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Inmaculada Martinez-Zarzoso *(University of Goettingen and University Jaume 1)*
Leon Pilgrim *(University Jaume 1)*

Website:
https://infer-research.eu/

Contact:
publications@infer.info

Revisiting the Link between Income Inequality and Emissions

Inmaculada Martínez-Zarzoso[*, **] and Leon Pilgrim[*],

[*]University of Goettingen

[**]University Jaume I

Corresponding author email: martinei@uji.es.

Abstract

The present study aims to shed light on the relationship between income inequality and greenhouse gas emissions by analyzing how income inequality affects carbon dioxide emissions and the emissions-income relationship. Since the literature on the impact of income and income inequality on emissions is still inconclusive, this paper offers further insights on how the effects of income and income inequality on emissions vary in countries with different income levels. The estimations are based on an unbalanced panel dataset that includes annual values for the industry structure, the share of the urban population, civil liberties and political freedom, globalization, and education covering 177 countries from 1990 to 2018. The paper finds evidence for a generally negative impact of income inequality on emissions patterns that turns positive for countries above a certain threshold of GDP per capita, which has not been reached by all high-income countries. Moreover, the results support the relationship proposed by the EKC only in richer countries.

Key words: Income per capita, income inequality, CO2 emissions, environmental Kuznets curve

Revisiting the Link between Income Inequality and Emissions

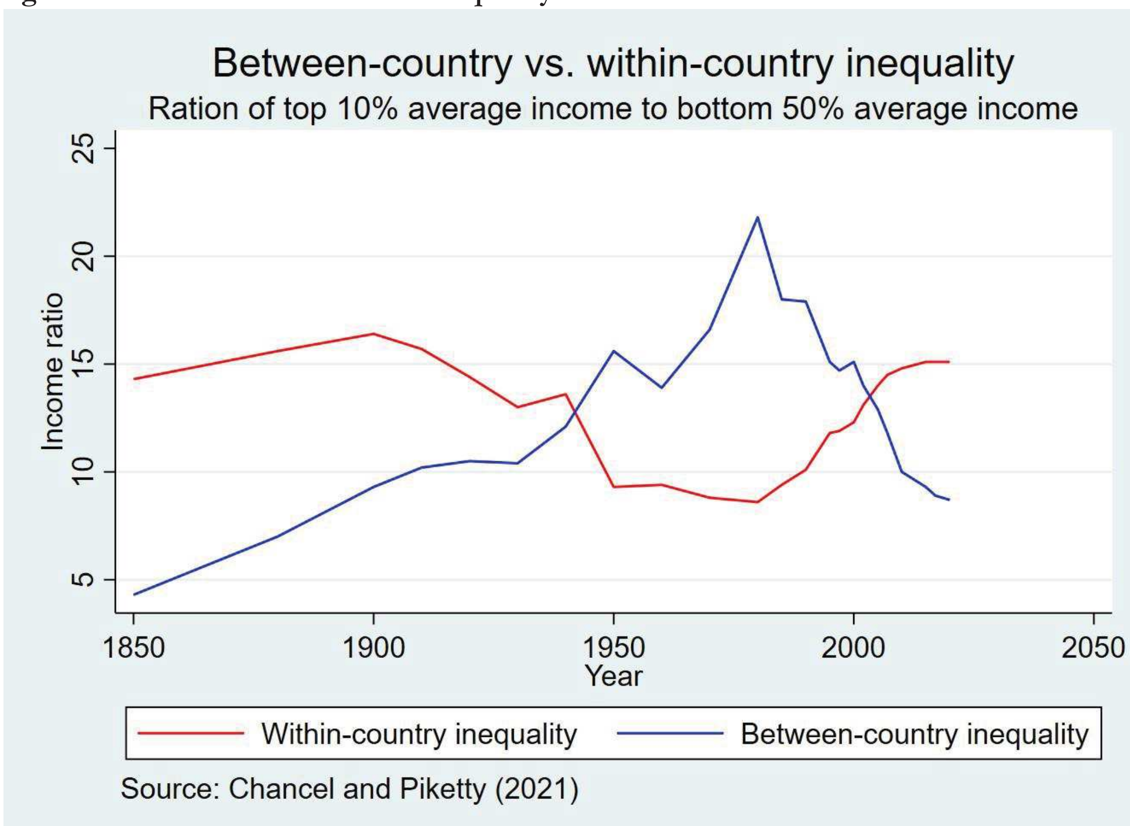
1. Introduction

Since the adoption of the Sustainable Development Goals (SDGs) at the UN Sustainable Development Summit in New York in 2015, several trade-offs arose due to interactions between different SDGs. The first SDG, aimed at ending poverty, can be achieved by reducing economic inequality or promoting economic growth that does not come along with rising income inequality (Adams, 2004; Dollar & Kraay, 2004). The theoretical literature suggests that economic growth and income inequality are two potential mechanisms to affect environmental quality via the emissions of greenhouse gases (Hailemariam et al., 2020). Therefore, potential interactions between economic growth and income inequality might cause conflicts with achieving the SDGs aimed at combatting climate change and its impacts (SDG 13). Current trends of income inequality and carbon dioxide emissions prove the need for urgent action to simultaneously reduce income inequality and preserve environmental quality.

In the remainder of this paper, income inequality is defined following Klasen et al. (2016) as "the uneven distribution of some resource, that is, people having different amounts of something". For this paper, the term "something" refers to income. There are two components of economic inequality. The unequal distribution of wealth is highly pronounced, while the concentration of income is less distinct but still severe within countries (WIR, 2022). However, the present paper focuses on income inequality because of the superior quality and better data availability. The World Inequality Report (WIR, 2022) highlights the seriousness of current income distributions. The wealthiest 10% of the global population earn 52% of total income worldwide, which equals an annual average income of 87,200€ purchasing power parity (PPP). The poorest 50% of the global population earn 8.5%, resulting in an annual average income of 2,800€ PPP (WIR, 2022). However, income inequality is less pronounced than wealth inequality, where the top 10% of the population own 76% of total household wealth (WIR, 2022). Figure 1 displays the development of global within- and between-country income inequalities from 1850 to 2020. The inequalities are measured as the annual average income ratio of the top 10% to the bottom 50%, with higher values indicating higher inequalities. A value of five, as it is the case for between-country inequality during the early 1850s, indicates that the top 10% average income equals five times the bottom 50% average income (WIR, 2022).

The graph shows that between- and within-country inequalities developed independently from each other. While between-country inequality has been decreasing since the 1980s, within-country inequality has been rising since the late 1980s. The first trend is entirely driven by the recent catchup of the countries at low stages of economic development (WIR, 2022). Since the early 2000s, within-country inequality has been the primary driver of global inequality, accounting for 68% of global inequality in 2020 (WIR, 2022). While global economic inequality is driven by inequality between different countries and inequality within countries, this paper assumes the latter to be more relevant for affecting environmental quality because most measures to tackle income inequality or to reduce emissions are designed at the national level. Additionally, emissions are rarely internalized globally (Weitzman, 2015).

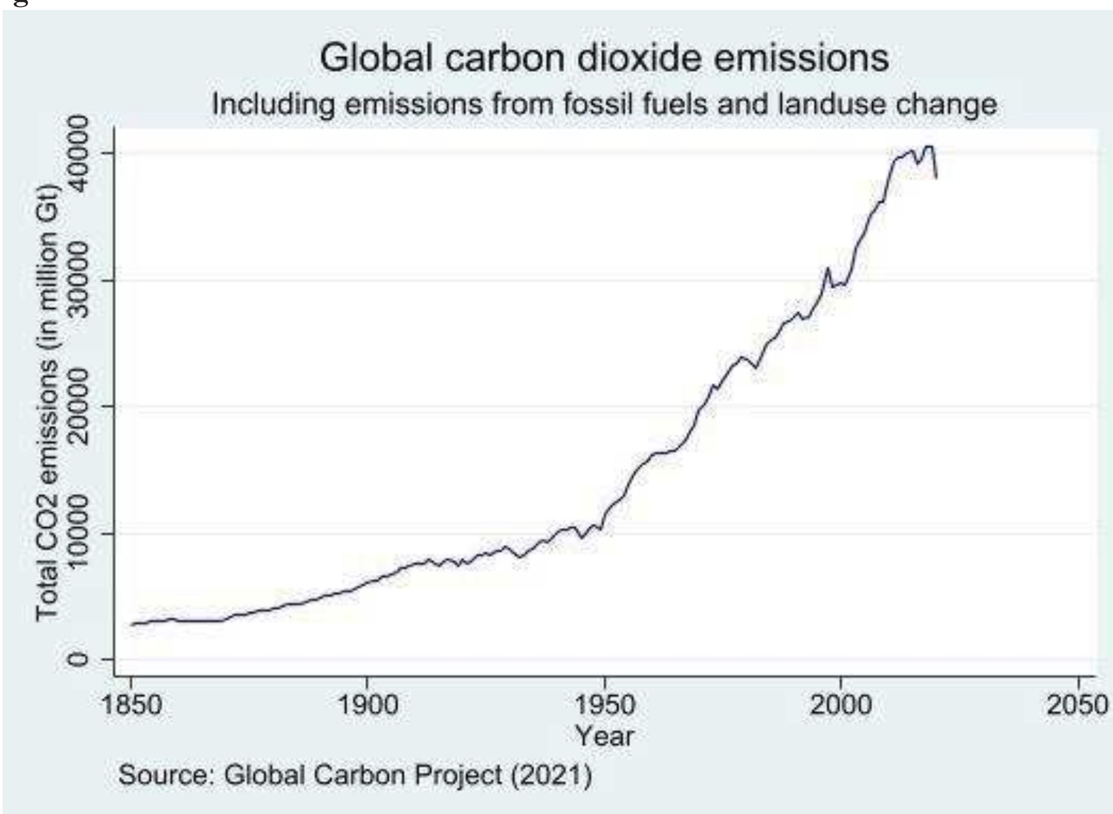
Figure 1: Global trends in income inequality



Analogously, environmental concerns are on the rise since the consequences of climate change have become more relevant and materialize in all regions of the world. The emission of greenhouse gases is one principal driver contributing to climate change through its direct effect on global warming (Lacis et al. 2010), with carbon dioxide being the most emitted greenhouse gas (IPCC, 2014). The share of carbon dioxide in total greenhouse gases is 75%, while methane and nitrous oxide account for a total share of 16% and 6% (IPCC, 2014). Since Stern (2008) labelled greenhouse gas emissions "the biggest market failure the world has seen", little has been achieved in preventing climate change, and atmospheric concentration of carbon dioxide continued to rise from 385.60 ppm (parts per million) in 2008 to 408.52 ppm in 2021 and is far from stabilizing (Ritchie and

Roser, 2020). Figure 2 shows the trend in global carbon dioxide emissions from fossil fuel use and landuse change from 1850 to 2020. Global carbon dioxide emissions have been on the rise since 1850; however, they have started skyrocketing shortly after World War II (Friedlingstein et al., 2021). However, one has to bear in mind that one main driver of increases in accumulated carbon dioxide emissions is population growth. The increase is less pronounced for per capita emissions. Still, emissions reductions will not necessarily reduce accumulated atmospheric concentration of carbon dioxide which is crucial for preventing climate warming.

Figure 2: Global trends in CO2 emissions



Carbon dioxide emissions differ substantially across countries with different incomes. 86% of total carbon dioxide emissions are emitted by high and upper-middle income countries, home to onehalf of the global population, with China being the most significant single country emitter (Ritchie, 2018). The poorest 9% of the global population contribute 0.5% of total carbon dioxide (Ritchie, 2018). These discrepancies are reflected in current studies analyzing the inequality of carbon dioxide emissions (Chancel, 2021). Not only do the emissions differ substantially across regions and countries, but the negative impacts of carbon dioxide emissions and climate change materialize differently across countries since climate vulnerability varies substantially between regions and countries. Many countries classified as least developed countries (LDC) rank among the most climate-vulnerable countries because resources for prevention measures are low and the exposure to climate hazards is high (Bruckner, 2012).

The individual severities of income inequality and carbon dioxide emissions are undisputed. However, several researchers started hypothesizing about interlinkages between emissions and income inequality. Several theoretical mechanisms have been proposed such as higher income inequality potentially leading to increasing emissions because a high number of extremely rich people contribute extensively to the emission of carbon dioxide due to their consumption patterns. Exemplary pollutive activities that can be afforded by the wealthiest only include big cars, frequent long-distance air travel, extensive consumption of meat, or motor sports. In a society with fairly equally distributed income only very few individuals could afford these consumption patterns. In highly unequal societies, however, both ends of the distribution are assumed to be more extreme. As a consequence of that, a higher number of individuals can afford luxury pollutive activities. Contrarily, it could be assumed that the very poor do not contribute to carbon dioxide emissions because they mainly rely on subsistence economic activities. Since theory suggests the number of extremely poor to be higher in more unequal societies, the consequence would be that higher income inequalities reduce emissions.

