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Abstract

In this paper, we attempt to record the imprint of air pollution on economic growth and vice versa, the tendency of economic growth on air pollution. In order to carry out the study, we first review the relevant literature to find the methodologies and the main results of such a study.

The variables examined in our study are the following: PM2.5 (Particulate Matter Lower than 2.5 micro), GDPperCapita (GDP per capita), GDPperHourWorked (GDP per working hour), Unemployment, HealthExpenditure (Part of the budget for the health sector), CurrentHealthSpending (Expenditures for medical care), Temperature (Average annual temperature) and Rainfall (Average annual precipitation in mm). The databases used are OECD and DataWorldBank and the data consist of OECD countries

The methodology consists of three different models in each of which different type of regression is used to produce a different result and to compare them at the end. The first model uses panel data with fixed, random and pooled Ordinary Least Squares regressions. The second model uses "Difference and System GMM" estimators. Last but not least, the third model uses the augmented mean value (AMG) estimator.

The result is ambiguous as in some cases pollution seems to have a positive relationship with economic growth and in other cases their relationship is negative. On the contrary, the economic product always has a positive effect on air pollution.

1. Introduction

Air pollution is a major threat to human health. The World Health Organization (OECD, 2016) estimates that only 1 in 10 people worldwide live in areas where air pollution is within recommended levels, and air pollution is responsible for 7 million deaths per year (one in eight deaths). Air pollution dominates all other major preventable causes of death, including smoking, alcohol consumption, traffic accidents and communicable diseases such as AIDS, malaria and tuberculosis. As air pollution continues to grow at an alarming rate worldwide, especially in low- and middle-income countries, these numbers are expected to increase greatly in the coming years.

The consequences of air pollution on human health have led to the introduction of increasingly stringent environmental regulations around the world (Botta and Koźluk, 2014), but there is still controversy about the appropriate level of stringency. Enforcing environmental regulations is typically seen as a trade-off between creating health benefits and imposing costs on the economy, as resources are redirected from productive activities to pollution control activities. However, this ignores that health benefits can lead to improved productivity, which can translate into greater economic output.

The aim of this study is to provide a review of the existing literature and add new insights by estimating the impact of air pollution on economic activity, using data from all OECD countries. The empirical results show that higher levels of air pollution, as measured by the concentration of PM2.5 (the pollutant with the greatest estimated effects on mortality and health), exert a significant direct burden on the economy by reducing output per capita. This implies that reducing air pollution could bring great economic benefits in addition to improving the quality of life and health.

In cost-benefit analyzes of air pollution control policies, the benefits are typically dominated by non-economic impacts, such as avoided deaths. In contrast, financial benefits—such as sick leave at work—appear second in these ratings. For example, the US Environmental Protection Agency estimates that the benefits of the Clean Air Act amendments over the period 1990-2020 amount to $12 trillion (with 2006 as the base year), with 85% of these benefits attributed to the reduction of premature mortality (US EPA, 2011). Similarly, recent OECD analysis estimates the total annual market cost of air pollution (including reduced agricultural yields, absenteeism and health costs) to be 0.3% of global GDP in 2015, while welfare costs from non-economic impacts represent 6% of total income (OECD, 2016).

In a similar strand of argument, poor air quality can cause immediate reductions in economic activity because it negatively affects cognitive or physical ability (Graff Zivin and Neidell, 2018). This literature focuses mainly on the observation of changes in individual productivity caused by exposure to poor air quality. For example, there is evidence that air pollution reduces the productivity of workers on a large farm in California (Graff-Zivin and Neidell, 2012), a clothing factory in India (Adhvaryu et al., 2014) or a call center in China (Chang et al., 2016). There is also evidence that pollution affects productivity in high-skill tasks, such as student performance on standardized high school exams (Ebenstein et al., 2016) or investor performance on the New York Stock Exchange (Heyes et al., 2016). A large-scale study using data from the industrial manufacturing sector in China found evidence that a 1$\mu g/m^3$ increase in the average annual PM2.5 concentration (from an average of 53 $\mu g/m^3$) reduces worker productivity (value added per worker) by 1.1% (Fu et al., 2017).

Taken together, all the aforementioned studies suggest that air pollution negatively affects productivity, but they focus on idiosyncratic groups (e.g. packaging companies, traders, stockbrokers) or non-OECD countries with high levels of pollution (China, India). In this research, we add to the literature by providing an estimate of the potential impact of air pollution (measured by PM2.5 concentration) on aggregate economic activity in developed and developing countries, using regional data for the period 1995-2019 on a sample of OECD countries. We focus on the relationship between annual pollution and economic output, for the population at large, and thus avoid both concerns on idiosyncratic populations and the potential effects of within-year productivity shifts and reallocation of factors across firms.

Estimating the causal effect of air pollution on economic outcomes at the aggregate level is difficult due to the effect of reverse causality. Not only can air pollution affect economic output and productivity (the outcomes we seek to measure), but economic activity clearly affects emissions through various potential channels. To achieve consistency in our results, we resort to stationarity checks. We also adopt a strategy with control variables, such as temperature and precipitation, to isolate changes in the environment that are not related to economic activity. More generally, this research tries to give an answer to the question: "Is environmental pollution a brake on the economic development of states?"

The results show that air pollution significantly affects economic activity. Specifically, the relationship between air pollution (PM2.5) and GDP per capita seems to have two directions. In some examples the relationship between the two is negative while in others it appears positive. This is because it is possible that air pollution, especially in the long term, affects the productivity of workers and leads to a reduced economic product, while on the other hand, the more the pollution of the environment increases, the more efficient production techniques are used which lead to an increase in economic output product.

The second relationship examined is the effect of economic variables on air pollution. In this case there is also heterogeneity between states. Some models show a negative relationship between economic variables and air pollution due to the most polluting production techniques. In some other cases the relationship is positive mainly because countries may turn to greener production methods or import goods whose production leads to high air pollution (Dasgupta et al., 2002).

