estimated to be positive in both autocracies and democracies, but substantially larger in autocracies. For most of the other pollutants, economic growth in autocracies is associated with less pollution in the residential sector. Agriculture-related emissions behave largely similarly in both sub-samples, although the magnitude of the coefficients on NH_3 and PM10 appear larger in autocracies.

The evidence from sector-specific emissions suggests that the difference in growth-related overall emissions between democracies and autocracies stems mainly from industrial production, the energy sector, and transportation. There is no convincing evidence of differences between the political systems in the agricultural and the residential sector.

A possible explanation could be preferential treatment or protectionist behavior of autocratic states towards state-owned enterprises. The sectoral distribution of state-owned enterprises from OECD (2017) shows that the three single largest sectors of state-owned enterprises, measured by employment, are electricity and gas (9%), manufacturing (9%), and transportation (19%).[9] These sectors are comparable to the sectors that drive the effect of economic growth on pollution (energy, transportation, and industry). With respect to the differences in the effect of economic growth on pollution in these sectors, it may be that in implementing environ-

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[9] If sectors are distinguished by equity value, the shares are slightly different: electricity and gas (21%), transportation (18%), manufacturing (6%). However, the finance sector, with a share of 26% of the equity value, is also crucial.

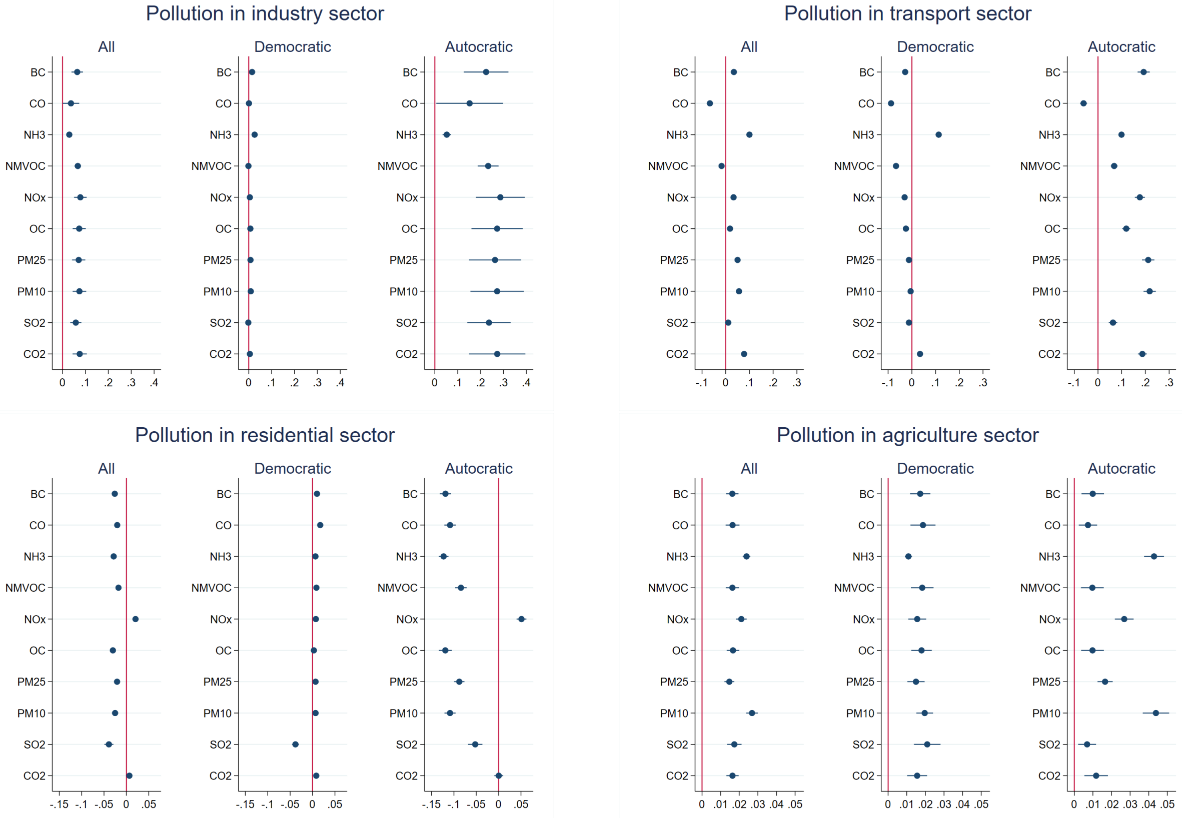

Figure 10: Estimates for nighttime lights on industry-, transport-, residential- and agriculture-related emissions

mental regulations, autocracies are more lenient toward state-owned enterprises or even whole sectors dominated by state-owned enterprises. The literature on state-owned enterprises and environmental pollution is relatively scarce and focused mainly on China. Yet, there is a hint of the special treatment of state-owned companies with respect to environmental monitoring and regulations. Jiang et al. (2014) show that state-owned enterprises in China pollute more than privately owned firms. Differences in emissions between private and state-owned companies could also be the consequence of differences in technology or efficiency. However, Wang et al. (2002) find that, compared to private firms, state-owned enterprises in China have greater bargaining power with local authorities that are seeking to enforce fines for emitting pollution. Maung et al. (2016) investigate the impact of political connections on environmental fees assessed against Chinese firms and find that state-owned enterprises pay fewer environmental levies, compared to private firms. Thus, a more lenient policy towards state-owned companies, or the sectors in which state-owned companies typically operate, could explain these differential effects.