The present study aims to shed light on the relationship between income inequality and greenhouse gas emissions. In other words, this paper links absolute income levels and income inequality to emissions, analyzing how income inequality affects carbon dioxide emissions and the emissions-income relationship. As discussed below, the literature on the impact of income and income inequality on emissions is still inconclusive. This paper contributes to the literature by delivering further insights on how the effects of income and income inequality on emissions differ in countries with different income levels.

This paper is closely related to two strands of literature. First, it builds on results from studies addressing the causal relationship between absolute income levels and emissions with the predominant Environmental Kuznets Curve (EKC) theory. Most of the studies analyzing the effect of income levels on emissions and environmental quality use GDP (Gross Domestic Product) per capita as an income measure (Bo, 2011; Özokcu and Özdemir, 2017; Shahbaz et al., 2013). The EKC is a theoretical relationship between income per capita and environmental quality indicators that takes an inverted U-shape. It suggests that environmental degradation increases with rising incomes at the early stages of growth and peaks at a certain income level. After having reached this threshold, increasing incomes are associated with higher environmental quality, meaning lower levels of emissions (Blignaut and de Wit, 2004). It was first developed in a path-breaking study analyzing the potential impacts of the North American Free Trade Agreement (NAFTA) on the environment by Grossman and Krueger (1991).

The second strand of literature emerged from the EKC literature and expands the income-emission literature with income inequality. The present paper is to be categorized in this strand of literature. The general hypothesis of this strand is that absolute levels of income are not the only determining factor that shapes emissions patterns because the distribution of income has to be considered as an essential additional factor (Grunewald et al., 2012). Income inequality is measured primarily with the Gini coefficient or income ratios (Berthe and Elie, 2015). The possible outcomes include a positive effect of income inequality on emissions supporting the equality hypothesis and a positive effect indicating a trade-off between more equal distributions of income and low emissions.

Theory and empirics of both strands of literature have been studied extensively without obtaining unambiguous results, which are sensitive to the data used, the chosen indicator of environmental quality, and the methods applied. Still, the current literature provides solid arguments to believe that the relationship between income inequality and emissions is non-linear and depends on numerous factors, including absolute levels of economic development.

The present analysis uses Gini coefficients for disposable income as an income inequality measure. Analogous to Grunewald et al. (2017) and Wan et al. (2022), Gini coefficients are retrieved from Solt (2020) whose Standardized World Income Inequality Database (SWIID) addresses previous limitations of income inequality data, such as low coverage across countries and over time and reduced comparability across observations, providing highly sophisticated and comparable data. Furthermore, the World Bank Indicators (WDI) provide GDP per capita data, and the emissions data stem from Ritchie and Roser (2020). The estimations are based on an unbalanced panel dataset that includes annual values for the industry structure, the share of the urban population, civil liberties and political freedom, globalization, and education covering 177 countries from 1990 to 2018. In this paper, it is argued that country and time fixed effects allow to rule out endogeneity bias. The main results support previous findings from Grunewald et al. (2017), indicating that income inequality on carbon dioxide emissions is sensitive to absolute income levels. More specifically, the paper finds evidence for a generally negative impact of income inequality on emissions patterns that turns positive for countries above a certain threshold of GDP per capita. This threshold has, however, not been reached by all high-income countries. Moreover, the results support the relationship proposed by the EKC in richer countries only. Lastly, the study expands the analysis to other greenhouse gas emissions and reveals that the effect of income and income inequality differs substantially for different types of greenhouse gas emissions.

The paper is structured as follows. Section two reviews the theoretical and empirical literature on the relationship between income, income distribution, and environmental quality. Section three describes the dataset used. Section four outlines the analysis's empirical framework, and section five provides the main results, the results for other greenhouse gases, and further robustness tests. Lastly, section six concludes.

2. Literature review

As indicated, the paper is based on the literature investigating the relationship between income and environmental quality with the predominant EKC theory. Section 2.1 gives a condensed overview of the most relevant theoretical and empirical findings. Section 2.2 provides a more comprehensive summary of the theoretical background and underlying arguments. The empirical conclusions of the relevant studies that address the relationship between income inequality and environmental quality with a focus on carbon dioxide emissions are provided in section 2.3.

2.1 Economic growth and environmental quality

The relationship between income and environmental quality has been assessed constantly over the past three decades and the argument that economic activity affects environmental quality is no longer subject to doubt. Ravallion et al. (2000) conclude that the consumption of all goods and services entails emissions either directly via consumption or indirectly via production. The first comprehensive assessments of how economic growth affects environmental quality date back to the early 1990s when the influential study by Grossmann and Krueger (1991) finds an inverted Ushape relationship between per capita GDP and air pollution. Since then, various empirical and theoretical studies have sought to analyze the relationship focusing on different regions, time periods, proxy variables for environmental degradation, and estimation techniques. Considering this extensive research, it is somehow not surprising that there is no consensus for universally applicable results.

The findings from Grossman and Krueger (1991) indicate that at low levels of income, increasing per capita GDP, as a potential consequence of NAFTA, is associated with increasing air pollution, while the relationship reverses at high levels of GDP per capita. Due to the similarity of the results to the famous Kuznets Curve[1], this relationship was then termed the Environmental Kuznets Curve. The results of Panayotou (1993) and Panayotou (2000) tend to support the EKC for two indicators of environmental quality, namely deforestation and a more general environmental degradation measure combining pollution and resource depletion measures.

Following Grossman and Krueger (1991), Panayotou (1993) identifies three main drivers that are most relevant for shaping this relationship. The first driver is structural change. At low levels of development, environmental degradation is minor due to the prevalence of subsistence economic activity and limited waste generation. With increasing incomes and intensification and industrialization of the economy, increasing resource depletion and waste generation lead to higher environmental degradation. At more advanced stages of economic growth, the structural change theory suggests that the economy is driven by information-intensive industries and services, which do not deplete the environment and explain the decrease in environmental degradation.

The second theoretical argument of how income levels affect environmental quality is related to the development of new technologies. Panayotou (1993) argues that the development of cleaner production technologies, which is assumed to occur at elevated stages of growth, reduces the amount of energy required to produce one unit of output and similarly reduces the emissions per unit of output. Therefore, cleaner technologies will reduce emissions and lead to reduced environmental degradation.

Lastly, he assumes the demand for environmental quality to follow the pattern of a luxury good and that the increased demand at higher levels of income facilitates the implementation of more stringent environmental regulations through higher environmental awareness. If executed properly, more stringent environmental regulations are assumed to reduce emissions and preserve environmental quality.

Slightly different theoretical explanations relate to the scale effect, composition effects, and the technology effect (Copeland and Taylor, 2004; Orubu and Omotor, 2011). The scale effect is based on the fact that increasing production outputs will cause increases in the demand for natural resources as an input production factor. It will also increase the generation of production-based waste and emissions. Additionally, the scale effect potentially explains the reduction of

[1] The original Kuznets curve describes an inverted U-shape relation between inequality and development, which was first discovered by Kuznets (1955).

environmental degradation at high income levels because it becomes relatively cheaper to reduce emissions and to adopt environmental regulations (Orubu and Omotor, 2011). The composition effect refers to the structural composition of the economy and is quasi-identical to the argument above related to structural change (Grossman and Krueger, 1991; Panayotou, 1993). The technology effect is based on the same assumptions as the technological development argument from Grossman and Krueger (1991) and Panayotou (1993). Stern (2017) concludes the 'proximate factors' theoretically explaining the EKC to be (i) scale effect, (ii) composition effect, (iii) substitution of less environmentally damaging production input factors, and (iv) technology development.

As indicated in the introduction, not all studies confirm these results, and several theoretical mechanisms have been established to explain non-findings of the EKC. While the majority of the studies agree on the initial decrease of environmental quality at lower levels of income, the existence of turning points (Agras and Chapman, 1999) and the increase of environmental quality at high income levels are subject to discussion. This poses several threats to the EKC theory and is particularly important when deriving policy recommendations.

The findings by Ekins (1997) indicate a lack of unequivocal evidence for the EKC and claim that turning points occur at extremely high income levels. Influential work has been conducted by Stern (2004), who, among others, raises several theoretical critiques. Stern (2004) and Arrow et al. (1995) argue that several studies falsely made the unrealistic assumption that feedback effects would not occur. They argue that environmental quality is likely to affect economic activity and thus the income measure, which can no longer be considered truly exogenous.

Barbier (1994) finds significant empirical evidence for causal effects of environmental quality on economic development, which can be argued to result in biased EKC estimates because of reverse causality. Stern (1998) argues that many studies erroneously neglect this mechanism. Moreover, Stern (2004) raises the argument that production has shifted from emitting traditional pollutants to alternative pollutants such as solid waste, which most of the studies do not account for. He argues that efforts in reducing emissions of a specific pollutant are likely to cause increased emissions of a different pollutant. The argument is straightforward. Suppose the production costs increase because producers face additional costs emitting a specific pollutant. In that case, the producers are incentivized to reduce the emission of the particular pollutant and might ignore potential increases of a different pollutant. However, according to the author, the results would support the EKC but its side effects must be considered. The outcome is undesirable since environmental quality would be reduced via the shift of emissions to other pollutants.

In addition to that, Stern (2004) claims the decrease in emissions at high income levels to be caused by a shift of pollutive industries from high-income countries to low-income countries. The underlying Heckscher-Ohlin trade theorem suggests that each country specializes in the production of goods that use the country-specific abundant input factor intensively under free trade. Put differently, high-income countries specialize in less pollutive, human capital-intensive activities such as services while low-income countries specialize in more pollutive natural resource-intensive activities like industry and manufacturing. In this case, the results would provide evidence for an EKC-type relationship for wealthier countries but the fact that emissions are not reduced globally is ignored.

Copeland and Taylor (2004) add to the argument that stricter environmental regulations will affect the allocation of production plants. Since environmental regulations are more stringent in highincome countries, pollutive industries face higher production costs in these countries (Jaffe et al., 1995; Mani and Wheeler, 1998). This argument is often referred to as the pollution haven hypothesis which explains that producers will relocate their production to countries with low environmental regulations to minimize production costs. In order to attract productive industries, countries would then engage in a "race to the bottom" minimizing their environmental regulations (Dasgupta et al. 2002).

Lastly, the use of average income measures is heavily criticized (Stern, 2004; Stern et al., 1996). This critique is based on the fact that income is not normally distributed and that there are usually more individuals found below the average than above. He claims the median income to be more relevant than the average income in determining the income effect on environmental quality. In a more recent work, Stern (2017) argues that in order to provide policy makers with solid, unambiguous recommendations, the focus should be shifted towards investigating non-growth drivers of pollution.

The numerous theoretical mechanisms supporting and contradicting the existence of an EKC show that conclusions must be drawn with caution. The apparent policy recommendation that countries could economically "grow out of" environmental degradation was drawn hastily (Panayotou, 1997). The results of climate science must be considered because the existence of climate tipping points and irreversible destruction of natural resources makes the conclusion invalid and leads to faster extinction of the environment. IPCC (2022) states that a reduction in carbon dioxide emissions becomes futile after passing certain tipping points.

Analogous to the theoretical mechanisms, which do not permit to withdraw a unique explanation in favor or against the existence of the EKC, the empirical results neither provide precise results.

The individual results are susceptible to the chosen indicator for environmental quality, the chosen period of time, country coverage, and econometric estimation method.

Studies using carbon dioxide as an air quality indicator to proxy for environmental quality generally tend to confirm the inverted U-shaped relationship (Dinda, 2004). Besides Grossman and Krueger (1995) and Grossman and Krueger (1991), several older and more recent studies validate the EKC hypothesis. A recent study from Touitou and Langarita (2021) examines how economic growth affects carbon dioxide emissions in the case of Algeria for the time period from 1973 to 2016 using the auto regressive distributed lag method. They prove a direction of causality that goes from economic activity to emissions and find that economic growth affects carbon dioxide emissions. Further studies confirming the effect on carbon dioxide emissions are Selden and Daqing (1994), Shukla and Parik (1992), Ahmed and Long (2012), and Apergis and Ozturk (2015). However, the results are mixed for studies using water quality indicators or tend to reject the EKC hypothesis when other environmental quality indicators such as municipal solid waste, urban sanitation, or access to safe drinking water are used (Dinda, 2004). Economic theory suggests that using local pollutants the probability of finding prove for the EKC increases, while the usage of global pollutants generally does not provide results in favor of the EKC (Dinda, 2004). A potential explanation for these differences can be drawn from environmental economics theory, arguing that local impacts are nationally internalized and thus might cause regulative actions to correct the external impacts at the regional level (Stern et al. 1996). Moreover, it could be argued that the emitters of greenhouse gases are not necessarily the ones that internalize the costs, considering the emission of greenhouse gases as an externality (Stern, 2008).