The paper is organized as follows. Section 2 provides background on the potential effects of pollution on economic outcomes based on the existing literature. Section 3 reviews the variables used in the empirical model. Section 4 describes our approach to estimating the causal effect of pollution on economic activity, Section 5 provides the main results of our empirical analysis and discusses the implications of our results, including comparing the results with those of other studies, comparing the economic benefits of reducing pollution. Finally, the 7th section presents some shortcomings that exist in the model and future research paths.

2. Literature Review

In general, there are many reasons for air pollution to be related to the economic output of an area. On one hand, air pollution can reduce the economic output and the economic growth due to fatigue and the reduction of mental function of workers on the long-term, sick leaves and reductions in worker productivity. On the other hand, the economic product can lead to an increase in air pollution mainly due to the increased transport industry and increased production.

The Organisation for Economic Co-operation and Development (OECD) in a recent report (Dechezleprêtre, et. al, 2020) provides data on the impact of air pollution on economic activity for Europe. The authors argue that increases in air pollution can induce significant reductions in economic activity due to reductions in per capita output. This study contributes greatly to broader efforts to understand the drivers of productivity decline. The findings have essential implications for cost-benefit assessments of air pollution reduction policies and highlight that much stricter regulations could be in place to improve air quality, even if one ignores the effects this would have on reducing mortality and focus on the financial benefits they will present. They also suggest that air pollution control policies can make a significant contribution to economic growth and can usefully complement other mainstream structural policies.

More specifically, a negative correlation between the concentration of PM2.5 (tiny particles or droplets in the air that are two and one half microns or less in width) and the economic output is observed. A reduction of 1μg/m3 of PM2.5 in the European Union area results in a 0.8% increase of GDP. This translates in 120$ billion, which is almost the GDP of small countries like Slovakia and Hungary. Moreover, the European Council estimates that the non-economic benefits of air pollution reduction are between $30- $100 billions annually. Taking into consideration the direct and indirect benefits of intervention policies to air pollution reduction we suggest that the estimated benefits exceed the estimated costs.

Other researchers have found that there is a strong correlation between the air pollution and the number of sick leaves. Ostro and Rothschild (1989) concentrates on the Norwegian labor force and confirms that air pollution has negative implications in the productivity. An increase of the mean PM2.5 levels by 1 $\mu g/m^3$ leads to an increase of sick leaves by 0.6%.

The research by Fu et al.(2017) reports a negative relationship between air pollution and short-term productivity of workers in Chinese construction companies for the period 1998-2007. Using a large data set from construction companies in China, the effect of air pollution on labor productivity.

This study shows a significant economic loss in labor productivity and therefore production in China in general due to air pollution. This also suggests a huge social benefit, (besides the immediate improvement in quality of life from improving air) i.e. the increase in overall output and labor productivity and thus economic output. This study contributes to the limited literature on the effect of air pollution on short-term labor productivity by providing empirical evidence that captures all the channels through which pollution can affect productivity.

The results of this research cannot be used to predict the long-term effects of air pollution on labor productivity, but they do suggest that short-term effects have long-term effects on workers and reduce their productivity, while helping to build the hypotheses on which this study is based.

Chang et al. (2016) study the effect of air pollution and worker productivity in a peach packing company. They argue that many companies spend too much money and resources to identify and study the actions that lead to work productivity in order to implement them. In particular, only in the American market, approximately $60 billion is spent and mainly concerns ergonomics and workplace design and payments and telecommunications between employees. However, something that companies and analysts seem to ignore is air pollution in the workplace. And yet, there is evidence, as mentioned above, that even moderate levels of pollution can impair performance through changes in respiratory, cardiovascular and brain function.

After a series of empirical experiments, the research concludes that a 10 unit change in PM2.5 significantly reduces worker productivity by about 6 percent. More importantly, PM2.5 begins to affect productivity at levels well below current US air quality standards. These findings are based on extensive laboratory and epidemiological evidence on the relationship between PM2.5 and individual health outcomes, providing evidence that outdoor pollution can negatively affect the productivity of indoor workers.

Since these productivity effects also affect firm profits, firms can internalize some of the costs of reducing workers' exposure to air pollution. Installation of sophisticated filtration systems has the potential to remove PM2.5 from the air current technology is limited in its ability to completely remove PM2.5, particularly the smallest and most harmful particles (Mostofietal. 2010; Shi, Ekberg and Langer 2013). Furthermore, since PM2.5 accumulates in the body over several days, exposure away from the office, where workers spend most of their time, cannot be controlled through corporate investment, and the control they can exercise is limited.

Emissions reductions are a major challenge for the private sector, as the bulk of explosion to pollution occurs outside the boundaries of the enterprise. Thus, productivity-enhancing investments in this context are most effective through publicly coordinated pollution reductions rather than unilateral efforts by firms. Determining optimal regulatory standards requires policymakers to balance the costs and benefits of additional regulations. The results indicate that pollution has significant costs beyond health effects and quality-of-life issues typically considered in the calculation at both the academic and policy-making levels. The findings also suggest that pollution can have a compounding effect on the overall economy.

Typically, pollution is a necessary consequence of production, and thus of economic development. But the findings suggest that pollution reduces labor productivity, and labor productivity is an important determinant of economic growth. By applying the estimated impacts to all US manufacturing suggests that modest reductions in PM2.5 pollution from 1999 to 2008 yielded nearly $20 billion in benefits. In light of growing evidence that PM2.5 exposure can affect cognitive performance (Lavy, Ebenstein, and Roth 2014), the overall productivity benefits may actually have been substantially greater. The effects of fine particulate pollution on high-skilled labor and human capital accumulation are fruitful areas for future research.

In addition to studies that indicate the direct relationship between air pollution and labor productivity (i.e. economic output), there are also studies that frame the field of ecological economics, i.e. the relationship between air pollution and economic development in general. Both fields, however, do not differ much in the conclusions they offer as they indicate a negative relationship between economic growth and air pollution. The relationship between air pollution and economic growth is one of the most important relationships in empirical studies in the field of ecological economics. Since the beginning of the 1990s, when the population was more aware of climate change and global warming, the study of ecological economics is a very important study that examines the overall utility of economic development, from the perspective of the environment.