6 Robustness Checks

To show that the results do not depend on a specific measure or choice of variable, robustness tests were conducted using different measures for democracy, different functional forms of nighttime lights and pollution, an alternative measure for nighttime lights, and country-year fixed effects.

6.1 Different measures for Democracy

Several different measures of democracy were used to account for the criticism from Cheibub et al. (2010) discussed in the data section. In all robustness tests in which a different measure of democracy is used, the control variable for democracy and the interaction term with nighttime light luminosity were replaced.

Figure A1 shows the results of the alternative categorization of polity2 from the PolityIV project as described in the data section. The results are similar to the baseline results: the effect of economic growth on pollution is larger in autocracies than in democracies. From this, it appears that the results do not depend on the specific choice of cut-offs used to distinguish between democracies and autocracies based on the polity2 variable.

Figure A2 uses continuous polity2 scores instead of the classification discussed above. The negative and significant interaction of nighttime light luminosity and the polity2-score for most of the pollutants confirms the findings of the baseline model: the effect of economic growth is weaker in democracies than in autocracies.

Furthermore, the continuous 'Machine Learning Democracy Index' (MLDI) by Gründler and Krieger (2021) and the dichotomous democracy measure from Bjørnskov and Rode (2019) were used to verify the robustness of the results. The results from the MLDI measure in Figure A3 show the same pattern as the baseline results: the point estimates of nighttime lights are positive for all pollutants and insignificant only for CO and OC. Furthermore, the interaction between nightlight and the democracy measure is negative, which again implies that the association between nighttime lights and pollution is less pronounced in more democratic countries. As with the results with the continuous polity2 score, the interaction between nightlight and democracy is positive and significant for NH_3.

Figure A4 shows the results when using the dichotomous democracy measure by Bjørnskov and Rode (2019). As with the results for the MLDI, nighttime lights are positively associated with pollution, but less so in democracies, with the exception of pollutants OC and NH_3. The association found in the main analysis is therefore not attributable to the specific measurement of democracy but is robust to the use of different measures of democracy.

6.2 Functional form of nighttime lights

The study further uses the logarithm (adding a small constant) and the inverse hyperbolic sine function of nighttime lights as functional forms. The alternative results for the logged nighttime lights are presented in Figure A5. The same pattern as the baseline results, albeit with a smaller effect of nighttime lights in democracies, emerges for a majority of coefficients. As in the baseline results, NH_3 is an exception. In contrast to the baseline results, OC has a smaller effect in democracies. For PM10 and PM25, the coefficients on democracies and autocracies are not statistically significantly different.

The pattern is also confirmed when using the inverse hyperbolic sine function (see Figure A6): point estimates of nighttime lights are larger in autocracies. NH_3 and OC are the exceptions. Thus, the main results remain unaltered: the association between nighttime lights and pollution is stronger in autocratic regimes, irrespective of the chosen functional form.

6.3 Gross cell product

The use of nighttime lights in this empirical approach relies crucially on the assumption that nighttime lights are an appropriate proxy for economic activity. Alternatives to using nighttime lights in a local setup are scarce. A fine-scale geo-referenced dataset of economic output that covers the whole world is unavailable, let alone for a sufficiently long time period. The best available alternative dataset is the gridded G-Econ dataset v4.0 by Nordhaus (2006). It offers an approximation of gross cell product (GCP) at PPP on a 1°x 1°resolution. The calculation of the gridded GCP is simple: GCP is equal to population per cell times GCP per capita. Data on GCP per capita is a combination of gross regional product, regional income by industry, regional employment by industry, regional urban and rural population, and employment data. For a detailed explanation of the approach see Nordhaus (2006). A weakness of the gridded G-Econ dataset is that it is less reliable in developing countries. Because the data used for the calculation depends almost entirely on the availability of data in each country, the (usually) better data quality and availability from official sources makes this approach more reliable for developed countries. The data is available for 1990, 1995, 2000, and 2005. Data for the years between the five-year intervals is created using linear interpolation.

Figure A7 presents the results of regressing the interaction of GCP and the political regimes on the ten pollution measures. Similar to Figure 5, where nighttime light interactions are plotted, the results with GCP imply that the association between nighttime lights and pollution is lower in democracies than in autocratic regimes. The point estimates of GCP in autocratic regimes are larger than in democratic regimes for all pollutants. In seven out of the ten pollutants, the association is significantly different for democratic and autocratic regimes. This supports the main findings of the baseline regressions and suggests that the results are not driven by the use of nighttime lights but are robust to using different measures for economic activity.

6.4 Country-year fixed effects

It is also possible that the baseline regression does not sufficiently control for all possible intervening factors at the country level. Although the study controls for the most important determinants, i.e., political system, economic growth, globalization, and human capital, there could be additional factors that are both correlated with pollution and related to the variables of interest. Although country fixed effects take time-invariant factors into account, some factors at the country level may change over time. Country-year fixed effects are therefore included in this robustness check. The downside of using country-year fixed effects is that all variables at the country level are automatically eliminated from the equation. Thus, the association between democracy and pollution itself cannot be estimated in this test.

Figure A8 shows the results of the regressions with the polity interaction when country-year fixed effects are included. As in the previous section, these results confirm the findings of the baseline analysis. The effect of nighttime lights is estimated to be larger in autocratic countries for all pollutants with the exception of NH_3.