Additionally, the choice of the econometric framework applied influences the results.[2] Furthermore, the choice of countries and time leads to different results. As in any empirical work, the external validity must be assessed carefully. This is particularly true for the EKC literature since findings obtained from estimations based on samples including solely industrialized countries may not hold for countries at lower levels of economic development. Similar caveats arise for single country analyses. A detailed analysis of the individual empirical studies targeting the EKC goes beyond the scope of this work and will not provide further insights that are relevant for understanding the following analysis and is therefore not provided here.[3]

[2] For a critical analysis of the commonly applied estimation techniques, see Stern (2004). [3] See Shabaz and Sinha (2019) for a detailed review.

2.2 Income inequality and environmental quality

Since empirical research has not provided conclusive results analyzing income levels as a driver of environmental quality, several researchers included income distribution patterns to analyze whether income inequality explains environmental quality trends rather than absolute levels of income. Similarly, the literature has discovered several theoretical mechanisms at play that potentially shape the relationship between income inequality and environmental quality in different ways (Cushing et al., 2015; Berthe and Elie, 2015). A distinction is typically made between the "equality hypothesis" that claims income inequality and emissions to be positively associated and a theory suggesting a trade-off between inequality and emissions. This section examines the theoretical arguments for both theories and concludes with an overview of the empirical results.

2.2.1 Equality hypothesis

The equality hypothesis suggests that income inequality is harmful to environmental quality. Since the mechanisms are based on socioeconomic models, many do not seem straightforward. In these cases, this section will also provide concrete examples to enhance the understanding. A potential policy recommendation drawn based on the equality hypothesis would suggest addressing income inequalities. In this case, reducing these inequalities would, as a side effect, lead to reduced emissions and henceforth conserve environmental quality.

Boyce (1994) analyzes whether greater inequalities of power and wealth are associated with environmental degradation because of (i) asymmetries in the power-weighted social decision rule and (ii) impacts on valuations of the costs and benefits of economic activities, and (iii) time preferences. Boyce (1994) hypothesizes that pollutive economic activity is a function of the balance of power between winners and losers. According to the power-weighted social decision rule, economic activities generate monetary net benefits and costs of environmental degradation. Here, winners are defined as individuals who benefit from pollutive economic activities, while losers are those who bear net costs. The cost-bearing losers favor environmental regulations restricting the economic activity to minimize the costs they face. Contrarily, the winners favor less regulative policies to maximize their benefits. Thus, the stringency of the implemented regulations depends on the political power of winners and losers, which itself depends on the numbers involved, their economic power, and their political influence (Boyce, 1994). A situation similar to this would occur when considering a hypothetic society of manufacturers and fishermen. Now, the production of the manufacturing good pollutes the river and causes the extinction of fish. The manufacturers continue benefiting from their economic activity, while the fishermen's profits are reduced due to river pollution. As a result, the society would be highly unequal, characterized by many wealthy manufacturers and many poor fishermen. Now, fishermen favor policies that reduce pollution, while manufacturers favor the contrary. The power-weighted social decision rule would suggest that the fishermen who are poorer are less able to translate their preferences into policy regulations than the economically better-off manufacturers. The result would be a conservation of the status quo, including lax restrictions on the pollutive activity.

However, the result predicted by the power-weighted social decision rule is sensitive to several assumptions. It is reasonable to assume that higher income inequality leads to higher inequality of political power. Now, the outcome of the power-weighted social decision rule depends on the income distribution. When winners are more powerful than losers in terms of income, greater income inequality leads to lax environmental policies and environmental degradation. Gassebner et al. (2008) argue that the declining share of industrial production is likely to cause a reduction in the political power of the individuals working in the production. Vice versa, the power-weighted social decision rule predicts that greater income inequality leads to less environmental degradation under the assumption that losers are politically more powerful than winners. The argument must be considered with caution since income distribution is not the only aspect that shapes political power. Ethnicity, gender, race, and numerous additional aspects are likely to be important (Gassebner et al., 2008).

Moreover, the impact of environmental valuation plays a vital role in shaping the outcome of the power-weighted social decision rule. The outcome is sensitive to the winners' and losers' preferences for good environmental quality and their willingness to pay (Boyce, 1994). When the losers bear the net costs of a pollutive economic activity, their preference for restricting the activity is high. However, their willingness to pay for the restriction is limited by their ability to pay. Assuming the losers to be relatively poor, their willingness to pay for environmental quality is low which results in higher environmental degradation. Vice versa, assuming the losers to be relatively wealthy, their willingness to pay is high and leads to strict environmental regulations. Going back to the previous example of fishermen and manufacturers, the output would change when we assume different preferences. Disregarding the fishermen, when the relatively wealthy manufacturers enjoy spending holidays at the riverside, which include activities that rely on good water quality like fishing or swimming in the river, their preferences would switch from less stringent environmental regulations to more stringent regulations to preserve fish stocks and water quality.

The last argument from Boyce (1994) adds a further dimension to the analysis connecting, inequality and time preferences. Assuming that the environmental costs from pollutive activities often materialize with a time delay, while the economic benefits occur immediately, the losers are affected in the future. Therefore, they may not defend themselves in the present. In addition to that, when everyone is affected by costs and benefits in the same way but the costs must be born in the future, a higher rate of time preferences results in acceptance of long-run costs for short-run benefits. In other words, when individuals value the present more than the future, environmental degradation is not prevented because its negative impacts materialize in the future. The general relevance of time preferences for environmental quality is widely accepted and reflected in the famous work by Hardin (1968) in the so-called Tragedy of the Commons (Feeny et al., 1990). However, Boyce (1994) hypothesizes greater economic inequality to result in higher rates of environmental time preferences for all income levels. As both extreme ends of the income distribution become more extreme, for the very poor, day-to-day survival becomes more important, which drives degrading activities to generate short-term economic benefits to secure survival, e.g., poor peasants in Central America cultivate steep hillsides causing rapid soil erosion. The poor themselves are most affected by the environmental degradation they cause which potentially results in a vicious circle (Durning, 1989; IBRD, 1992). In a similar fashion, economic theory would predict that the wealthier, typically characterized by higher saving rates, should also be characterized by lower time preferences. However, Boyce (1994) claims this argument to be too sanguine, arguing that institutions are a mechanism at play that cannot be disregarded. The importance of institutional quality is set forth with the following example of a dictator that controls the country-wide rate of resource extraction and is likely to extract natural resources as quickly as possible to generate as much profit as possible because his political power is unstable and might be lost when oppressed fellow citizens overthrow him. Therefore, he extracts as much as possible before getting overthrown. To sum up, economic inequality increases time preferences for the wealthy because they fear the loss of power (Boyce, 1994).

The arguments of Borghesi (2006) are in line with the equality hypothesis. He states that finding cooperative solutions to environmental problems is more difficult to achieve in unequal societies since these generally face more severe social issues and conflicts among the political powers. The mechanism of an unequal society undermining social cohesion was also stated by Wilkinson and Pickett (2009), Boyce (2003), and Boyce (2007). Theory suggests that trust among strangers arises from egalitarian norms while social inequality is harmful to trust (Delhey and Dragolov, 2014; Cushing et al. 2015). Based on findings from Barro (1999), who finds a positive relationship between inequality and economic growth for high-income countries, and findings from de Bruyn et al. (1998), who find that income growth is associated with increasing carbon dioxide emissions in four Organisation for Economic Co-operation and Development (OECD) countries, researchers argue that higher income inequality may increase environmental degradation via its positive effect on growth rates in developed countries (Borghesi, 2006; Wilkinson and Pickett, 2010; Berthe and Elie, 2015).

Another theoretical reason supporting the equality hypothesis, the emulation theory, is based on Veblen (1899). It hypothesizes that at high levels of inequality, poor individuals desire to emulate the consumption patterns of the wealthy because they tend to compare themselves to individuals from the superior class and emulate their consumption patterns (Cushing et al., 2015; Grunewald et al., 2017). Grunewald et al. (2017) conclude that an increase in consumption of pollutionintensive goods, such as big cars, leads to higher emissions relative to societies with more equal income distributions. This is often referred to as conspicuous consumption (Berthe and Elie, 2015).

Moreover, the poor might try to realize these consumption levels by increasing working hours or through credit financing. The latter implies a positive relationship between inequality and emissions, further supporting the equality hypothesis. Wilkinson and Pickett (2010) further add to this argument and claim that greater economic equality limits the social pressure to consume.

2.2.2 Trade-off theory

However, numerous theoretical aspects speak against the equality hypothesis, indicating a tradeoff between income inequality and environmental quality. Ravallion et al. (2000) and Heerink et al. (2001) argue that when the marginal propensity to emit increases with income, the distribution becomes relevant for analyzing the relationship between income levels and environmental quality. Based on results from Grunewald et al. (2017), Jakob et al. (2014), and Seriño and Klasen (2015), which indicate that the marginal propensity to emit correlates negatively with income, it can be concluded that higher income inequality leads to reduced emissions (Grunewald et al. 2017).

The trade-off theory is further supported by assuming that higher income inequality leads to a higher share of the population living outside the carbon economy, a reasonable assumption for lower income countries. However, the consequence is not that individuals living outside the carbon industry do not produce emissions. Their emissions stem from biomass and traditional fuels and are not captured in estimated carbon dioxide data. However, Grunewald et al. (2017) argue that their marginal propensity to emit is close to zero and that increasing their share would decrease total emissions. Scruggs (1998) questions several of the arguments brought up by Boyce (1994) to support the equality hypothesis and tests whether political and economic quality result in higher environmental quality. He tackles the argument that the wealthy prefer environmental degradation, arguing that preferences for environmental degradation vary across traditional income and power groups depending on several factors. Olson (2009) finds the demand for collective goods to be positively associated with income, and thus the wealthier will execute more stringent environmental regulations and limit pollutive activities (Cushing et al., 2015). In this case, societies with a highly unequal income distribution will experience a higher demand for environmental quality. Scruggs (1998) also argues that generalizations about the relationship between income inequality and environmental degradation cannot be valid without an in-depth analysis of preferences for environmental quality which he claims to be heterogenous within income groups. He argues that the power-weighted social decision rule is of limited explanatory power because preferences for environmental quality differ within groups.

Further aspects in contra the equity hypothesis rely on Hardin (1968), showing that inequalities can lead to more effective collective action for lower environmental degradation (Scruggs, 1998). Scruggs (1998) expresses several doubts about the equality hypothesis but he does not exclude that income inequality can be related to environmental quality.

The theoretical mechanisms are heterogenous and highly sensitive to different assumptions. This is also clearly reflected in the conclusions from Cushing et al. (2015) and Berthe and Elie (2015). Cushing et al. (2015) provide an in-depth review of the causal mechanisms shaping the relationship between income inequality and environmental degradation. The authors categorize several hypotheses according to three main arguments. First, inequalities in political power determine whose interests are reflected in policy outcomes. Second, inequalities in social and economic power affect the intensity of consumption. Third, social cohesion, trust, cooperation, and support for public goods lead to environmentally protective policies. Similarly, Berthe and Elie (2015) cluster the theoretical mechanisms in two channels; one operating through economic behavior and the other through political choices. The economic behavior channel argues that the effect of inequality on environmental quality depends on the relationship between individual income and individual environmental pressure and the effect of inequality on social cohesion and its consequences for environmental pressure. The political channel argues that environmental quality depends on environmental policies. These policies are determined by the preferences of different social groups and how these preferences fit the political system.

The heterogeneity of the theoretical arguments is reflected in Table 1, which gives a condensed overview of the main justifications of both theories.