Emissions of carbon dioxide into the atmosphere are thought to increase global warming through the greenhouse effect. The central trend of this particular literature field focuses on the effects of the greenhouse effect on the economy, due to natural disasters, depletion of natural resources, more energy-intensive processing and effects on the health of workers. The relationship between air pollution and income is described by the environmental Kuznets curve, which is an inverted U-shaped curve.

The environmental impacts of economic development have attracted the attention of economists in recent years. One particular aspect, the link between the environment and economic growth/development, has generated much debate in recent decades, and a substantial literature on the pollution–income growth relationship has grown. Common to all studies is the claim that environmental quality deteriorates in the early stage of economic growth/development and improves at a later stage as an economy develops. In other words, environmental stress increases faster than income in the early stages of development and slows relative to GDP growth at higher income levels. This relationship between change in income and environmental quality has been called the Environmental Kuznets Curve (EKC). The inverted-U relationship takes its name from the work of Kuznets (1955) who hypothesized a similar relationship between income inequality and economic growth. In the first stage of industrialization, pollution increases rapidly because increasing material production is given high priority and people are more interested in jobs and income than clean air and water (Dasgupta et al., 2002). Rapid growth inevitably leads to greater use of natural resources and emissions, which in turn put greater pressure on the environment. People are too poor to pay for pollution abatement and usually ignore the environmental consequences of development. At a later stage of economic development, as income increases, people value the environment more, actions to reduce pollution intensify, and the level of pollution decreases. Thus, the EKC hypothesis posits a well-defined relationship between the level of economic development and environmental pollution in general (including air pollution, resource depletion, etc.) and assumes an inverted U-shaped curve when pollution indicators are plotted per capita income.

The EKC results thus show that economic growth could be compatible with environmental improvement if appropriate policies are taken. It is an important premise that only when income increases can effective environmental policies be implemented. Clearly, before adopting a policy, it is important to understand the nature and causal relationship between economic growth and environmental quality (Coondoo and Dinda, 2002). Therefore, the relevant question is whether economic development can be part of the solution and not the cause of the environmental problem. This has been the main motivation for empirical studies on the EKC looking for evidence of the relationship between income and environmental pollution, and has given rise to a vast body of empirical research in recent years.

3. Data

The variables examined in our study are the following: PM2.5 (Particulate Matter Lower than 2.5 micro), GDPperCapita (GDP per capita), GDPperHourWorked (GDP per working hour), Unemployment, HealthExpenditure (Part of the budget for the health sector), CurrentHealthSpending (Expenditures for medical care), Temperature (Average annual temperature) and Rainfall (Average annual precipitation in mm). The databases used are OECD and DataWorldBank.

Particulate Matter (PM) consists of solid and liquid particles in the air that can vary significantly in size. The definition of PM has evolved over time. Total particulate matter, which was first defined in 1971, consists of particles smaller than 100 micrometers in size. Recognizing growing evidence that only particles smaller than 10 micrometers penetrate the lungs, the definition was changed from TSP to PM10 in 1987. Further research showed that the smallest of these particles, those smaller than 2.5 micrometers, penetrate deep into the lungs and through of these in the bloodstream. As a result, the Environmental Protection Agency began defining PM2.5 separately from PM10 in 1997.

PM2.5 sources consist of a wide range of both natural and anthropogenic sources. Natural sources include volcanoes and wildfires, while anthropogenic sources are largely the result of burning fossil fuels, particularly when gases from power plants, industries and cars interact to create PM2.5. Given their small size, PM2.5 can remain suspended in the air for extended periods of time and can travel hundreds of miles.

GDP per labor hour, on the other hand, is a measure of labor productivity. It measures how efficiently labor (as an input to economic output) is combined with other factors of production and used in the production process. Labor input is defined as the total number of hours worked by all persons engaged in production. Labor productivity only partially reflects labor productivity in terms of workers' personal abilities or effort intensity.

Unemployment is also a key economic indicator because it signals the ability (or inability) of workers to easily obtain gainful employment to contribute to the economy's production process. This does not include people who leave the labor force for other reasons, such as retirement, higher education and disability. More unemployed workers means that less total economic output will occur than would otherwise occur.

In our research, unemployment plays a control variable role. Its aim is to reveal what part of the change in GDP per capita and GDP per hour worked is due to unemployment so that the effect of air pollution on these two variables is clearer.

Some other variables used as control variables are health expenditure as part of public expenditure or as citizens' personal expenditure on medicine.

The average annual temperature refers to the average of the maximum and minimum temperatures of a year, taking the average of the coldest month of the year and calculating it by the average of the warmest month of the year. Mean annual temperature is a valuable climatological tool that can assess the climate change of an area.

Average annual precipitation is the amount of precipitation we expect per year (in a given area). It is obtained and defined by calculating the average (average) rainfall recorded in an area per day and is measured in mm.

These two environmental variables were used as they both have an effect on human health and also affect air pollution. Therefore, it was necessary to check whether these two variables alone affect the GDP per capita in the first part as well as whether they affect air pollution in the second part of the research.

Table 1: *Summary statistics*

Variables	Observations	Mean	Standard Deviation	Min.	Max.
GDP per Capita	937	26761.9	20789.8	1102.1	118823.6
PM2.5	945	16.2	6.3	5.9	36.3
GDP per hour Worked	899	44.4	19.2	11.7	99.1
Unemployment	924	8.67	4.93	1.48	33.29
Temperature	945	9.44	5.87	-7.43	25.15

As we can observe in Table 1, the average GDP per capita of our sample is $26,762, while the lowest income is $1102 and the highest is $118,823. This means that the countries that were included in the model present the necessary differentiation so that the data are not biased. In addition, the second variable that is quite interesting to us in the model and expresses atmospheric pollution, PM2.5, also shows quite a large variation as its average value is 16.2 µg/m3 while the minimum value is 5.9 and the maximum 36.3 . Generally, all the variables present the required differentiation as in all of them the min and max are quite far from the average.