7 Conclusion

This paper has investigated the association between economic growth and pollution at the grid level. Using a panel dataset from 1992 to 2013, the relationship was tested for ten major air pollutants (CO_2, CO, NO_x, SO_2, NMVOC, NH_3, BC, OC, PM_{10} and $PM_{2.5}$) responsible for serious health problems and climate change. There is a positive and robust association between local economic growth and emissions for all pollutants. The only exception is carbon monoxide, for which the coefficient is insignificant.

Although democracies are estimated to generate more pollution overall, the relationship between economic growth and pollution is weaker than in autocracies, suggesting that there is 'greener,' i.e., a less 'dirty', growth in democracies. This finding could be driven by a greater commitment to climate change mitigation in democracies, legally binding limits, environmental regulations, or a greater public demand for lower pollution levels. Nevertheless, the findings clearly show a positive, albeit smaller impact of economic growth on pollution in democracies. Thus, to achieve 'green' growth, also democratic countries must further increase their efforts with respect to climate change and pollution mitigation. The findings are robust to using different measures of democracy, different functional forms of the main explanatory variable, the inclusion of country-year fixed effects, and different approaches to measuring economic growth at the grid level.

The differences in the relationship between economic growth and pollution between political systems become even greater when non-linearities are considered. Including a squared coefficient in autocracies shows either a linear or a quadratic effect of economic growth on pollution, i.e., the higher the level of economic activity, the larger is the effect of additional economic growth on pollution. In democracies, it is the opposite. A large majority of the squared coefficients indicate a decreasing marginal effect of growth on pollution. This emphasizes the necessity to use localized data instead of country averages, considering the fallacies associated with country averages outlined in previous sections.

An analysis at the sector level shows that the difference in the effect of economic activity on pollution between political systems is mainly driven by the industry, energy, and transport sectors. In these sectors, the association between economic growth and the emission of air pollutants is substantially larger in autocracies. The systematic difference in these sectors could be driven by state-owned enterprises and preferential treatment, e.g., in terms of environmental monitoring of these firms in autocracies. In contrast, no systematic differences between democracies and autocracies could be identified in the agriculture and residential sector.

Overall, the results imply that democracies have fewer pollution emissions caused by economic growth than do autocracies. Yet, economic growth increases pollution in autocracies and democracies, even if this increase is less pronounced among democracies. The findings suggest an inverted U-shape for nine of the ten pollutants studied among democracies, which implies that economic growth could become 'green' and eventually lead to less pollution. For carbon dioxide (CO_2), for which the net effect on global climate change is largest among all pollutants, no inverted U-shape is found. In other words, the empirical evidence suggests that economic growth is unlikely to contribute to, much less solve, the problems associated with climate change. Instead, active policies aimed at combating climate change and mitigating pollution are necessary to achieve reductions in emission, especially of carbon dioxide, in all countries irrespective of the political system.

Appendix

Table A1: Descriptive statistics

Varaibles	(1) Obs	(2) Mean	(3) S.D.	(4) Min	(5) Max
Avg. Nightlight	1,282,616	1.415	3.990	0	61.51
Autocracy	1,282,616	0.217	0.413	0	1
Democracy	1,282,616	0.466	0.499	0	1
Partial democracy	1,282,616	0.316	0.465	0	1
Polity2	1,282,616	4.667	5.949	-10	10
Democracy (Gruendler-Krieger)	1,282,616	0.535	0.377	0.00722	0.980
Democracy (Bjornskov-Rode)	1,282,616	0.523	0.499	0	1
Avg. Rainfall	1,282,616	186.2	183.7	0	2,655
Avg. Temperature	1,282,616	10.05	13.68	-23.62	57.55
Population density	1,282,616	47.51	198.8	0	14,213
KOF Globalisation Index	1,282,616	62.69	14.63	19.82	90.32
Human Capital Index	1,282,616	27.31	7.380	10.37	37.26
Capital per worker	1,282,616	147,473	110,678	786.1	817,594
GDP per capita	1,282,616	18,041	15,313	218.0	153,458
Gross Cell Product (PPP)	796,362	0.728	4.189	0	264.7

Table A2: Classification of sectors from the EDGAR database

Category	**Description (EDGAR)**	**IPCC 1996**
Energy	Public electricity and heat production	1A1a
Energy	Other Energy Industries	1A5
Energy	Other Energy Industries	1A1bc
Energy	Fugitive emissions from solid fuels	1B1
Energy	Fugitive emissions from solid fuels	1B1x
Energy	Fugitive emissions from oil/gas/gaseous fuels	1B2
Energy	Fugitive emissions from oil/gas/gaseous fuels	1B2x
Industry	Fossil fuel fires	7A
Industry	Solvent and other product use: paint	3A
Industry	Solvent and other product use: degrease	3B
Industry	Solvent and other product use: chemicals	3C
Industry	Solvent and other product use: other	3D
Industry	Cement production	2A1
Industry	Lime production	2A2
Industry	Limestone and dolomite use	2A3
Industry	Soda ash production and use	2A4
Industry	Production of chemicals	2B
Industry	Production of metals	2C
Industry	Production of pulp/paper/food/drink	2D
Industry	Production of other minerals	2A7
Industry	Non-energy use of lubricants/waxes (CO2)	2G
Industry	Manufacturing Industries and Construction	1A2
Transport	Domestic aviation	1A3a
Transport	Road transportation (resuspension)	1A3b
Transport	Road transportation (no resuspension)	1A3b
Transport	Rail transportation	1A3c
Transport	Inland navigation	1A3d
Transport	Other transportation	1A3e
Transport	Int. Aviation	1C1
Transport	Int. Shipping	1C2
Residential	Residential and other sectors	1A4
Residential	Solid waste disposal on land	6A
Residential	Wastewater handling	6B
Residential	Waste incineration	6C
Residential	Other waste handling	6D
Agriculture	Manure management	4B
Agriculture	Direct soil emissions	4D1
Agriculture	Manure in pasture/range/paddock	4D2
Agriculture	Other direct soil emissions	4D4
Agriculture	Rice cultivation	4C
Agriculture	Agricultural waste burning	4F