Table 1: Theoretical mechanisms

Equality Hypothesis	Trade-off Theory
- Power-weighted social decision rule (Boyce, 1994) ○ Under the assumption that higher income translates into greater political power - Inequality increases rates of time preferences (Boyce, 1994) - Negative effect of inequality on cooperative solutions (Borghesi, 2006) - Emulation theory (Veblen, 1899) ○ The poor imitate the consumption pattern of the rich in unequal societies	- Power-weighted social decision rule ○ Under the assumption that demand for collective goods correlates with income (Scruggs, 1998) - Positive correlation between marginal propensity to emit with income (Jakob et al., 2014; Seriño and Klasen, 2015) - Typically, higher share of individuals living outside the carbon industry in countries with unequal distribution of income

2.2.3 Empirics

The heterogeneity of the theoretical arguments results in a pronounced need for empirical research to validate or reject several arguments.

Torras and Boyce (1998) empirically investigate the possible effects of changes in income distribution patterns on a set of water and air pollution indicators from the Global Environment Monitoring System (GEMS). Their panel dataset includes proxies for income, income inequality, literacy, political rights and civil liberties, and urbanization from 1977 to 1991. Using OLS regression techniques, they find that the inclusion of income inequality generally diminishes the statistical significance of the coefficient for GDP per capita. Moreover, they find mixed effects for income inequality, indicating that higher inequality is associated with higher pollution levels for some pollutants, but only in low-income economies. These findings provide slight evidence for the hypothesis that income inequality negatively impacts environmental quality (equality hypothesis). However, the results do not hold for all pollutants. Moreover, their results show that literacy, civil liberties and political rights are associated with better environmental quality, especially in lowincome countries. Scruggs (1998) performs empirical tests of the equality hypothesis. Using ambient, water, and air pollution measures for a cross-section of approximately 25 countries, he analyzes the effect of income distribution and political equality using pooled models. His results provide weak evidence for the equality hypothesis, suggesting that not the distribution but the absolute level of income predicts environmental quality. In line with this, political equality does not significantly predict environmental quality. Alternative measures of income inequality do not change these results. He concludes that income inequality does not systematically affect environmental quality. Magnani (2000) examines the impact of income inequality measured with Gini coefficients on environmentally related R&D expenditures, where R&D expenditures proxy environmental awareness across the population. Higher expenditures would indicate that public engagement in environmental problems is high; in other words, the affected care a lot about environmental quality. The author tests a non-linear model where environmental quality depends on income levels and income inequality using a panel dataset covering the period from 1980 to 1991 and including 19 OECD countries. The pooled OLS model results indicate that higher income inequality reduces environmental care supporting the equality hypothesis, while the random effects model does not provide significant results. The paper concludes with slight evidence towards the existence of the equality hypothesis.

Marsiliani and Renström (2000) address the question of why Scandinavian countries perform better than other European countries in terms of environmental protection. The authors investigate the impact of income inequality on environmental protection. They use two panels, including 7 (from 1978 to 1997) and 10 (from 1983 to 1997) industrialized countries exploring the hypothesis that countries characterized by an equal distribution of income implement more stringent environmental policies. The dependent variable, environmental protection is proxied by sulfur, nitrogen oxides, and carbon dioxide emissions per unit of GDP. Using OLS, regressing GDP per capita and Gini coefficients on emissions intensity indicates that higher income inequality increases emissions intensity. However, a fixed effects estimation does not support significant results. The authors conclude that the empirical results support the arguments of the equality hypothesis but notice that unobservable country-specific characteristics may play an important role. Similar results are obtained by Martínez-Zarzoso and Phillips (2020), who test the hypothesis that oppression of the press leads to less stringent environmental policies in more unequal societies. They investigate the effects using two panel datasets from 1994 to 2005; one containing a sample of OECD and BRIICS (Brazil, Russia, India, Indonesia, China, South Africa) countries, while the second dataset contains information on 82 countries. Their fixed effects regressions generally confirm the hypothesis. However, the negative correlation between increasing income inequality and stringency of environmental regulation holds only for non-rich countries, providing slight evidence for the equality hypothesis. Moreover, the results indicate positive effects of press freedom on the stringency of environmental policies. The authors conclude that the effects of income, the structure of the economy, and freedom of the press on environmental regulations are highly nuanced.

Ravallion et al. (2000) use a panel dataset of 42 countries covering the period from 1975 to 1992 to estimate the effect of income and income inequality on carbon dioxide emissions. In order to control for non-linear effects of income, the authors include the squared income term, following the EKC theory. The model is estimated using fixed effects techniques and pooled OLS regression techniques. However, the results between the different models differ substantially but the authors claim the pooled OLS model to be more appropriate. The results indicate that higher withincountry inequality is associated with lower levels of carbon dioxide emissions and the impact of inequality decreases at higher income levels. Additionally, the effect of income becomes more pronounced at higher levels of income inequality. The authors conclude that increasing inequality leads to lower emissions but increases their sensitivity to income.

Based on simple aggregation, Heerink et al. (2001) similarly provide support for including income inequality measures in empirical assessments of the relationship between income and environmental quality. The authors obtain similar results to Ravallion et al. (2000), including the Gini coefficients and a second-order polynomial term for income, using a cross-section design with observations for sulfur dioxide, suspended particulate matter, and carbon dioxide emissions for 65 countries. The results for carbon dioxide emissions indicate that income inequality is negatively associated with emissions and confirm the inverted U-shape relationship between income levels and emissions. These results point toward the existence of a trade-off between environmental quality and income equality.

Drabo (2011) addresses the question of how income inequality affects health via environmental outcomes. In order to estimate the effect of environmental quality, in a first step, he assesses how income inequality affects the environment using an instrumental variable approach to control for potential endogeneity arising from reverse causality and measurement issues. Drabo (2011) defines the age-dependency ratio as an instrumental variable. He claims the exclusion restriction to hold because the age-dependency ratio is unlikely to affect environmental quality and the relevance criterium to be fulfilled because the age-dependency ratio determines income inequality via its distributive effect. Moreover, the author controls for population density, fertilizer use, foreign direct investment, trade openness, and education. The results verify the EKC hypothesis for carbon dioxide emissions and indicate a positive causal effect of income inequality on emissions supporting the equality hypothesis. Borghesi (2006) empirically examines how income inequality affects carbon dioxide emissions using a panel dataset covering 37 countries from 1988 to 1995. He estimates emissions using pooled OLS and fixed effects models, including a linear, a quadratic, and a cubic term of income, population density, the industrial share of GDP, income inequality, and the interaction term between income levels and income inequality. The findings of the two different models contradict each other in terms of coefficient signs and statistical significance for the impact of inequality on emissions. The author further assesses the hypothesis that the contrasting results depend on differential impacts of income inequality for high- and low-income countries. However, the fixed effects model provides statistically insignificant coefficients for the impact on emissions, neglecting the equality hypothesis and the trade-off theory, stating that income inequality does not affect emission patterns systematically.

Comprehensive research was conducted by Grunewald et al. (2017). The authors contribute to the existing literature by applying a grouped fixed effects estimator based on Bonhomme and Manresa (2015) to account for the time-variant effects of environmental regulations. Furthermore, they claim their dataset to be superior to previous studies through country and time coverage as well as through the quality of the data. The dataset covers 120 countries from 1960 to 2001 and uses the improved Gini coefficients from Solt (2009). Controlling for different industry shares, their findings indicate that the effect of inequality and emissions depends on the level of income. More specificly, higher income inequality is associated with lower carbon dioxide emissions in low and middle-income countries. In contrast, the opposite holds for upper middle-income and highincome countries. In other words, the findings confirm the equality hypothesis for countries above a certain income threshold while for countries under the income threshold the trade-off theory is confirmed.

The most recent empirical assessment of the relationship between income inequality and carbon dioxide emissions was conducted by Wan et al. (2022). The authors use a panel dataset covering 217 countries from 1960 to the latest and apply an instrumental variable approach to estimate causal effects. They estimate carbon dioxide emissions with income inequality and a quadratic function of GDP controlling for nonlinear impacts of urbanization, trade, foreign direct investments, economic structure, and political rights. The coefficients for income and the squared income term support the EKC relationship, while income inequality is always negatively associated with emissions providing empirical evidence for the trade-off theory. Moreover, the authors empirically test the relevance of three underlying mechanisms. They find a diminishing marginal propensity to emit combined with a diminishing marginal propensity to consume and R&D expenditures to significantly predict pollution outcomes. One major difference between the approach pursued by Wan et al. (2022) and the present approach is that Wan et al. (2022) do not include the interaction term of their income measure and their inequality measure. Hence, they exclude potential nonlinearities in the effect of inequality and potential sensitivities across different income levels. The results do not support the argument that political freedom significantly affects the relationship.

Further empirical studies add to the results. Liu et al. (2019) find higher income inequality to be associated with increasing carbon emissions in the short term, while the effect reverses in the long term. Hence, results are sensitive to the time horizon chosen. In addition to that, several empirical studies analyze the relationship for a single country without conclusive results, including Zhang and

Zhao (2014) and Golley and Meng (2012) for China, Uzar and Eyuboglu (2019) and Demir et al. (2019) for Turkey, Jiao et al. (2021) for India as well as Jorgenson et al. (2017) and Baek and Gweisah (2013) for the US.[3,4] The studies from Grunewald et al. (2017), Ravallion (2000), and Wan et al. (2022) are closely related to this paper because they are based on similar data sources and estimation methods.

3. Data and Variables

This study is based on an unbalanced panel dataset covering 177 countries, of which 54 countries are currently classified as high-income countries, 51 as upper-middle income countries, 51 as lowermiddle income countries, and 21 as low-income countries. Table 13 in the Appendix provides a list of all the countries included. The dataset contains annual measurements from 1990 to 2018 for different greenhouse gases and socioeconomic measures with a total number of observations of 5,133. Emissions are used as dependent variable; the main explanatory variables are GDP per capita and Gini coefficients. Further socioeconomic variables are included as control variables.

Following Grunewald et al. (2017) and Wan et al. (2022), the Gini coefficients are obtained from the most recent version of the SWIID from Solt (2020). The SWIID maximizes data comparability and availability across countries and years. The remaining issues with comparability are captured in the standard errors (Solt, 2020). However, Jenkins (2015) and Wittenberg (2015) criticize the imputation model of the SWIID, providing limited support for the World Income Inequality Database (WIID). Still, the benefits of the SWIID are crucial for comparisons in the present estimations. The database contains Gini coefficients before and after tax. For this analysis, posttax coefficients are used because redistributive policies differ substantially across countries, and pre-tax Gini coefficients can be considered a theoretical measure with restricted practical relevance. Therefore, the paper hypothesizes that its effect on carbon dioxide emissions is limited. However, a robustness test will be conducted using pre-tax Gini coefficients.

The emission data is retrieved online from OurWorldInData.org from Ritchie and Roser (2020) and contains annual information about carbon dioxide emissions from the Global Carbon Project and other greenhouse gas emissions from the CAIT Climate Data Explorer. The dataset convinces with per capita figures and its high coverage. However, the data is estimated, which presents a potential drawback since it does not account for emissions from burning traditional fuels. GDP

[3] This list is not exclusive and only provides a selection of empirical studies.
[4] Liobikiene (2020) provides a review of selected papers revising the impact of income inequality on carbon dioxide emissions.

per capita data is taken from the WDI. The national measures are converted to constant 2017 international $ using purchasing power parity rates to enable comparability. Data on industry shares for the manufacturing and service sectors[5] is retrieved from the WDI. They are measured as valueadded, i.e., the net output of a sector after adding up all outputs and subtracting intermediate inputs in percentages of total GDP. The WDI also supplies data on urban and rural populations, enabling the construction of the shares of the population that lives in urban areas. To proxy for the effects of globalization, trade as the sum of exports and imports of goods and services as a share of GDP is included, also retrieved from the World Bank. Indicators for political freedom and civil liberties stem from Freedom House (2020). Both indicators rank from one to seven, where one indicates high levels and seven denotes low levels of civil liberties and political freedom. Following Torras and Boyce (1998), the measures are integrated into a combined measure by subtracting both values from 14, which results in a composite index of political and civil freedom with higher values indicating greater freedom. The education index is an average of mean years of schooling and expected years of schooling obtained from the HDR (UNDP, 2020) capturing education attainments comprehensively and is thus superior to any single measure[6].