4. Methodology

After the stationarity checks are done and there is a clearer picture of which variables to use we move on to formulating the model that will be used to produce the most appropriate results (Table C). In the empirical model of this paper there are two sections. In the first section the dependent variable is GDP per capita and in the second the concentration of harmful microparticles in the atmosphere (PM2.5). In each of these phases three different models are used mainly to exhaust all possible options and to extract the best possible results.

In the first model, a distinction is made between estimators PooledOLS, FixedEffects and RandomEffects. The PooledOLS estimator ignores the panel structure and simply estimates the sample coefficients like ordinary least squares regression. This has the effect of losing the specific conditions of each different element of the sample and as a result, the loss of heterogeneity. In our case, the special conditions that the different countries present to each other are lost.

Fixed effects control for unique country characteristics that may vary over time or across countries but not both. For example, in our country-specific fixed effects research model, we assume that each country has distinct, time-invariant characteristics. However, this hypothesis may be extremely strong and not borne out by the empirical findings.

In a random effects model, each level can be thought of as a random variable from an underlying process or distribution. Random effects estimation provides inferences about the specific levels (similar to a fixed effect), but also information about the sample level and thus the missing levels. This is often referred to as commutability, which is the idea that the data in a random effect are not separate and independent but are truly representative levels from a larger collection of levels, which may not even be observed. The model under PooledOLS is as follows:

$$Y_{i,t} = \beta_0 + \alpha_1 X_{1,i,t} + \alpha_2 X_{2,i,t} + \alpha_3 X_{3,i,t} + \alpha_4 X_{4,i,t} + \alpha_5 X_{5,i,t} + \varepsilon_{i,t} \qquad (1)$$

Where Y represents GDP per capita in the first stage and PM2.5 in the second, β0 the fixed coefficient, Xit the coefficient of each independent variable, α the coefficient of each independent variable and ε the random error. The i represents the countries and t the year. The fixed effects model (like the random effects model) has the following form:

$$Y_{i,t} = \beta_0 + \alpha_1 X_{1,i,t} + \alpha_2 X_{2,i,t} + \alpha_3 X_{3,i,t} + \alpha_4 X_{4,i,t} + \alpha_5 X_{5,i,t} + \gamma_i + \varepsilon_{i,t} \qquad (2)$$

Where Y represents GDP per capita in the first stage and PM2.5 in the second, X represents the value of each independent variable, α represents the coefficient of each independent variable, γ represents an observable effect which is constant over time and e represents the random error. i represents the countries and t represents the year. In the case of fixed and random effects i has a different role than before. In the case of fixed effects, it is the particularity that represents each country in the data, while in the random effects model it is also a particularity for each country, which is however random and uncorrelated.

In the second phase, a model with "Difference and System GMM" estimators is used. The difference and system GMM estimators can be seen as part of a broader trend in econometric practice toward estimators that make fewer assumptions about the underlying data-generating process and use more sophisticated techniques to isolate useful information. The difference and system GMM estimators are designed for panel data analysis and incorporate the following assumptions about the data generation process:

• The process can be dynamic, with current realizations of the dependent variable being influenced by previous ones.

• There may be arbitrarily distributed fixed sub-effects. This argues against cross-sectional regressions, which must essentially assume fixed effects, and in favor of a panel setting, where variation over time can be used to determine the parameters.

• Some regression factors may be endogenous.

• Idiosyncratic disorders (other than fixed effects) may have specific patterns of heteroscedasticity and serial correlation.

• Idiosyncratic disorders are not correlated across individuals.

• Some regression factors may be predetermined but not strictly exogenous. That is, regardless of current disturbances, some regressors can be influenced by previous ones. The lagged dependent variable is an example.

• The number of time periods of available data, T, can be small.

In the third phase, a more complex model is used. The augmented mean value (AMG) estimator of Eberhardt and Teal (2010) has been used in the past to examine phenomena such as the determinants of default (Saldías, 2013) and interest rates (Lanzafame, 2016). In contrast to our analysis, the aforementioned studies rely on the standard mean value (MG) estimator of Pesaran and Smith (1995) instead of FMOLS-MG augmented with the joint dynamic procedure. The FMOLS-MG method was used by Oikarinen et al. (2018). The goal of incorporating the joint dynamic process is to remove cross-layer correlation from the long-run model by identifying joint trends caused by unobservable factors.

Alternative estimators include the standard mean (MG) estimator, the Pesaran (2006) CommonCorrelatedEffectMeanGroup-CCEMG estimator, and the potential CCEMG (DCCEMG) estimator of Chudik and Pesaran (2015). The MG estimator allows for spatial heterogeneity and is suitable for non-stationary but cointegrated data, but does not accommodate the dependence on cross-stratified data. The CCEMG estimator is based on MG, but aims to eliminate the polarization of spatial dependence by including the cross-sectional means of the dependent and independent variables as additional regressors. The DCCEMG approach additionally includes lagged cross-stratified means of dependent variables that aim to eliminate bias due to weakly exogenous regressors and endogeneity. Another potential complication with (D)CCEMG estimators is that, due to the many additional variables (aimed at eliminating cross-layer dependence) compared to less complex models, the estimate of the slope coefficient (β) may no longer be consistent.

5. Results

The results of our research have several directions. It seems that depending on the method used at each level of the econometric model, the relationships between the variables change and, in some cases, the resulting coefficients are not statistically significant. In each case there is an explanation for each case which can be supported by the principles of economic sciences and by the pre-existing literature.

1. Dependent variable Per Capita GDP

- First generation Models

The pooled OLS in this particular model gives a good picture of the effects of each variable on GDP per capita, but it is not the most reliable model as the specificities of each country are not taken into account at all and therefore the result may differ in reality. This is also reflected in Rsquared which only reaches 18%.

Fixed Effects model between the different levels, ie countries tries to solve this problem. This practically means that each country is separated from the rest and therefore the results are different. Nevertheless, it seems that the values of the coefficients of each variable have the same direction and approximately the same values. Also, as in the pooled OLS model the standard errors of the variables are quite low, with the exception of the variable for urbanization and temperature.

In the Fixed Effects model, the particularities of each country which may have been skipped from the variable selection are taken into account and expressed with a constant in the model. In this particular case, the R-squared remains low, so again perhaps the specific model does not give the optimal result.