Table A3: Baseline regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES	BC	CO	NH3	NMVOC	NOx	OC	PM25	PM10	SO2	CO2
Avg. Nightlight	0.0405***	0.0121	0.0229***	0.0503***	0.0616***	0.0229***	0.0417***	0.0387***	0.0204***	0.0842***
	(0.013)	(0.015)	(0.001)	(0.006)	(0.008)	(0.008)	(0.012)	(0.011)	(0.007)	(0.010)
Avg. Rainfall	8.60e-06	2.75e-05***	-2.02e-06	2.22e-05***	-5.62e-06	2.39e-05***	1.55e-05*	1.26e-05	-6.40e-06	-3.86e-06
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Avg. Temperature	-0.000513	-0.000217	-0.00185***	-0.000210	0.000877**	-0.00156***	-0.000587	-0.000646	-0.000334	0.00103**
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Log(pop dens)	0.00748***	-0.00235**	0.0193***	0.00660*	0.00941***	0.00795***	0.00730***	0.0115***	0.000268	0.0106***
	(0.001)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Human Capital Index	-0.00204	0.00859***	0.00480***	0.00190	0.00127	0.00756***	-0.00133	-0.00157	0.00157	-0.00557***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Log(Capital p.c.)	0.0669***	0.0273***	0.120***	0.0779***	0.0790***	0.0408***	0.0685***	0.0673***	0.0442***	0.0704***
	(0.007)	(0.008)	(0.002)	(0.004)	(0.004)	(0.004)	(0.006)	(0.006)	(0.004)	(0.005)
Log(GDP p.c.)	0.0281***	0.0515***	0.0167***	0.0465***	0.0511***	0.00804***	0.0187***	0.0244***	0.0386***	0.0218***
	(0.002)	(0.002)	(0.002)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)	(0.003)
KOF Globalisation Index	0.00294***	0.00401***	-0.00122***	0.00557***	0.00637***	0.000630**	0.00244***	0.00243***	0.00266***	0.00330***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Democracy	0.00520**	0.0193***	-0.00563	0.0266***	0.00219	0.0294***	0.00812***	0.0149***	-0.00258	-0.0118***
	(0.003)	(0.003)	(0.004)	(0.006)	(0.004)	(0.003)	(0.003)	(0.003)	(0.008)	(0.003)
Partial democracy	0.0274***	0.0247***	0.0310***	0.0435***	0.0188***	0.0334***	0.0290***	0.0384***	0.0229***	0.00627***
	(0.002)	(0.002)	(0.003)	(0.004)	(0.003)	(0.003)	(0.002)	(0.003)	(0.005)	(0.002)
Observations	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616
R-squared	0.787	0.747	0.983	0.905	0.906	0.923	0.837	0.853	0.869	0.892
Grid FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: All variables are regressed on the respective air pollutant. The air pollutants are a standardized measure of average emissions per square meter. Observations are at the grid level. Nightlight measures average light intensity at night from 0 to 63. Control variables are rainfall, temperature, log of population density, human capital index, log of capital per worker, log of real GDP per capita (PPP), KOF globalization index, and dummies for democracy and partial democracy. Standard errors clustered at the grid level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A4: Nighttime lights and interaction with political regimes