Table 2: Summary statistics

	Source	Mean	Min	Max	Std. Dev.	N
Dependent variables						
Production-based emissions of CO2 per capita in million tonnes	owid	4.703	.02	68.724	6.565	5033
Greenhouse gas emissions per capita in tonnes of CO2-eq	owid	8.118	-50.487	86.991	9.005	4670
Methane emissions in tonnes CO2-eq per capita	owid	1.970	0	36.392	2.862	4671
Nitrous oxide emissions per capita in tonnes CO2-eq	owid	.637	0	8.239	.876	4671
Independent variables						
GDP per capita PPP (constant 2017 international $)	WDI	16649.847	436.720	120647.823	18675.588	4902
Gini, Disposable Income	SWIID	.392	.162	0.683	.091	3991
Gini, Market Income	SWIID	.457	.177	0.739	.070	3991
Population	SWIID	35599808	8910	1427647789	134910465.390	5063
Services, value added (% of GDP)	WDI	52.242	10.859	94.256	11.896	4459
Manufacturing, value added (% of GDP)	WDI	13.146	0	49.879	7.162	4358
Urban population (% of total population)	WDI	54.587	5.416	100	23.238	5104
Freedomhouse Index	Freedom House	7.235	0	12	3.902	5012
Trade (% of GDP)	WDI	83.372	.021	437.327	49.613	4429

[5] Service sector includes wholesale and retail trade, transport, education, health care, real estate services, and bank services.

[6] Table 2 gives an overview of the variables, with sources and summary statistics.

Education Index	HDR	.580	.081	0.943	.189	4550
Year			1990	2018		5133

4. Empirical methods

This section explains the model specification in greater detail which is based on theoretical and econometric rationales. Moreover, the section provides information on the variables included and potential endogeneity issues.

The model specification follows a similar logic as Grunewald et al. (2017), focusing on per capita emissions as the outcome variable. The model extends the EKC theory to allow income inequality to affect the outcome variable via non-linear relationships. The baseline model includes a secondorder polynomial of the absolute income measure, an income inequality measure and the interaction of both terms. It is extended by further controls and time and country fixed effects. Therefore, I propose the following estimation equation:

$$CO2_{it} = \beta_0 + \beta_1 GINI_{it} + \beta_2 GDP_{it} + \beta_3 GINI_{it} * GDP_{it} + \beta_4 GDP^2_{it} + X_{it} + \alpha_i + \varphi_t + e_{it} \quad (1)$$

where i and t denote country and year, respectively. $CO2_{it}$, the main dependent variable, refers to the log of per capita carbon dioxide emissions in country i and year t. $GINI_{it}$ refers to the log of the post-tax Gini coefficient, whereas GDP_{it} denotes the log of per capita PPP-adjusted GDP in constant international \$. Further explanatory variables are included in the vector X_{it} while α_i and φ_t denote the country and time fixed effects, which are applied in order to control for unobserved effects. To allow for within-country correlations, standard errors are clustered at the country level (Wang et al., 2021).

Following the majority of the literature, this paper uses Gini coefficients as a main explanatory variable. As a sophisticated measure of income inequality, the Gini coefficients are superior to income ratios. While income ratios only consider the specific shares, the Gini coefficients account for the whole population, e.g., the ratio of the top ten percent average income to the bottom half average income ignores the incomes of the population that are neither included in the top ten percent nor the bottom half. Besides controlling for income levels as a significant determinant of environmental outcomes, the inclusion of GDP per capita and its squared term enables an empirical assessment of the EKC theory controlling for a non-monotonic relationship, including the inverted U-shaped form predicted by the EKC theory. Grunewald et al. (2017) conclude that the elasticity of emissions with respect to inequality differs across different income levels. Hence, the inclusion of the interaction term is crucial to investigate whether the effect of income inequality on emissions depends on income levels.

One potential driver of emissions patterns is the composition of the economy. It is reasonable to assume that a country whose primary industry is the manufacturing sector generates more emissions than a country where the third sector mainly contributes to the GDP, even though both countries are at similar levels of GDP. Following Grunewald et al. (2017) and Wan et al. (2022), this paper controls for the effect that the economy's composition has on emissions. To proxy for the economy's composition, the shares of value-added are included in the control vector.

Moreover, Wan and Wang (2014) hypothesize that the relationship between urbanization and carbon dioxide emissions may follow an inverted U-shape pattern. The rationale behind this is that individuals living in urban areas consume more compared to individuals living in rural areas at low levels of urbanization. Consequently, urbanization would lead to increasing emissions at the initial stages. However, after a certain threshold, additional urbanization is hypothesized to lead to decreasing emissions because urban areas are gernerally characterized by higher productivites, a predominant third sector, and the development of clean technologies. In the later stages of urbanization, theory predicts a reversal of the relationship (Wan and Wang, 2014). In order to control for this non-linear relationship, the urban population as the share of the total population and its squared term are included.

Furthermore, it is reasonable to assume that trade affects emission outcomes in several ways. First, one could assume countries that are more globalized to be more likely to engage in trade of waste and trade pollutive industries since trade in waste has been growing at exceptional rates over the past decades (Kellenberg, 2015). In this case, low-income countries would import pollutive industries from wealthier countries. A different mechanism is related to recently developed technologies that enable less pollutive production and might reach countries that are more globalized faster than remote countries. This suggests a positive impact of trade on emission patterns. Trade openness, as the share of the sum of exports and imports of total GDP, is a proxy for globalization. Antweiler et al. (2001) and Lopez (1994) argue that trade openness potentially affects emissions through scale, technological, and composition effects. Their findings support the mechanism that inflows of foreign capital and trade liberalization are associated with an inflow of cleaner production technologies. Saini and Singhania (2018) provide a detailed overview of the empirical and theoretical literature on the impact of growth, emissions, and FDI on environmental indicators and conclude that the results on the nexus between FDI and energy consumption, cleaner energy, and carbon dioxide emissions remain inconclusive. Therefore, trade openness is included in the control vector.

The power-weighted social decision rule argues that emission levels depend on the political power and preferences of the population. It is reasonable to assume that political power is more equally distributed in countries with sound political rights and civil liberties, allowing the economically disadvantaged to equally lobby for their preferences. Therefore, it is reasonable to assume that countries with higher political and civil freedom experience lower emissions because individuals will be able to translate their demand for environmental quality into environmental regulations. In order to accurately capture this effect, I follow Torras and Boyce (1998) in using the composite measure of political freedom. Additionally, education can increase environmental awareness and reduce emissions (Cheng et al., 2020). Torgler and García-Valiñas (2007) argue that higher education leads to more environmentally friendly behaviour. Egbetokun et al. (2019) revise the EKC model for Nigeria, including education expenditure, and find evidence indicating a positive effect of education expenditure on awareness of climate change and global warming but not on local pollution. More precisely, they find that higher education expenditure is associated with lower carbon dioxide emissions. I capture these effects using the sophisticated education index obtained from the HDR. The choice of model specification is not only based on previous literature but is also supported by several econometric rationales. First, we apply the Breusch and Pagan Lagrangian multiplier test to decide between random effects and an OLS specification[7]. The null hypothesis that variances across countries are zero is rejected, indicating that random effects are superior to the OLS specification. However, the Hausman test is performed to assess whether the fixed effects model or the random effects model is more appropriate to capture the bias stemming from unobservable variables[8]. In order to control for unobserved heterogeneity, country and year fixed effects treat the unobserved differences between countries and time periods as a set of fixed parameters estimated by including country and time dummies. Random effects methods construct the variance of the residuals using the unobserved heterogeneity. However, the assumption for random effects that the unobservable variables are uncorrelated with the explanatory variables does not hold. The Hausman test uses the null hypothesis that the estimates using random effects methods do not differ significantly from the estimates of a fixed effects model. Rejecting the null hypothesis, the random effects model is likely to be biased, which provides strong support for using the fixed effects estimator (Hausman, 1978).

[7] The test gives a Chi^2=21870 with associated probability=0.00.

[8] The Hausman test gives a Chi^2=111.61 with associated probability=0.00.

However, the data does not meet the assumptions of the Hausman test which might be caused by heteroskedastic errors or intragroup correlation. In order to overcome this issue, I follow Mundlak's (1978) alternative to the Hausman test[9]. The Mundlak approach is a regression-based Hausman test that relaxes the assumption that the explanatory variables are uncorrelated with unobserved variables in the random effects estimation. The Mundlak approach also estimates random effects models, including group means of the explanatory variables. The results reject the null hypothesis suggesting that unobservable characteristics are related to the explanatory variables, implying that the fixed effects model is appropriate. In addition, the null hypothesis that dummies for all time periods are jointly equal to zero is tested to assess whether time fixed effects are required. The results imply that the null hypothesis can be rejected providing econometric evidence for using time fixed effects. However, one potential drawback of the fixed effects model is that it assumes that the heterogeneity between countries is time constant, which might not necessarily be given. Time fixed effects only account for shocks that affect countries equally. The major unobservable variable that potentially biases the regression outcome is the development of environmentally friendly technologies. Here, the paper follows Martínez-Zarzoso and Phillips (2020) and assumes the development of environmentally friendly technologies to be common in all countries. Lastly, since the results from the Hausman test indicate the presence of heteroskedasticity, I test the null hypothesis of homoskedasticity. The results do not permit rejecting the null hypothesis proving the existence of heteroskedasticity[10]. In order to account for heteroskedastic errors, I use Huber-White standard errors clustered at the country level (White, 1980).

However, potential biases through reverse causality or omitted variable biases cannot be ruled out entirely. Wan et al. (2022) claim that previous studies neglect the existence of reverse causality and apply instrumental variable estimation techniques to control for potential biases. It seems plausible that environmental degradation at extreme levels affects economic outcomes. However, this effect of environmental quality on the explanatory variables is assumed to be negligible for this paper for several reasons. While the effect on economic performance is somewhat straightforward, the effect on economic inequality is blurred. A credible channel could be that high levels of environmental degradation harm economic activity that relies on resources or intact ecosystems, e.g., tourism. Additionally, extremely low levels of environmental quality could be detrimental to growth via its adverse effects on employee health. In this direction of causality, a negative effect on growth would be reasonable to assume. This paper argues that this issue is less of a concern in the present analysis since

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[9] The Mundlack test gives a Chi^2=58.83 with associated probability=0.00.

[10] The test gives a Chi^2=71686 with associated probability=0.00.

these extreme cases have not been reached for the presently applied measure of environmental degradation; put differently, current carbon dioxide atmospheric concentration is

unlikely to affect economic inequality directly. The effect on economic growth is potentially more pronounced through costs arising from the transition to a carbon-neutral production (carbon price). The paper plausibly assumes that current carbon dioxide concentrations are far from determining within-country inequality, mainly because the harmful effects of carbon dioxide emissions, a global pollutant, are not fully internalized at local levels. However, regressions with lagged variables are included in the paper to provide empirical support against bias through simultaneity. Nevertheless, the qualitative argumentation of why endogeneity biases might be negligible combined with the model specification does not provide bullet-proof arguments for establishing causality. Therefore, I argue that the interpretation of the results needs to be done with caution keeping the limitations in mind. I suggest interpreting the coefficients as indicators for conditional correlation instead of causal effects.

5. Empirical Results

This section provides the description and interpretation of the empirical results. The first step will provide the baseline and main regression results, followed by some robustness tests. Lastly, the paper tests the external validity of the findings for different pollutants.

5.1 Main results

The following tables provide the regression results for different estimations. The dependent variable is the log of carbon dioxide emissions per capita if not indicated differently. Moreover, the tables provide information on the fixed effects used, the within-R-squared, the turning points of a potential EKC, and the marginal effects. The marginal effects indicate which level of GDP per capita in 2017 international $ is required for the inequality-emissions relationship to turn positive. The EKC turning points indicate which level of GDP per capita needs to be reached for the effect on emissions to become negative. For quantitative interpretations of the coefficients, it is essential to consider that the dependent variable and the main explanatory variables are transformed using logarithms to increase the model fit as indicated by the Akaike and Bayesian information criteria based on Stoica and Selen (2004)[11]. The main variables of interest are post-tax Gini coefficients and GDP per capita, which are used to analyze the central question of how income inequality affects carbon dioxide emissions and how the relationship differs across countries that are characterized by different income levels. Moreover, the squared term of GDP per capita enables an empirical assessment of the EKC hypothesis. The main findings can be concluded as follows: First and most importantly, the relationship between income inequality and emissions changes with absolute incomes. More specifically, the overall correlation is negative but switches sign

[11] AIC (BIC)log-log model=-3311.25 (-3075.02); AIC level-level model= 7379.72 (7615.94).

for countries above a certain level of income. Second, the results support the EKC relationship. Third, the two correlations mentioned above are entirely driven by more prosperous countries while there is no significant effect for lower-income countries. Fourth, the inclusion of the control vector does not change the results, indicating that besides urbanization, none of the hypothesized variables is associated with significant changes in carbon dioxide emissions. Lastly, the validity of the whole set of findings mentioned above holds true for carbon dioxide emissions and cannot be extended to the emissions of other greenhouse gases. In order to observe how the results depend on the model specification, Table 3 displays the baseline estimates for four different models, excluding the set of control variables. The first column contains the results for the OLS model specification, the second column displays random effects results, and the third column displays fixed effects regression results using country fixed effects only. The fourth column displays the results for the preferred model specification, including time and country fixed effects. The standard errors are clustered at the country level in column (1) and (2).