In the next model, random effects are used, which is a combination of the previous two, as each country is taken into account separately, but at the same time the data is examined collectively. In this case the results are almost identical to the Pooled OLS regression

As can be seen from the values and direction of the above coefficients of the variables, a clear relationship between the variables can be seen, as well as with the 3 methods the results are statistically significant and very similar in each case.

As can be seen from the values and the direction of the above coefficients of the variables, a clear relationship between the variables can be seen, as well as with the 3 methods the results are statistically significant and very similar in each case (Table 2).

GDP per capita is therefore quite affected by GDP per capita per working hour and their relationship is positive, while negative, as predicted, is the relationship between GDP per capita and unemployment. GDP per capita per hour worked indicates a country's productivity, and logically, as productivity increases, so will a country's GDP. Conversely, the higher the unemployment, the less productive a country is and therefore the lower its GDP per capita will be. Regarding temperature, the literature shows that lower temperatures create problems in productivity mainly due to diseases and lower efficiency of production systems, so the positive relationship between them is justified.

The main variable that we study, PM2.5 has a positive effect on GDP per capita. This may be due to the Environmental Kuznets Curve discussed earlier in the literature. Based on this theory, the relationship between the two variables is of the inverted U type, which means that up to a point in GDP per capita, the relationship between the two variables is positive, while after this turning point, the relationship between the two becomes negative. As can be seen in the literature, this happens because the poorer countries, as they develop economically, do not pay much attention to environmental pollution, while from one point on they try to use their economic development to limit it.

Finally, it is worth commenting that the standard errors in most variables have low values compared to the coefficient values. This means that in general the individual values of the countries do not deviate much from the averages in each sample and the values of the coefficients are quite representative for each variable in terms of the average values of the more general sample.

Table 2: *1st generation models Summarized Table*

	GDP Per Capita (Pooled)	GDP Per Capita (Fixed Effects)	GDP Per Capita (Random Effects)
PM2.5	0.28*	0.294***	0.280***
	(0.160)	(0.113)	(0.111)
GDP per hour worked	1.03***	0.953***	1.034***
	(0.154)	(0.136)	(0.124)
Unemployment	-2.279***	-2.280***	-2.279***
	(0.248)	(0.249)	(0.244)
Urbanization Index	1.528	4.101**	1.528
	(0.912)	(2.177)	(1.081)
Temperature	0.038***	0.037**	0.038*

	(0.008)	(0.020)	0.020
Constant	0.019***	0.015**	0.020***
	(0.004)	(0.007)	(0.005)
Number of observations	813	813	813
R-squared	19%	18%	19%

Notes: First differences are used. *: P ≤ 0.05, **: P ≤ 0.0, ***: P ≤ 0.01

- Second generation models

In the second generation models, as mentioned in the methodology, the inclusion of lagged cross-sectional means or factors extracted from cross-sectional menas tend to minimize cross-dependence and highlight the true effect of dependents. Morooever, the use of heterogenous estimators that provide per cross-section estimation provides higher granularity to our results.

Summarizing the above results, it seems that the specific models give a different substance to the previous model, as the main variable that interests us in the specific model has a different direction regarding its relationship with GDP per capita. In particular, previously the concentration of micro particles in the atmosphere, PM2.5, had a positive effect on GDP per capita. On the contrary, in the other two models (GMM, AMG) it seems that PM2.5 has a negative effect on the GDP per capita, as also results from the literature. Nevertheless, in model MG the relationship between the two variables continues to be positive.

Apart from PM2.5, the remaining variables have the same relationship with GDP per capita as they did in the previous model. In this model, the difference is in the prices they present, which are a little lower. In this model the relationships of the variables with GDP per capita are milder.

Table 3: *Second generation results*

	(GMM)	(AMG)	(MG)
PM2.5	-1.051**	-0.104*	0.789*

	(0.508)	(0.074)	(0.453)
GDP per hour worked	1.221***	0.579***	0.944***
	(0.293)	(0.137)	(0.356)
Unemployment	-0.630	-1.792***	-2.595***
	(1.122)	(0.342)	(0.708)
Urbanization Index	0.106	3.930	13.373
	(0.777)	(4.474)	(69.059)
Temperature	0.248*	0.032*	0.148
	(0.137)	(0.024)	(0.123)
Common Trend		1.120***	
		(0.027)	
Constant	7.501***	0.008***	
	(2.349)	(0.007)	
Number of Observations	740	813	716

Notes: *: P ≤ 0.05, **: P ≤ 0.0, ***: P ≤ 0.01

- Third Generation Models

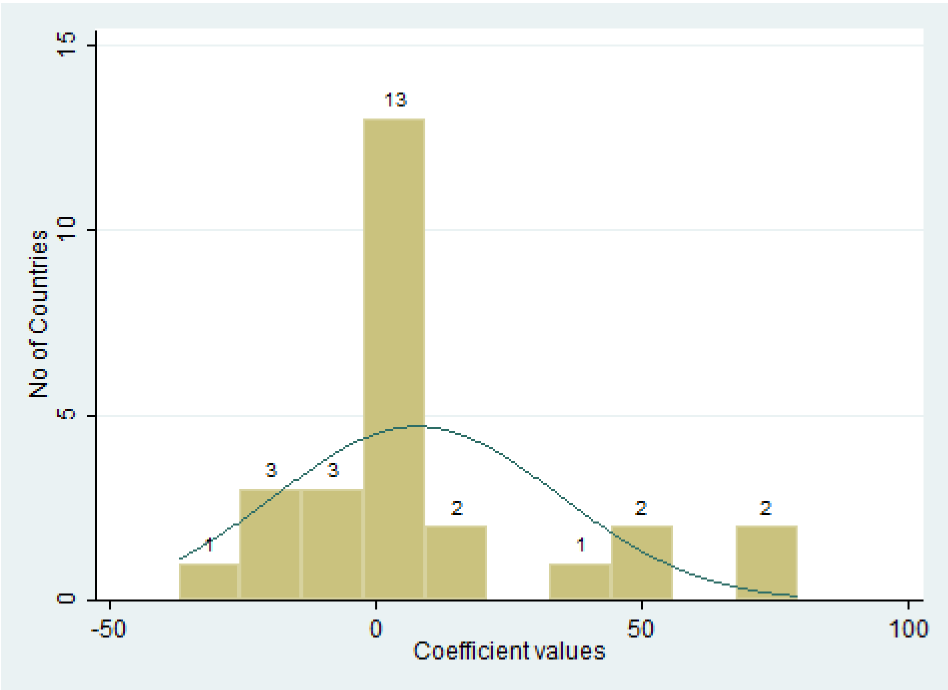
In the third generation, the Common Correlated Effects (CCE) and Dynamic Common Correlated Effects (DCCE) models are used. In practice, these two methods use the average of the coefficients to derive the estimator.