VARIABLES	(1) BC	(2) NH3	(3) CO2	(4) PM25	(5) PM10	(6) NMVOC	(7) CO	(8) NOx	(9) OC	(10) SO2
NL x Autocratic	0.0863***	0.0204***	0.168***	0.0811***	0.0721***	0.110***	0.0482	0.136***	0.0365**	0.0626***
	(0.030)	(0.002)	(0.022)	(0.026)	(0.025)	(0.012)	(0.033)	(0.017)	(0.018)	(0.015)
NL x Part. Dem.	0.0386***	0.0317***	0.0669***	0.0383***	0.0388***	0.0535***	0.0144	0.0509***	0.0207***	0.0268***
	(0.011)	(0.003)	(0.008)	(0.009)	(0.009)	(0.007)	(0.012)	(0.006)	(0.006)	(0.006)
NL x Democratic	0.0180***	0.0207***	0.0485***	0.0230***	0.0217***	0.0191***	-0.00700	0.0278***	0.0169***	-0.00345
	(0.006)	(0.001)	(0.005)	(0.005)	(0.005)	(0.006)	(0.007)	(0.005)	(0.004)	(0.004)
Avg. Rainfall	7.17e-06	-2.00e-06	-6.38e-06	1.43e-05*	1.15e-05	2.03e-05***	2.64e-05***	-7.91e-06	2.35e-05***	-7.77e-06
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Avg. Temperature	-0.000751	-0.00192***	0.000729	-0.000775	-0.000834	-0.000573	-0.000440	0.000562	-0.00162***	-0.000632
	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Log(pop dens)	0.00697***	0.0193***	0.00972***	0.00686***	0.0112***	0.00594*	-0.00275**	0.00857***	0.00780***	-0.000198
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Human Capital Index	-0.00309*	0.00475***	-0.00732***	-0.00221	-0.00236	0.000472	0.00771***	-0.000351	0.00727***	0.000498
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Log(Capital p.c.)	0.0607***	0.121***	0.0585***	0.0631***	0.0628***	0.0701***	0.0225***	0.0685***	0.0389***	0.0388***
	(0.006)	(0.002)	(0.004)	(0.005)	(0.005)	(0.004)	(0.007)	(0.004)	(0.004)	(0.004)
Log(GDP p.c.)	0.0216***	0.0145***	0.0138***	0.0135***	0.0192***	0.0364***	0.0452***	0.0426***	0.00658**	0.0302***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)	(0.002)	(0.003)	(0.003)	(0.005)
KOF Globalisation Index	0.00244***	-0.00107***	0.00219***	0.00198***	0.00208***	0.00500***	0.00367***	0.00544***	0.000457*	0.00230***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Democracy	0.0739***	-0.00355	0.105***	0.0661***	0.0660***	0.119***	0.0758***	0.109***	0.0487***	0.0662***
	(0.023)	(0.004)	(0.017)	(0.020)	(0.019)	(0.011)	(0.025)	(0.014)	(0.014)	(0.013)
Partial democracy	0.0656***	0.0212***	0.0882***	0.0634***	0.0650***	0.0880***	0.0514***	0.0879***	0.0462***	0.0509***
	(0.017)	(0.003)	(0.012)	(0.015)	(0.014)	(0.008)	(0.019)	(0.010)	(0.010)	(0.009)
Observations	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616	1,282,616
R-squared	0.788	0.983	0.895	0.837	0.854	0.907	0.748	0.910	0.923	0.871
Grid FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: All variables are regressed on the respective air pollutant. The air pollutants are a standardized measure of average emissions per square meter. Observations are at the grid level. Nightlight measures average light intensity at night from 0 to 63. Control variables are rainfall, temperature, log of population density, human capital index, log of capital per worker, log of real GDP per capita (PPP), KOF globalization index, and dummies for democracy and partial democracy. Standard errors clustered at the grid level. *** p<0.01, ** p<0.05, * p<0.1

Table A5: Linear and squared nighttime lights for different political systems

VARIABLES	(1) BC	(2) CO	(3) NH3	(4) NMVOC	(5) NOx	(6) OC	(7) PM25	(8) PM10	(9) SO2	(10) CO2
Panel A: All countries										
Avg. Nightlight	-0.0237	-0.0408	0.0294***	0.0196	0.0154	-0.0272	-0.0194	-0.0211	0.00223	-0.000260
	(0.045)	(0.050)	(0.002)	(0.016)	(0.023)	(0.027)	(0.039)	(0.037)	(0.022)	(0.030)
Nightlight squared	0.00226	0.00186	-0.000229***	0.00108	0.00162	0.00176	0.00215	0.00210	0.000640	0.00297**
	(0.002)	(0.002)	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
Panel B: Democracies										
Avg. Nightlight	0.0159***	0.00924***	0.0288***	0.00723	0.0220***	0.0183***	0.0196***	0.0198***	0.0114**	0.0155***
	(0.002)	(0.002)	(0.002)	(0.009)	(0.004)	(0.002)	(0.003)	(0.004)	(0.005)	(0.003)
Nightlight squared	-0.000316***	-0.000857***	-0.000393***	-0.000555***	-0.000902***	-0.000249***	-0.000291**	-0.000258*	-0.000889***	-6.28e-06
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel C: Autocracies										
Avg. Nightlight	-0.0757	-0.134	0.0200***	0.0769*	0.0553	-0.123	-0.0731	-0.0790	-0.00466	0.0305
	(0.138)	(0.156)	(0.003)	(0.045)	(0.065)	(0.081)	(0.120)	(0.113)	(0.065)	(0.085)
Nightlight squared	0.00685	0.00694	0.000245**	0.00321*	0.00526*	0.00596*	0.00654	0.00626	0.00341	0.00737**
	(0.006)	(0.006)	(0.000)	(0.002)	(0.003)	(0.003)	(0.005)	(0.005)	(0.003)	(0.004)
Controls:	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Grid FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: All variables are regressed on the respective air pollutant. The air pollutants are a standardized measure of average emissions per square meter. Observations are at the grid level. Nightlight measures average light intensity at night from 0 to 63. Control variables are rainfall, temperature, log of population density, human capital index, log of capital per worker, log of real GDP per capita (PPP), KOF globalization index, and dummies for democracy and partial democracy. Standard errors clustered at the grid level. *** p<0.01, ** p<0.05, * p<0.1