These baseline regression results indicate a negative correlation between the Gini coefficients and carbon dioxide emissions, providing weak support for the trade-off theory and supporting previous findings from Wan et al. (2022). The first coefficient of the main specification in column (4) indicates that an increase in the Gini coefficient of one percent is associated with emissions that are reduced by 4.8 percentage points, all else equal. The quantification of the coefficients should be considered carefully. Still, it can be concluded that, due to the significance and coefficient sizes, the changes are substantial. However, the results are more nuanced since the positive significant interaction term indicates that the emissions-inequality elasticity will turn positive in countries above a certain threshold of GDP per capita. This is in line with findings by Grunewald et al. (2017) and the estimation results of the present study provide further empirical evidence in favor of the argument. The income thresholds are reported as marginal effects. They are obtained by setting the first derivative of the regression equation with respect to the Gini coefficient equal to zero. The values range among the upper values of GDP per capita from the used sample but have been reached by several high-income countries. It is noteworthy that the marginal effects differ substantially for the different model specifications.

Additionally, the baseline results provide support for the EKC theory. The significant positive coefficient for GDP per capita and the significant negative coefficient of its squared term have the expected signs, providing support for the inverted U-shaped form. Table 3 provides information about the turning points for an EKC. In other words, the turning point indicates which level of GDP per capita is necessary for the relationship between GDP per capita and emissions to turn negative. It is worth reporting that the turning points are susceptible to the model specification. In the preferred model, countries with GDP per capita above 91,148 $ are associated with experiencing decreases in carbon dioxide emissions when per capita GDP rises.

The results for the different econometric specifications differ only moderately. However, the Mundlak (1978) approach provides evidence for the superiority of the fixed effects estimation. Further tests conclude that time fixed effects are needed and support the chosen model specification.

Table 3: Baseline results - different model specifications

	(1) **OLS**	(2) **RE**	(3) **FE**	(4) **FE**
Gini, Disposable Income	-6.19205*** (.45524)	-4.12844*** (1.25306)	-3.86916** (1.2396)	-4.77862*** (1.28069)
GDP per capita	4.66912*** (.12357)	4.27142*** (.5303)	4.24508*** (.5485)	4.11737*** (.56374)
Gini*GDP per capita	.56121*** (.04856)	.36025* (.13097)	.34492* (.12936)	.44134** (.13331)
(GDP per capita)^2	-.16443*** (.00777)	-.18084*** (.02937)	-.18392*** (.0302)	-.16165*** (.03238)
Constant	-29.04121*** (.56884)	-23.82433*** (2.4727)	-23.19711*** (2.57808)	-23.88722*** (2.5983)
Observations	3848	3848	3848	3848
R-squared	.86737	.47290	.47423	.49298
Marginal Effects	61912.949	94848.898	74419.977	50386.513
Turning Point (EKC)	283209	51546	41663	91148
Time FE	No	No	No	Yes
Country FE	No	No	Yes	Yes

Standard errors are in parentheses
**** p<.001, ** p<.005, * p<.01*

The findings of the baseline model confirm previous findings obtained by Grunewald et al. (2017) and Wan et al. (2022). An essential contribution of this paper is the empirical assessment of how the results differ across countries with different income levels. Therefore, Table 4 reports the results of the preferred baseline specification, including country and year fixed effects for different income groups. According to the 2022 World Bank income group classification, countries are assigned to the four income groups: low-income, lower-middle income, upper-middle income, and high-income. Here, this paper argues that the fact of countries switching between different income groups over time does not pose a threat to the estimation because its single purpose is to cluster similar countries. Summary statistics for the explanatory variables by income group can be found in Table 14 in the appendix.

While column (4) in Table 3 reports the coefficients for the whole panel dataset of 177 countries, these results are shown for the different income groups in Table 4. Several findings are of major importance. First, the negative coefficient of the inequality proxy remains significant only for upper-middle income and high-income economies. The coefficient shrinks close to zero for lowincome and lower-middle-income economies and is insignificant at standard significance levels. This difference in significance points towards the fact that the overall coefficients are driven by more prosperous countries and that inequality does not affect carbon dioxide emissions in poorer countries. However, the finding should be considered with care because the separation in different income groups reduces the number of observations per income group, which is particularly low for the low-income sample. In addition to that, the values of the dependent variable are very low for the sample of low-income countries ranging from 0.02 to 0.532. The low values with smaller variances further harm the explanatory power of the results for poorer countries. The fact that the present results do not provide significant effects of the inequality measure on emission data may not exclude the existence of such effects. Second, the finding from the results using the whole sample, that the effect depends on income levels, can only be confirmed for upper-middle- and high-income countries. The interaction term is omitted for low- and lower-middle income countries, as the linear regression estimation offers a better fit. These results indicate that the isolated correlation of income inequality and carbon dioxide emissions in high-income countries is negative and turns positive for countries above a certain threshold of GDP per capita, which many countries have not yet reached. The income thresholds for the upper-middle and high-income countries are above the means in both income groups. For the upper-middle income group, the mean GDP per capita is 12,105 $, about 8,000 $ below the turning point, and for the high-income sample, the mean is 38,558 $, about 3,000 $ below the threshold. For upper-middle income economies, the threshold has been reached by 8% of the total observations, while 45% of the observations in the high-income sample are above the critical threshold. Third, the linear term of GDP per capita remains positive and significant for all income groups indicating that economic development harms environmental quality via increased emissions. However, the inclusion of its squared term does only improve the estimation results for the high-income country sample. The results provide support for the EKC relationship only in high-income countries. At the same time, the coefficients indicate that carbon dioxide emissions in poorer countries are determined more accurately by a linear function of income. Since evidence for the EKC relationship can only be found in column (4), it is the only specification with a turning point close to the mean per capita GDP of the sample of high-income countries. The caveats mentioned above for (1) and (2) remain valid here. Therefore, the paper argues that insignificant coefficients do not necessarily imply the inexistence of effects due to data issues.

Table 4: Baseline results by income group

	(1) Low-Income	(2) Lower-Middle Income	(3) Upper-Middle Income	(4) High-Income
Gini, Disposable Income	-.84019	-.35051	-8.79026***	-9.10895***
	(.59927)	(.38197)	(1.59798)	(1.64142)
GDP per capita	.82818**	1.40838***	1.58169***	5.96258***
	(.21747)	(.15135)	(.20764)	(1.29965)
Gini*GDP per capita			.88593***	.8561***
			(.15981)	(.16656)
(GDP per capita)^2				-.23532**
				(.06867)
Constant	-8.9203***	-12.27042***	-14.09576***	-34.56546***
	(1.36258)	(1.20128)	(2.02488)	(6.22983)
Observations	410	1098	1136	1204
Countries	21	51	50	52
R-squared	.48898	.6517	.50937	.46293
Marginal Effects	-	-	20375.432	41776.871
Turning Point (EKC)	-	-	-	38835
Time FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	yes	Yes

Robust standard errors are in parentheses
**** p<.001, ** p<.005, * p<.01*

Table 5 contains the main regression results for the fixed effects model, including the set of control variables. For the sake of completeness, further regressions included the squared term of the income inequality measure. However, the coefficient is insignificant and the results remain unchanged. As argued before, the country and time fixed effects reduce threats of endogeneity. However, omitted variables potentially cause biases in the estimation. The paper intents to capture the most relevant biases that are not captured in the fixed effects with the inclusion of the set of control variables. The results from the income groupwise regressions extended by a wider set of controls are displayed in Table 5. The main results generally confirm previous findings.

The first column in Table 5 reports the results for the whole set of countries, providing evidence that supports previous findings. The results in column (1) support the sensitivity of the relationship between income inequality and emissions, confirming the generally negative correlation as well as the EKC relationship between income and emissions. Again, the trade-off theory is supported by the significant negative coefficient of the income inequality measure. Furthermore, the positive significant interaction term proves its sensitivity to absolute income levels. The threshold indicates that the conditional correlation of inequality turns positive for countries with a level of GDP per capita above 36,828 $. This value has only been reached by one country of the upper-middle income country sample, Equatorial Guinea, in 2008 and 2009. For the sample of high-income countries, the critical value of 37,945 $, is slightly below the mean GDP per capita value the income group, supporting that several countries have crossed the threshold and are experiencing a positive inequality-emissions elasticity. The results for the whole set of countries are similar to the results obtained by Wan et al. (2022), providing general support for the trade-off theory. However, the present results contribute significantly to the understanding. The inclusion of the interaction term provides crucial insights as to how the coefficient changes for countries with different income levels. While Wan et al. (2022) conclude a negative effect of income inequality on emissions, this paper indicates that the results do not hold for wealthy countries, nor can the data provide support for this argument. Due to the similarity of the data used in both analyses, it can be concluded that higher income countries entirely drive the results from Wan et al. (2022).

The evidence supporting the EKC must be considered with care because the turning point is outof-sample. Consequently, the often hastily drawn conclusion that countries can simply grow out of environmental degradation does not appear to be a sound basis for policy recommendations. Additionally, it is noteworthy that the inclusion of the control variables barely changes the results. Coefficient sizes, however, are reduced.

The income groupwise regression results in column (2) to column (4) provide further insights. Again, inequality is negatively associated with carbon dioxide emissions and its effect depends on levels of GDP per capita. However, similar to the income groupwise baseline results, the findings can only be confirmed for upper-middle and high-income countries, indicating that richer countries entirely drive the results found in column (1). The inclusion of non-linear terms for low-income and lower-middle income countries does not improve the estimation fit and is therefore omitted. In addition to that, the results indicate the inverted U-shaped relationship between GDP per capita and carbon dioxide emissions as proposed by the EKC theory. Again, the findings hold for the whole set of countries and for the sample of high-income countries. Column (5) provides a reasonable turning point of 54,176 $, which is still above the mean GDP per capita in the sample of high-income countries in 2018 of 44,907 $ and is above the 2018 average GDP per capita of many high-income countries, including Germany (53,487 $), Canada (48,797 $) and the United Kingdom (46,853 $). Still, several countries have passed the critical threshold and are estimated to experience lower emissions, holding all other factors constant.

Although the inclusion of the control variables barely changes the results, it provides valuable further insights. First, the non-significance of value-added for the manufacturing and service sectors provides evidence that the economy's composition does not significantly affect carbon dioxide emissions. Second, the results show a non-linear relationship between urbanization and carbon dioxide emissions. The linear term is positive and significant and its squared term is negatively significant at the 10% significance level. These coefficients support the hypothesis of an inverted U-shaped pattern (Wan and Wang, 2014). Third, the results cannot confirm the hypothesis that political freedom and civil liberties are particularly important determinants of the outcome of the power-weighted social decision rule and henceforth affect carbon dioxide emissions. The Freedom House Index is not significant at common significance levels, and its sign does not comply with the expectations. These non-findings can result from the fact that the power-weighted social decision rule does not determine emission outcomes in practice or that the assumptions of the power-weighted social decision rule are ambiguous. Section 2 displayed that the predicted outcome of the power-weighted social decision rule depends on the preferences of the individuals benefitting from pollutive economic activities and the preferences of the cost-bearers. It is plausible that preferences are not homogenous within these groups, resulting in contradicting effects which potentially results in a net effect that does not significantly differ from zero. Fourth, it is reasonable that poorer countries that are highly open to trade are more likely to import pollutive industries, while globalized countries that can afford to pay for clean environments and good environmental quality tend to export pollutive industries. Contrarily, the trade of cleaner production technologies potentially reverses the expected sign. However, the results do not allow to draw any conclusion because the insignificant coefficients do not validate any theory. A potential explanation could be that the effects cancel out. The simple inclusion of the trade measure does not allow to validate one specific line of argumentation. Lastly, a proxy for education is included to control for the influence arising from individuals who experienced higher education being more aware of environmental quality and taking action to conserve environmental quality. Again, the positive sign of the coefficient and its non-significance at conventional levels do not provide support for the hypothesized mechanism. However, the inclusion of the control variables does increase the goodness of fit of the model, as indicated by the increased values of the within-R-squared compared to Table 3 and Table 4.

One caveat has to be considered comparing the main regression results with the baseline results. Namely, the number of observations is reduced drastically since data availability is poor for measures that proxy education or political freedom and civil liberties. This is particularly impactful for the regression results in column (2) because the number of countries included shrinks to 16.