In this particular model, however, it seems that the values of the variables are not statistically significant, so we cannot draw safe conclusions about the relationships of the variables using it. Finally, in this sample the values of the standard errors are very high without exception. This means that no variable gives a faithful representation of the mean of each variable for the total sample (Table A).

An important finding of the third generation model is the ability to separate the results into groups of countries according to the average value of the coefficient for each country separately. More specifically, we distinguish that 13 countries have a value from 1-10 as was seen from the results of the table A. This means that for these countries a 1% change in PM2.5 leads to changes of 1% up to 10% in the GDP per capita of these countries.

This is not a given for all countries. Looking at Graph 1, it appears that there are several countries with a negative coefficient, but also some with values around 50 units or even 70 units.

This switching in the signs of the coefficients according to the peculiarities and income of each country verifies the EnvironmentalKuznetsCurve to the maximum. According to this, some countries prioritize increasing their GDP, neglecting the consequences this may have on the environment, while other countries, mainly richer ones, place more emphasis on reducing pollution.



Graph 1: *The effect of air pollution in GDP per Capita per Country*

2. Dependent variable PM2.5

At this point the dependent variable in the models is the concentration of microparticles in the atmosphere. This happens as we also investigate the inverse relationship of the other variables with air pollution, i.e. to what extent the above variables contribute to the increase or decrease of air pollution. As in the models with GDP per capita as the dependent variable, in this case there will be three generations of models.

- First Generation Models

As was the case when the dependent variable was the GDP per capita, all three models give us some important information about the variables under consideration as the vast majority of the coefficients are statistically significant. The only coefficient that appears as non-statistically significant in all three cases is the variable showing the degree of urbanization of a country. Regarding the remaining variables, the coefficients have values and directions as expected from the literature and environmental economics. As GDP and productivity (GDP per capita & GDP per hour Worked) increase, air pollution increases mainly due to greater industrial production and generally more polluting techniques. This can be included in the Kuznets curve (EKC), mainly in the stage before the turning point. This means that the countries we looked at may not have escaped the stage where growth also entails air pollution in terms of income and are not making substantial efforts to reduce pollution with greener policies.

Also the relationship between temperature and air pollution is positive and this is mainly explained by the Global Warming Effect which is a problem of the planet in the last decades. Finally, increased unemployment is associated with cases where people have lower levels of education and therefore such regions or countries are accompanied by higher levels of pollution.

Table 4: *1st generation models summarized table*

	PM2.5 (Pooled)	PM2.5 (Fixed Effects)	PM2.5 (Random Effects)
GDP per Capita	0.27**	0.029***	0.028**
	(0.011)	(0.113)	(0.011)
GDP per Hour	0.073**	0.104***	0.073*
	(0.029)	(0.044)	(0.041)
Unemployment	0.146**	0.148*	0.146***
	(0.069)	(0.082)	(0.081)
Urbanization	0.291	0.046	0.291
	(0.221)	(0.691)	(0.342)
Temperature	0.014***	0.014**	0.014**
	(0.003)	(0.006)	(0.006)
Constant	-0.012***	-0.012***	-0.013***

	(0.001)	(0.002)	(0.002)
Number of observations	813	813	813
R squared	24%	23%	24%

Notes: In all three regressions First Differences were used. *: P ≤ 0.05, **: P ≤ 0.0, ***: P ≤ 0.01

- Second Generation Models

The second generation models gave us some different results than the first generation samples. Nevertheless, as we saw above, in most cases the variables were non-statistically significant and the standard errors were high, as a result of which we cannot use them to analyze the relationship between the variables of interest.

The model that allows us to comment on the relationship between GDP and the other variables with air pollution is the Mean Group as most variables are statistically significant and the standard errors are low. This model basically confirms the results of the 1st generation with small differences in the values of the coefficients. Specifically, GDP has a positive relationship with PM2.5, as do the other variables.

Table 5: *Second Generation Models Summarized Table*

	PM2.5 (GMM)	PM2.5 (AMG)	PM2.5 (MG)
GDP per Capita	-0.154*	-0.001	0.074*
	(0.089)	(0.006)	(0.046)
GDP per hour worked	-0.110	0.019	0.132**
	(0.275)	(0.035)	(0.059)
Unemployment	0.572	0.125*	0.294**
	(0.847)	(0.074)	(0.152)
Urbanization Index	-0.293	0.966	0.192
	(0.701)	(0.707)	(2.004)