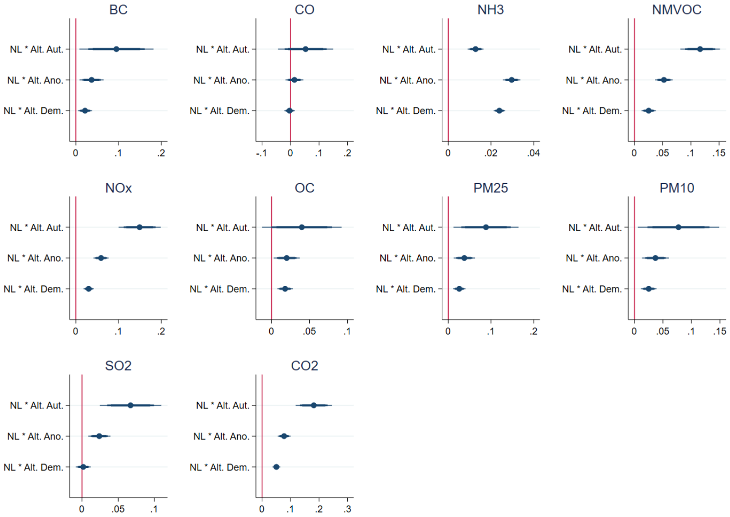

Figure A1: Alternative measure for democracy: different PolityIV cut-offs

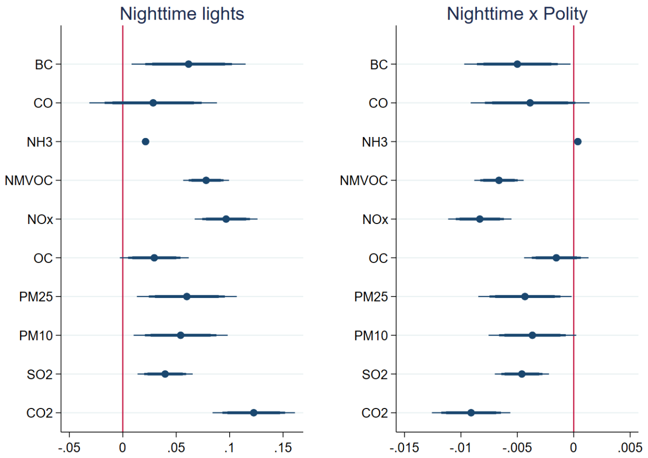

Figure A2: Nighttime light and polity interaction

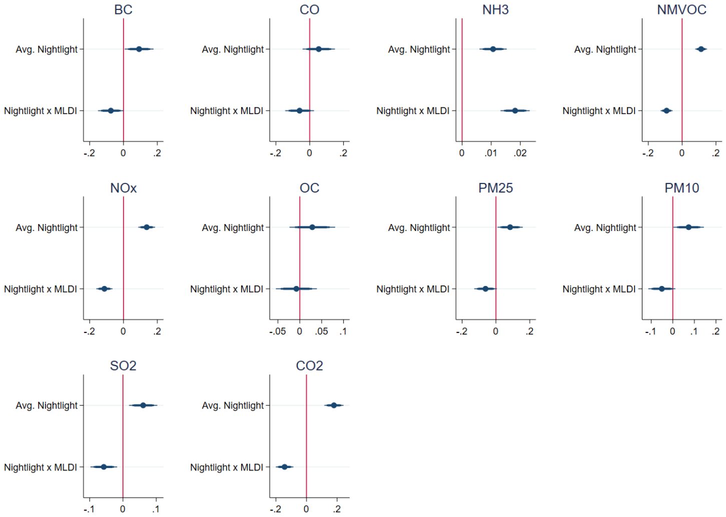

Figure A3: Machine Learning Democracy Index from Gründler and Krieger (2021)

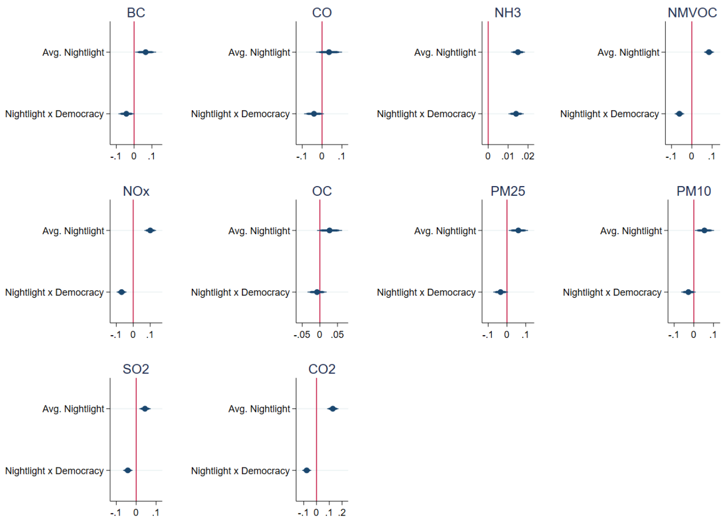

Figure A4: Dichotomous democracy measure from from Bjørnskov and Rode (2019)