Table 5: Main results by income group

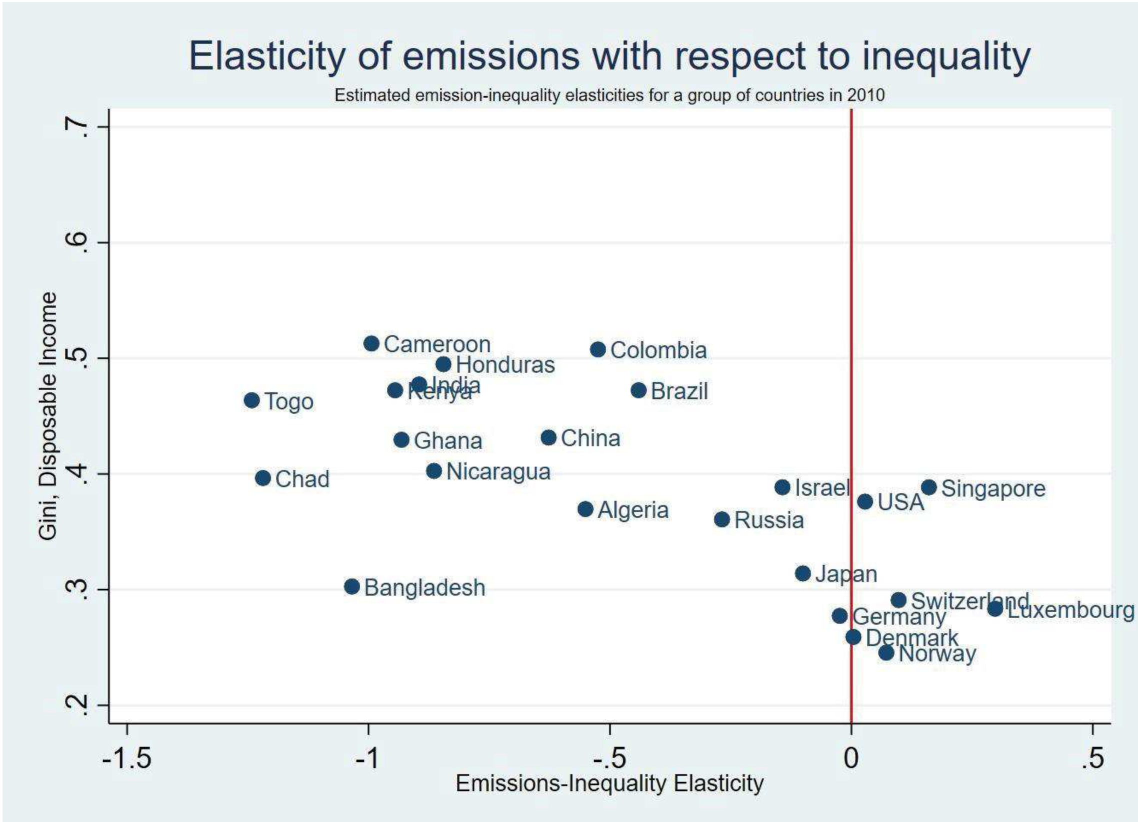
	(1) **Total**	(2) **Low-Income**	(3) **Lower-Middle Income**	(4) **Upper-Middle Income**	(5) **High-Income**
Gini, Disposable Income	-3.91772***	-.84562	-.29199	-6.01149***	-8.86354***

	(1.1187)	(.57914)	(.21084)	(1.6195)	(2.32764)
GDP per capita	3.21592***	.812*	1.03711***	1.1569***	5.93552***
	(.64777)	(.26165)	(.09819)	(.26275)	(1.41537)
Gini*GDP per capita	.36193**			.57176**	.84063***
	(.11793)			(.1689)	(.2318)
(GDP per capita)^2	-.11563**				-.22772**
	(.03727)				(.0753)
Services, value added	-.00222	.00465	-.00452	.00129	-.00253
	(.00219)	(.00635)	(.00228)	(.00423)	(.00446)
Manufacturing, value added	.00648	.01053	.01196	-.00043	.00941
	(.00403)	(.01264)	(.00468)	(.0046)	(.00542)
Urbanization	.04435***	-.02428	.06212***	.03759*	.00675
	(.01104)	(.01887)	(.01421)	(.01291)	(.02857)
(Urbanization)^2	-.00024*	.00032	-.0004**	-.00029**	.00001
	(.00009)	(.00016)	(.00012)	(.00008)	(.00018)
Freedom House Index	.00873	-.02581	-.00448	.00985	-.00431
	(.00484)	(.01509)	(.00855)	(.00959)	(.01803)
Trade openness	-.00036	.00599	.00136	-.00103	-.00089
	(.0005)	(.00305)	(.00072)	(.00095)	(.00055)
Education	.05069	-1.39283	1.22251	.32697	-.5324
	(.35742)	(.98044)	(.50546)	(.46687)	(.36372)
Constant	-21.11651***	-8.66724***	-11.47675***	-11.81424***	-35.09998***
	(2.80585)	(1.84233)	(.6684)	(2.33991)	(7.05142)
Observations	3156	271	933	882	1070
Countries	152	16	46	43	47
R-squared	.58199	.60763	.77087	.58004	.50941
Marginal Effects	50241.534	-	-	36828.307	37945.442
Turning Point (EKC)	242410	-	-	-	54176
Time FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors are in parentheses
**** p<.001, ** p<.005, * p<.01*

The regression results indicate that the conditional correlation between income inequality and carbon dioxide emissions differs substantially according to the levels of GDP per capita. This is further investigated and displayed in Figure 3, which shows the estimated elasticities of emissions for a group of random countries in 2010 for the model specification, including country and time fixed effects (Table 5, (1)). The vertical line reflects the threshold which is at 50,242 $. The findings support the evidence from Grunewald et al. (2017) and confirm their key result that decreasing income inequality will be beneficial to environmental quality in countries that have passed a certain threshold of GDP per capita. Figure 3 shows that few high-income countries were above the critical average GDP per capita threshold and experienced positive emissions-inequality elasticities in 2010.

Figure 3: Emission-inequality elasticities



Section 4 provides several qualitative arguments describing to what extent the model is assumed to be robust to bias through simultaneity and reverse causality. However, the endogeneity concerns raised by Wan et al. (2022) are addressed using lagged main explanatory variables to account for these potential biases. Table 6 provides the results for the main specification with a one-year lag of the main explanatory variables in column (1) and a two-year lag in column (2). Both models provide strong evidence for the previous results, including the main finding of the significant negative correlation of income inequality on emissions, which is sensitive to levels of GDP per capita, as well as the validation of the EKC hypothesis. Support is strong for the inverted U-shaped relationship between urbanization and carbon dioxide emissions. However, the interaction term is not significant at conventional levels for the two-year lag but confirms the results in the one-year lagged model at the 10% significance level. It is considerable that the turning points differ substantially for the two models. However, both are out-of-sample. Generally, the similarity of these results and the main results points towards a rejection of the presence of strong systematic bias resulting from simultaneity and provides some evidence for a unidirectional causality, where the main explanatory variables cause changes in the emission outcomes.

Table 6: Regression results – lagged independent variables

	(1)	(2)

	One year	Two years
Gini, Disposable Income (lagged)	-3.65259**	-3.30665**
	(1.13997)	(1.12677)
GDP per capita (lagged)	3.3594***	3.48743***
	(.64114)	(.60753)
Gini*GDP per capita (lagged)	.33565*	.29978
	(.1202)	(.11939)
(GDP per capita)^2 (lagged)	-.12771***	-.14154***
	(.03678)	(.03473)
Services, value added	-.00266	-.0031
	(.00222)	(.00234)
Manufacturing, value added	.0037	.00055
	(.00357)	(.00348)
Urbanization	.04786***	.05019***
	(.01039)	(.0101)
(Urbanization)^2	-.00028***	-.00031***
	(.00008)	(.00008)
Freedom House Index	.01154	.01487**
	(.00475)	(.00501)
Trade openness	-.00045	-.0004
	(.00049)	(.00048)
Education	.11243	.15172
	(.35432)	(.36091)
Constant	-21.39685***	-21.39162***
	(2.7714)	(2.64596)
Observations	3127	3077
Countries	153	153
R-squared	.57843	.56322
Turning Point (EKC)	145331	80789
Time FE	Yes	Yes
Country FE	Yes	Yes

Robust standard errors are in parentheses
**** p<.001, ** p<.005, * p<.01*

5.2 Robustness tests

This section provides the results of a sensitivity analysis, including several robustness checks that use different measures of income and inequality.

Table 7 displays the results for the main regression with an alternative inequality measure. Pre-tax Gini coefficients are included instead of the previously used post-tax Gini coefficients. The results change drastically, which does not necessarily threaten the validity of previous findings. The coefficients for income inequality are mostly insignificant. One potential hypothesis explaining the insignificant coefficients for the pre-tax Gini coefficients could argue that redistributive taxes substantially change the income pattern. This is potentially reflected in the relatively low correlation between the pre- and post-tax Gini coefficients of 0.432[12]. However, there is no theoretical link of how pre-tax income would affect carbon dioxide emissions. For this reason, the effect of the pretax Gini coefficients is expected to be less pronounced or not to affect the emissions pattern significantly, which is well reflected in the results. However, the results provide support for the EKC theory since the coefficients for GDP per capita and its squared term are significant and of the expected sign. This support for the inverted U-shaped relationship is only provided using the dataset that includes all countries. The general effect appears to be driven by high-income countries since the coefficients are only significant for this income group. It is noteworthy that the previous finding of the non-linear relationship of urbanization is confirmed using market income Gini coefficients.

Table 7: Robustness test using alternative measure of income inequality: pre-tax Gini coefficients

	(1) **Total**	(2) **Low-Income**	(3) **LowerMiddle Income**	(4) **UpperMiddle Income**	(5) **High-Income**
Gini, Market Income	1.14373	28.53125*	.46903	-.75176	-3.53755
	(1.39259)	(8.90218)	(3.27854)	(4.06275)	(4.54306)
GDP per capita	2.84767***	-6.74693	-.11983	.6592	5.47368***
	(.71912)	(3.70801)	(1.26208)	(2.5287)	(1.43287)
Gini*GDP per capita	-.16791	-4.0172*	-.05215	.0021	.33294
	(.15256)	(1.25393)	(.3918)	(.42351)	(.43567)
(GDP per capita)^2	-.12468***	.31181	.06669	-.00663	-.23734**
	(.03581)	(.2359)	(.07402)	(.13312)	(.06809)
Services, value added	-.00336	.00911	-.00443	.00059	-.00158
	(.00222)	(.00476)	(.00235)	(.00433)	(.00501)
Manufacturing, value added	.00759	.00055	.0125**	.00076	.00507
	(.0045)	(.0083)	(.00407)	(.00532)	(.00619)
Urbanization	.03985**	-.02716	.06621***	.04492**	-.00254
	(.01216)	(.01341)	(.01663)	(.01341)	(.03114)
(Urbanization)^2	-.00019	.00033	-.00043**	-.00031**	.00007
	(.0001)	(.00012)	(.00014)	(.0001)	(.00019)
Freedom House Index	.00685	-.02538	-.00787	.01823	.00178
	(.00526)	(.0139)	(.0084)	(.00977)	(.01695)
Trade openness	-.00037	.00483	.00155	-.00116	-.00132
	(.00053)	(.00248)	(.0007)	(.00105)	(.00061)
Education	.00607	-1.01977	1.09193	.1732	-.4799
	(.35676)	(.63847)	(.50599)	(.4376)	(.39925)

[12] Pairwise correlations can be found in Table 15 in the appendix.

Constant	-16.63377***	29.99329	-6.264	-6.90124	-28.909**
	(3.5943)	(15.47366)	(5.62409)	(12.11517)	(8.28547)
Observations	3156	271	933	882	1070
Countries	152	16	46	43	47
R-squared	.56798	.6909	.77098	.55803	.45627
Time FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors are in parentheses
*** $p<.001$, ** $p<.005$, * $p<.01$

In Table 8, another measure to proxy for income is used, namely the Human Development Index (HDI) sourced from the HDR (UNDP, 2020). The HDI is a composite index calculated with the geometric mean of normalized indices for measures of education, health, and income. The HDI range is between zero and one, where greater values indicate higher levels of human development.