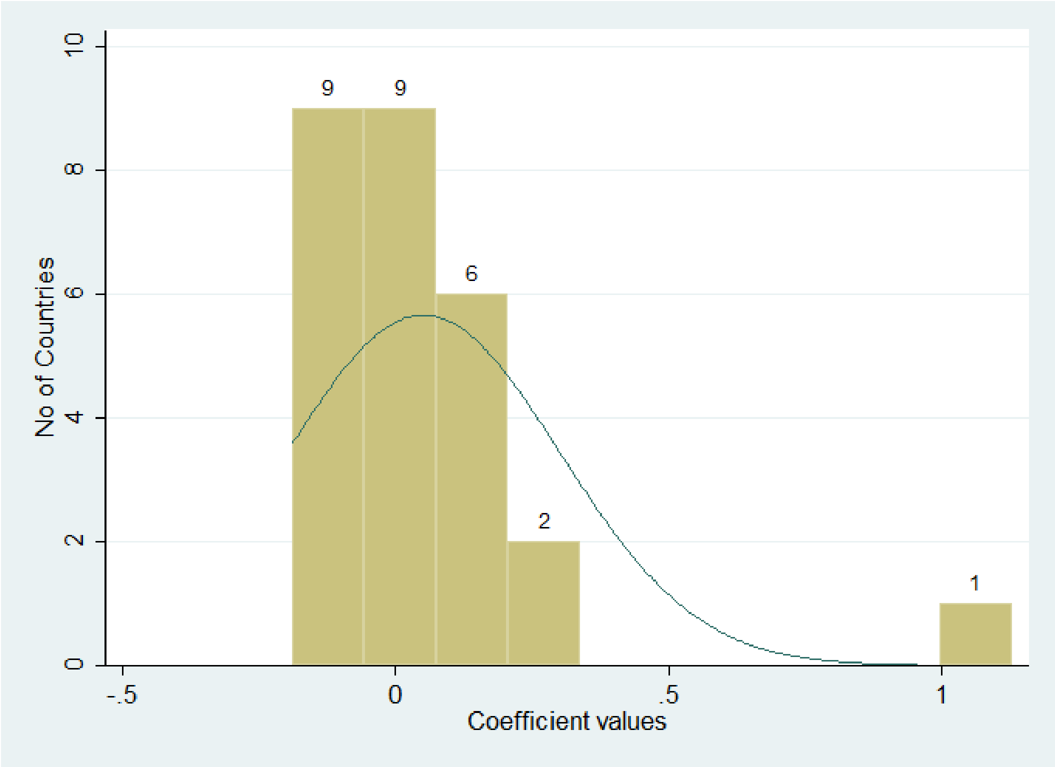
Temperature	0.168	-0.010	-0.014
	(0.104)	(0.009)	(0.022)
Common trend		1.086***	
		(0.044)	
Constant	4.425***	0.002	
	(0.514)	(0.001)	
Number of observations	740	813	813

Notes: *: P ≤ 0.05, **: P ≤ 0.0, ***: P ≤ 0.01

- Third Generation Models

The most important finding of this model is the ability to separate the coefficients by country. Specifically, this template averages the prices by creating the coefficient and separates it for each country. As we see in Graph 2, there are several countries with negative values and several with a positive coefficient.

This means that for some countries a greater increase in GDP leads to reductions in air pollution, while in most countries an increase in GDP leads to additional levels of pollution. The positive relationship can be justified, as we saw earlier, by the greater priority that the inhabitants of the richest countries give to the environment in which they live. The negative relationship means that an increase in GDP usually leads to more industrialization and therefore more air pollution.



Graph 2: *The effect of GDP per Capita on air pollution*

6. Conclusions

This paper aims to investigate the relationship between air pollution and economic growth. In addition to these two variables, there were also some other variables that were included in the models and had a complementary role in our research. In addition to the two main variables, the relationship of GDP per hour worked with unemployment, GDP per capita, the urbanization index of the countries and the average annual temperature (as a proxy variable for air pollution) were also examined. The results for these variables were not surprising as GDP per capita per hour worked is always positively related to GDP per capita and unemployment always has a negative impact on economic growth. The temperature and the urbanization index in several cases showed incoherence, so no safe conclusions can be drawn about these two variables and their relationship with GDP per hour worked.

The previous literature we investigated had already shown that there is a clear relationship between these two variables, but it seems that the direction of this relationship may not be the same for every economy.

In general, and especially in the models that have the greater explanatory power, we find that the relationship between PM2.5 (the model variable that determines air pollution) and GDP per capita (the model variable that determines economic output) of a country is negative. This means that as air pollution increases, the GDP of a country decreases. Based on the previous literature, this mainly results from the reduced productivity of workers, which is the result of either more sick leaves due to increased air pollution, but also from the more general mental and physical dysfunction caused by people's chronic exposure in polluted air as shown by long-term research.

In some other cases, air pollution has a positive relationship with economic growth. Contrary to previous literature that refers to long-term exposure to polluted air and reduced productivity, there is evidence that in the short term economic growth and air pollution have a positive relationship. This is due to the production techniques used by industries as usually the most efficient production techniques, especially by the end of the 2020s, are harmful to the environment and vice versa. The more polluted the air is, the more economic growth there is likely to be in the short term. In later stages countries turn to greener policies and the inhabitants themselves have greater demands regarding the quality of the environment in which they live (EnvironmentalKuznetsCurve).

Moreover, the effect of economic variables on air pollution was examined. Namely, the effect of economic growth, productivity (per capita GDP per working hour) and unemployment on air pollution was examined. Again, all coefficients have the expected direction based on previous literature.

Initially, the relationship of GDP per capita in most cases is positive. This is mainly due to the increased industrial production, which induces air pollution in early stages. But there are also cases where pollution has a negative relationship with the economic product of a country. This means that some countries, as they grow economically, find alternative ways and methods of production. It may also mean that these countries stop producing products with a high impact on air pollution and, if so, import them. In addition, the relationship between unemployment and air pollution is positive. This may again be linked to the Kuznets curve, since as mentioned above, in lower income countries and populations' environmental protection is overshadowed by the pursuit of income. The lower education of a country means that in the long run this country will be more polluting. Also, higher productivity leads to increasing air pollution. This is in agreement with previous literature and is due to the fact that the most efficient production techniques during the last decades have also been more polluting. Finally, the relationship between air pollution and temperature was also positive. This also results from the phenomenon of Global Warming as atmospheric pollution leads to higher temperatures.

In conclusion, this paper investigates with various data analysis techniques the effects of some important variables based on previous literature. We show that pollution does indeed reduce economic output in the long run in various ways, such as: a) shrinking the labor force (through mortality or migration due to pollution), b) reduction in working hours of workers (due to illness and sick leave), c) the reduction of labor productivity, d) decline of human capital as an input to the production process in the industrial and agricultural sector. Therefore, it can be used by policy makers to address and reduce air pollution as it affects people's lives in many direct and indirect ways.