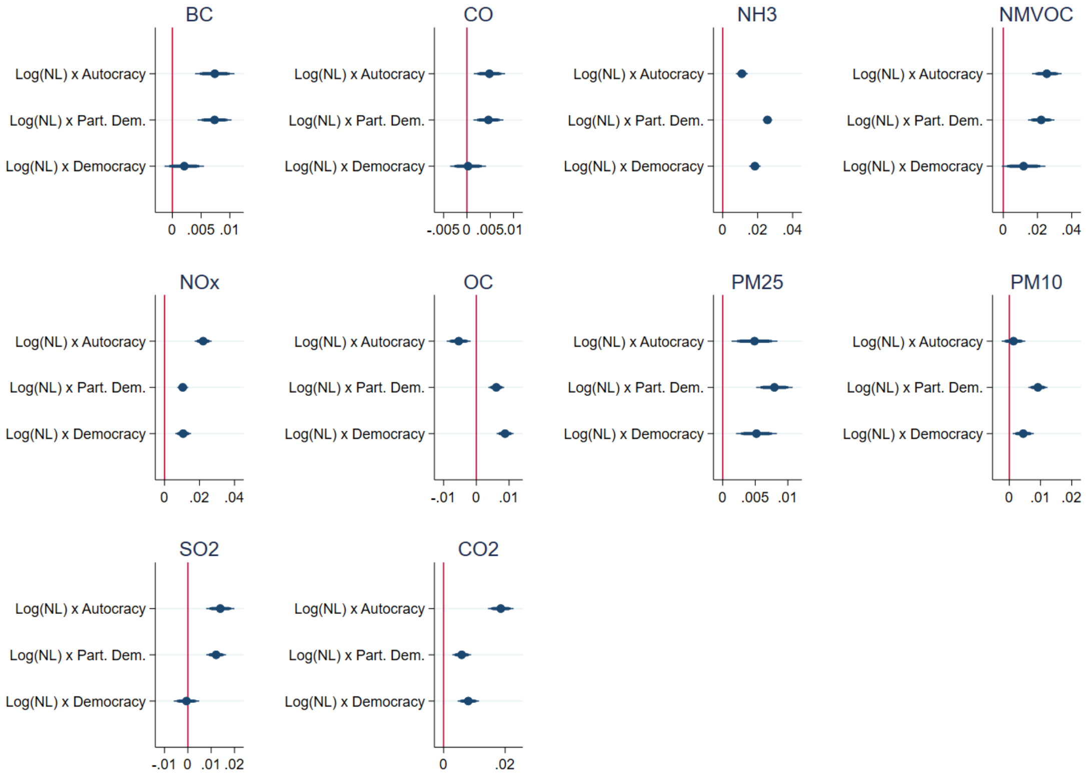

Figure A5: Logarithm of nighttime luminosity

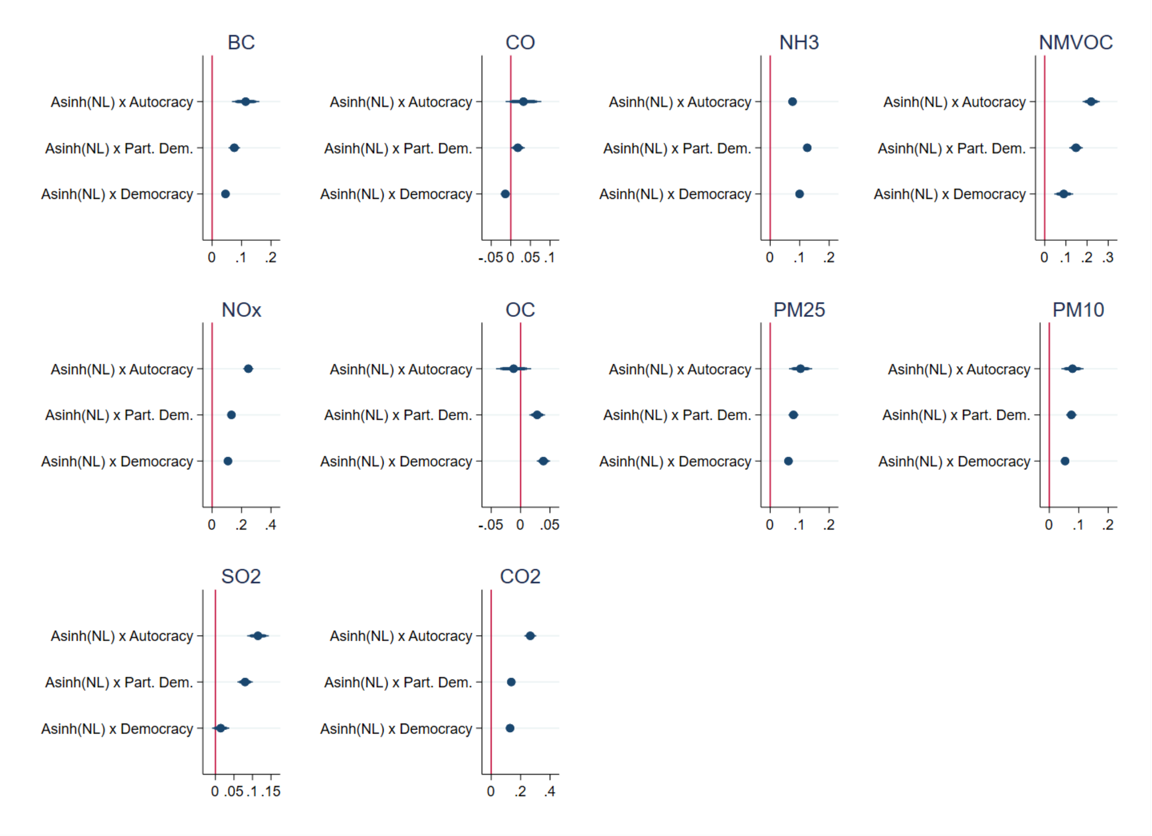

Figure A6: Inverse hyperbolic since function of nighttime luminosity