It was created to shift the focus of human development from economic income measures only toward more sophisticated criteria taking people's capabilities into account (Stanton, 2007). Therefore, higher values of HDI do not necessarily result from high income levels but can similarly be driven by long and healthy lives, being knowledgeable, or having a decent standard of living. Still, the correlation with GDP per capita is strong (0.74). The results do not support previous findings because the income inequality measure coefficient turns insignificant. In addition to that, the coefficients indicate a non-linear effect of the HDI on carbon dioxide emissions for middleincome countries. Contrarily to the previous findings, the shape does not follow the inverted Ushaped form. The results indicate that the effect of human development grows exponentially with income, contradicting the EKC theory; put differently, higher levels of human development are associated with increasingly higher per capita carbon dioxide emissions. Arguably, biases could arise because the HDI does not capture country and population sizes since it is not a per capita measure. Therefore, values could be driven by population sizes. However, the introduction of population measures to control for biases originating from different country sizes does not change the results. Additionally, multicollinearity could arise between the HDI and the education index since the education index is fully incorporated in the HDI. Again, the omission of the education variable does not change the results. However, the results support the inverted U-shaped effect of urbanization on carbon dioxide emissions.

Table 8: Robustness test using alternative measure of income: human development index

	(1)	(2)	(3)	(4)	(5)
	Total	**Low-Income**	**LowerMiddle Income**	**UpperMiddle Income**	**High-Income**
Gini, Disposable Income	-.60049	-3.9999	-1.2101	-.60838	.28408

	(.27769)	(2.57591)	(.67766)	(.49595)	(.41413)
HDI	6.23879***	3.93492	7.23525**	8.30269**	2.90244
	(1.35388)	(4.57866)	(2.15199)	(2.68379)	(4.36994)
Gini*HDI	-.10054	-3.21394	-2.17232	.44337	2.21126
	(.64674)	(2.38004)	(1.19203)	(1.03112)	(1.79806)
$(HDI)^2$	2.40942***	2.70895	4.71579***	5.44107*	-7.27082
	(.49993)	(1.6035)	(1.05333)	(1.91836)	(3.30866)
Services, value added	-.00196	.00304	-.00199	.00213	-.00228
	(.00274)	(.00674)	(.0029)	(.0044)	(.00381)
Manufacturing, value added	.00691	-.00993	.01965***	-.00088	.00975
	(.00445)	(.01432)	(.00549)	(.00411)	(.00474)
Urbanization	.07925***	.01447	.10487***	.06552***	-.02754
	(.01499)	(.03519)	(.02205)	(.0116)	(.02693)
$(Urbanization)^2$	-.00051***	-.00036	-.00084***	-.00049***	.00023
	(.00011)	(.00041)	(.00018)	(.00009)	(.00017)
Freedom House Index	.01535	-.03603	.00112	.02027	-.00078
	(.00698)	(.01888)	(.01132)	(.00992)	(.01477)
Trade openness	-.00058	.00741**	.0007	-.00113	-.00112
	(.00063)	(.00214)	(.00062)	(.00102)	(.0006)
Education	-2.27389***	-2.47484	-1.1705	-2.38118**	-2.14954**
	(.5905)	(1.37228)	(.72622)	(.73645)	(.682)
Constant	.93918	-1.53374	-.03357	1.70678	5.25736***
	(.97232)	(3.59153)	(1.21079)	(1.18612)	(1.42974)
Observations	3156	271	933	882	1070
Countries	152	16	46	43	47
R-squared	.47366	.56533	.71259	.55052	.48344
Time FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes

Robust standard errors are in parentheses
**** p<.001, ** p<.005, * p<.01*

In conclusion, the robustness tests do not confirm the main results. Therefore, the results must be considered with caution. The reported issues concerning a potential reverse causality and data quality issues, especially for lower income countries, remain present as the sensitivity analysis does not provide strong support for the main results. However, the present identification strategy is potentially not strong enough to control for all potential endogeneity and thus does not provide results that can be interpreted as pure causal effects. Assuming simultaneity not to bias the estimation results, biases could arise from measurement error, which is likely to be the case for lower income countries and from omitted variable biases. Altogether, I suggest considering the results as strong conditional correlations instead of direct causal effects.

6. Conclusions

Combining the most recent data available, this paper contributes to the literature by addressing the relationship between income inequality and carbon dioxide emissions with a focus on how effects differ across countries with different incomes. This analysis supports previous findings obtained by Grunewald et al. (2017) and further puts the results obtained by Wan et al. (2022) into context. Considering the research question of how income inequality affects carbon dioxide emissions, the main finding concludes that the effect is highly sensitive to absolute income levels. More specifically, the overall negative relationship between income inequality and carbon dioxide emissions turns positive for countries that have reached a certain threshold of GDP per capita. Considering the literature on the two predominant hypotheses, the results support the trade-off theory for poorer countries but support the equality hypothesis for wealthier countries. Moreover, the paper provides evidence for the existence of an EKC relationship between income and carbon dioxide emissions. However, both findings can only be confirmed in wealthier countries. Due to data issues, the results do not allow bullet-proof conclusions and results should be considered carefully. We interpret the significant coefficients as indicators for strong conditional correlations rather than pure causal effects. The sensitivity analysis confirms that income inequality rather than inequalities in health or education drive the results because the relationship remains significant for indicators based on economic income inequality only. In contrast, other combined measures of inequality provide non-significant results. The results do not provide strong support for any of the hypothesized transmission channels to shape emission outcomes significantly because, besides urbanizations, the estimates for the whole set of control variables are non-significant.

Several avenues for further research result from these findings. First, the variation of the inequality dimension would provide valuable insights for policy implementation. More research is required to assess whether the effect differs for between-country income inequality or how the extremely unequal distribution of wealth shapes the effect. Second, the control variables included in this study appear as non-significant which rules them out as potential transmission channels. Further empirical assessments are necessary to deepen the understanding of the mechanisms through which income inequality affects carbon dioxide emissions. The inclusion of data for environmental regulations or technological development could provide additional insights. Furthermore, the non-significant findings for poorer countries provide scope for further research. This avenue is closely related to improving data quality for dependent and explanatory variables. Lastly, other econometric techniques or regressions using an external instrumental variable such as massive cash transfers could strengthen the identification strategy and provide further empirical support in favor or against the results obtained.

The equality hypothesis suggests that policies aimed at reducing income inequality can be associated with reductions in carbon dioxide emissions in wealthier countries. The paper provides weak support for this hypothesis for the set of the wealthiest countries. For this finding to translate into distributive policies, policymakers must consider the individual country characteristics, particularly the level of income. Furthermore, caveats concerning tipping points and the urge for a fast response to climate warming question whether policies targeting income inequalities are suitable for reducing emissions. However, the weak identification strategy and the data issues for the sample of low-income countries suggest that further strengthening of the results is required for policy recommendations based on the findings.

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Appendix

Table 13: List of countries

Country
Low-Income
Afghanistan
Burkina Faso
Burundi
Central African Republic
Chad
Ethiopia
Gambia
Guinea
Guinea-Bissau
Liberia
Madagascar
Malawi
Mali
Mozambique
Niger
Rwanda
Sierra Leone
Somalia
Sudan
Togo
Uganda
Lower-Middle Income
Algeria
Angola
Bangladesh
Belize
Benin
Bhutan
Bolivia
Cambodia
Cameroon
Cape Verde
Comoros
Cote d'Ivoire
Djibouti
Egypt
El Salvador
Eswatini
Ghana
Haiti
Kenya
Kiribati
Kyrgyzstan
Laos
Lesotho
Mauritania
Mongolia
Morocco
Myanmar
Nepal
Nicaragua
Nigeria
Pakistan
Papua New Guinea
Philippines
Sao Tome and Principe
Senegal
Solomon Islands
Sri Lanka
Tajikistan
Tanzania
Timor-Leste
Tunisia
Ukraine
Uzbekistan
Vanuatu
Viet Nam
Zambia
Zimbabwe
Upper-Middle Income
Albania
Argentina
Armenia
Azerbaijan
Belarus
Bosnia and Herzegovina
Botswana
Brazil
Bulgaria
China
Colombia
Equatorial Guinea
Fiji
Gabon
Georgia
Grenada
Guatemala
Guyana
Iraq
Jamaica
Jordan
Kazakhstan
Kosovo
Lebanon
Libya
Malaysia
Maldives
Mauritius
Mexico
Montenegro
Namibia
North Macedonia
Panama
Paraguay
Peru
Romania
Russia
Saint Lucia
Saint Vincent and the Grenadines
Serbia
South Africa
Suriname
Thailand
Tonga
Turkey
Turkmenistan
Tuvalu
High-Income
Antigua and Barbuda
Australia
Austria
Bahamas
Chile
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Israel
Italy
Japan
Kuwait
Latvia
Lithuania
Luxembourg
Malta
Nauru
Netherlands
New Zealand
Norway
Oman
Palau
Poland
Portugal
Puerto Rico
Qatar
Saint Kitts and Nevis
San Marino
Saudi Arabia
Seychelles
Singapore
Slovakia
Slovenia
Spain
Sweden
Switzerland
Trinidad and Tobago

Honduras	Costa Rica	Bahrain	USA
India	Dominica	Barbados	United Arab Emirates
Indonesia	Dominican Republic	Belgium	United Kingdom
Iran	Ecuador	Canada	Uruguay

Table 14: Summary statistics by income group

Income group	GDP per capita					Gini				
	Mean	Min	Max	SD	N	Mean	Min	Max	SD	N
Low-income	1485.807	436.72	4344.530	570.049	564	.435	.315	0.583	.056	421
Lower-middle income	4597.778	562.648	15751.722	2672.005	1432	.433	.247	0.649	.075	1117
Upper-middle income	12104.801	996.878	41249.487	5589.624	1431	.417	.211	0.683	.089	1151
High-income	38558.351	4589.581	120647.823	19820.314	1475	.322	.162	0.518	.07	1302

Income group	Carbon dioxide emissions per capita					Total greenhouse gas emissions per capita				
	Mean	Min	Max	SD	N	Mean	Min	Max	SD	N
Low-income	.12617	.02	0.532	.0885	609	3.45673	-.699	19.568	3.31259	567
Lower-middle income	1.19132	.024	15.115	1.67257	1467	5.69698	-5.518	70.266	8.58349	1350
Upper-middle income	3.69393	.148	17.319	2.97738	1449	8.23062	-50.487	86.991	9.6914	1350
High-income	10.93556	1.259	68.724	8.50642	1508	12.22313	-8.667	51.838	8.54557	1403

Income group	Methane emissions per capita					Nitrous oxide emissions per capita				
	Mean	Min	Max	SD	N	Mean	Min	Max	SD	N
Low-income	1.24565	.187	7.232	1.12996	567	.77486	.124	8.239	1.44532	567
Lower-middle income	1.56982	.106	36.392	2.81162	1350	.54795	0	5.021	.76046	1350
Upper-middle income	2.60188	.179	23.12	3.737	1350	.53705	0	6.531	.65931	1350
High-income	2.04045	0	11.098	2.22668	1404	.76367	0	6.13	.83572	1404

Table 15: Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) CO2 per capita	1	0	0	0	0	0	0	0	0	0	0	0	0	0
(2) GHG per capita	.596	1	0	0	0	0	0	0	0	0	0	0	0	0
(3) Methane per capita	.277	.694	1	0	0	0	0	0	0	0	0	0	0	0
(4) NOX per capita	.112	.453	.488	1	0	0	0	0	0	0	0	0	0	0
(5) GDP per capita	.915	.55	.234	.135	1	0	0	0	0	0	0	0	0	0
(6) Gini (post-tax)	-.509	-.21	.006	-.132	-.497	1	0	0	0	0	0	0	0	0
(7) Gini (pre-tax)	.008	.125	.107	.183	.102	.432	1	0	0	0	0	0	0	0
(8) Population	.034	-.058	-.095	-.066	-.051	.058	-.039	1	0	0	0	0	0	0
(9) Services VA	.443	.146	-.075	-.008	.566	-.196	.223	-.08	1	0	0	0	0	0
(10) Manufacturing VA	.238	.059	-.021	.066	.207	-.085	-.01	.173	-.083	1	0	0	0	0
(11) Urbanization	.76	.464	.165	.195	.797	-.398	.089	-.065	.449	.22	1	0	0	0
(12) FHI	.379	.163	-.007	.205	.472	-.312	.234	-.084	.622	-.031	.355	1	0	0
(13) Trade openness	.323	.227	.039	.009	.345	-.212	-.096	-.191	.222	.06	.233	.134	1	0
(14) Education	.798	.436	.193	.196	.826	-.538	.076	-.04	.567	.166	.666	.566	.28	1