The results of the models used indicate that there are many points where the coefficients of our variables have a different direction and in these cases we cannot be sure of the accuracy of the result values. This can happen for a number of reasons. First the time period in which the data was received. In some cases the results may be distorted as they may have different values in the short and long term. For this reason, it is recommended in future research to choose a longer time horizon to examine the long-term effect or a shorter one to examine the short-term effect of the data. Another determinant of the quality of the results is the sample of data selected. In this particular research, the countries belonging to the OECD were chosen due to the difficulty of accessing larger databases to combine the data for more secure conclusions. Finally, this paper used specific empirical data analysis techniques and the results obtained are limited to these techniques. Other empirical analysis techniques can be used in future research to ensure greater internal validity.

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Table A: Summarized table with GDP per capita as dependent variable

	GDP per Capita (Pooled)	GDP per Capita (Fixed Effects)	GDP per Capita (Random Effects)	GDP per Capita (GMM)	GDP per Capita (AMG)	GDP per Capita (MG)	GDP per Capita (CCE)	GDP per Capita (DCCE)
PM2.5	0.28*	0.294***	0.280***	-1.051**	-0.104*	0.789*	0.074*	-0.051
	(0.160)	(0.113)	(0.111)	(0.508)	(0.074)	(0.453)	(0.046)	(0.069)
GDP per hour worked	1.03***	0.953***	1.034***	1.221***	0.579***	0.944***	0.132**	-0.149
	(0.154)	(0.136)	(0.124)	(0.293)	(0.137)	(0.356)	(0.059)	(0.232)
Unemployment	-2.279***	-2.280***	-2.279***	-0.630	-1.792***	-2.595***	0.293**	-0.009
	(0.248)	(0.249)	(0.244)	(1.122)	(0.342)	(0.708)	(0.152)	(0.139)
Urbanization Index	1.528	4.101**	1.528	0.106	3.930	13.373	0.192	-11.612
	(0.912)	(2.177)	(1.081)	(0.777)	(4.474)	(69.059)	(2.004)	(9.138)
Temperature	0.038***	0.037**	0.038*	0.248*	0.032*	0.148	-0.137	-0.008
	(0.008)	(0.020)	0.020	(0.137)	(0.024)	(0.123)	(0.022)	(0.028)
Common trend	-	-	-	-	1.120***	-	-	-
	-	-	-	-	(0.027)	-	-	-
Constant	0.019***	0.015**	0.020***	7.501***	0.008***	-	-	-
	(0.004)	(0.007)	(0.005)	(2.349)	(0.007)	-	-	-
Number of observations	813	813	813	740	813	813	692	599
R squared	19%	18%	19%	-	-	-	-	-

Notes: *: P ≤ 0.05, **: P ≤ 0.0, ***: P ≤ 0.01

Table B: Summarized table with PM2.5 as dependent variable

	PM2.5 (Pooled)	PM2.5 (Fixed Effects)	PM2.5 (Random Effects)	PM2.5 (GMM)	PM2.5 (AMG)	PM2.5 (MG)	PM2.5 (CCE)	PM2.5 (DCCE)
GDP per Capita	0.27**	0.029***	0.028**	-0.154*	-0.001	0.074*	0.074*	-0.051
	(0.011)	(0.113)	(0.011)	(0.089)	(0.006)	(0.046)	(0.046)	(0.069)
GDP per hour worked	0.073**	0.104***	0.073*	-0.110	0.019	0.132**	0.132**	-0.149
	(0.029)	(0.044)	(0.041)	(0.275)	(0.035)	(0.059)	(0.059)	(0.232)
Unemployment	0.146**	0.148*	0.146***	0.572	0.125*	0.294**	0.293**	-0.009
	(0.069)	(0.082)	(0.081)	(0.847)	(0.074)	(0.152)	(0.152)	(0.139)
Urbanization Index	0.291	0.046	0.291	-0.293	0.966	0.192	0.192	-11.612
	(0.221)	(0.691)	(0.342)	(0.701)	(0.707)	(2.004)	(2.004)	(9.138)
Temperature	0.014***	0.014**	0.014**	0.168	-0.010	-0.014	-0.137	-0.008
	(0.003)	(0.006)	(0.006)	(0.104)	(0.009)	(0.022)	(0.022)	(0.028)
Common trend	-	-	-	-	1.086***	-	-	-
	-	-	-	-	(0.044)	-	-	-
Constant	-0.012***	-0.012***	-0.013***	4.425***	0.002	-	-	-
	(0.001)	(0.002)	(0.002)	(0.514)	(0.001)	-	-	-
Number of observations	813	813	813	740	813	813	692	599
R squared	24%	23%	24%	-	-	-	-	-

Notes: *: P ≤ 0.05, **: P ≤ 0.0, ***: P ≤ 0.01

Table C: Unit Root test results for variables that are constant across MSAs

Variable	Levels			First Differences		
	Im-Pesaran-Shin	Augmented Dickey Fuller	Hadri	Im-Pesaran-Shin	Augmented Dickey Fuller	Hadri
	(1)	(2)	(3)	(4)	(5)	(6)
GDP per Capita	-1.4332	-1.739	42.253***	-3.957***	-4.159***	-2.698
PM 2.5	-0.878	-2.044	43.430***	-6.001***	-5.183***	1.415
GDP per Hour Worked	-1.897	-2.121	40.109***	-4.890***	-4.646***	-1.929
Health Spending	-10.956	-2.949***	39.006	-14.543***	-4.585***	-0.044
Unemployment	-2.263	-2.452	40.448***	-4.390***	-4.138***	3.796***
Urbanization	-0.856	-1.492	52.493***	-1.484	-3.366***	49.669***
Rainfall	-4.856***	-3.852***	-0.985	-7.058***	-5.143***	-5.143
Temperature	-5.101***	-4.409***	-1.254	-7.710***	-5.959***	-6.251

Notes: ***, ** and * denotes rejection of the null hypothesis at the 1%, 5% and 10% level of significance, respectively. All tests include a trend and an intercept.