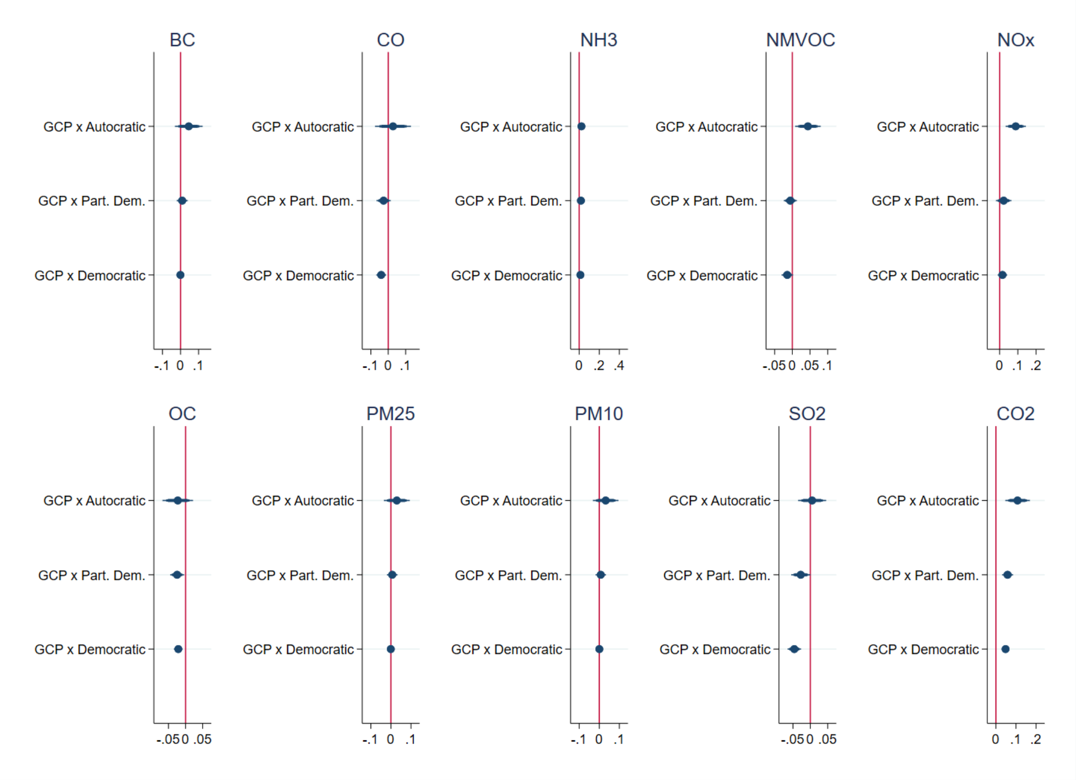

Figure A7: Gross Cell Product and Pollution in Political Regimes

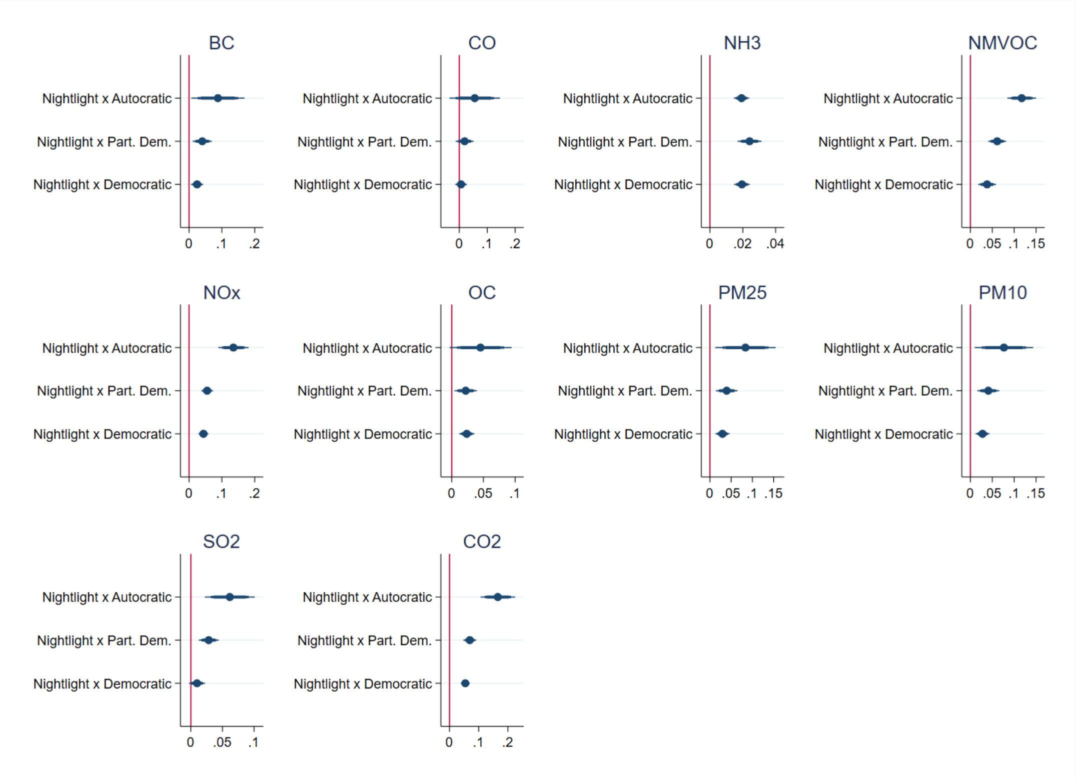

Figure A8: Country-year fixed effects

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