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Investigating the Carbon Leakage Effect on the Environmental Kuznets Curve Using Luminosity Data

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This paper studies the effect of carbon leakage on the environmental Kuznets curve (EKC) using satellite nighttime light data. I show that nighttime lighting is an important variable for estimating carbon dioxide emissions that is superior to other existing indicators and covers all countries in the world. I find evidence of an inverted-U shaped relationship between light and, thus, greenhouse gas emissions and income, with a turning point at approximately US $50,000. However, the relationship is primarily driven by changes in the structure of international trade, implying strong carbon leakage effects. Consequently, environmental regulations that become operative in only one part of the world may fail without global coordination.

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1 Introduction

Beginning with the Industrial Revolution, the working structure has shifted from farming towards manufacturing, and people have increasingly moved into cities to find employment in the second or even third sectors. This change came and still comes with a variety of positive and negative side effects. On the one hand, industrial production and economic and material prosperity has been growing rapidly. People suffer less from famine and medieval diseases. On the other hand, industrial production requires as input factors renewable and non-renewable resources, such as wood or oil, which come with undesirable byproducts, such as nitrogen oxides or carbon dioxide. Greenhouse gases that for the most part emerge as side products of burning fossil fuels in combustion engines accumulate in the atmosphere and cause a rise in the earth's surface temperature. The climate change is said to cause species extinction, droughts, flooding and other natural disasters (IPCC (2014), Stern (2007)). Consequently, it is safe to say that environmental degradation increases as income does. If the relationship between income and degradation correlates positively over the whole field of income, economic growth may be seen as having a detrimental effect on the environment and, thus, as a threat to sustainable development.

The existence of the environmental Kuznets curve (EKC) may put things right. The general assumption of this theory is that increasing income comes with more severe pollution and degradation, but after reaching a maximum turning point, economic growth correlates negatively with environmental damage. Consequently, passing the income threshold, which marks the split of correlation, may be a way to improve global environmental conditions. Although many studies on the carbon dioxide EKC have been conducted, it remains questionable whether there is an environmental Kuznets relationship between carbon dioxide and income at all. Previous studies have been based on small country samples (<=50) and have suffered from severe methodological problems, such as sample selection biases towards developed countries. Consequently, focusing on high-income countries may lead to the assumption that an EKC exists. However, highly developed countries have the potential to export greenhouse gas emissions by relocating production to low- and middle-income countries. According to the recent carbon leakage literature (see Felder and Rutherford (1992), Paltsev (2001), Babiker (2005)), this fact may be the cause of the descending part of the EKC. In addition, Stern et al. (1996) argue that existing estimates are biased by simultaneity, the deficient quality and availability of data or by the willful neglect of international trade that comes with carbon leakage.

There are two main contributions of this study. First, I avoid the problems mentioned by Stern et al. (1996) using a relatively new figure in terms of environmental degradation. The figure I use comes with a high data quality and does not suffer from simultaneity in single-equation ordinary least-square regressions: manmade nighttime lighting. Nighttime lighting is a crucial figure in the discussion on the existence of a carbon dioxide EKC, for many reasons. Studies indicate that nighttime lighting is highly correlated with ecological figures such as carbon dioxide emissions or the non-renewable part of emergy, or it serves as an important input factor in determining high-resolution emission grids (see Coscieme et al. (2013), Doll et al. (2000), Rayner et al. (2010), Ou et al. (2015)). In addition, in all World Bank income categories, I find

that light emission per capita is highly correlated with carbon dioxide equivalent emissions, primary energy use and electricity consumption. Thus, manmade nighttime lighting can be seen as an appropriate figure to measure the carbon dioxide emissions even in less developed countries for which no reliable emission data are available. Furthermore, using nighttime light instead of directly reported national carbon dioxide emissions is advantageous because many countries have incentives to manipulate their total emissions, which may lead to biased results in the context of the carbon dioxide EKC. These features allow for the analysis of a full set of countries (>160) and to avoid selection bias. Second, I introduce an efficiency figure defined as the ratio of income and light emissions—called EFFICIENCY—which allows for the investigation of the effects of international trade flows on national light and, thus, carbon dioxide equivalent emissions. By doing so, I can empirically examine the carbon leakage effect on the EKC. This empirical approach is of high relevance because it complements the general equilibrium-driven carbon leakage literature.

Because of some satellite calibration problems described later, I cannot use fixed effects panel-data models to estimate the EKC coefficients. Therefore, I use ordinary least square (OLS) models, including several fixed effects to achieve a slightly intercalibration of the satellite settings. Furthermore, trade flows cannot be included in the OLS EKC regression models because the ceteris paribus interpretation of the coefficient would fail otherwise. A solution to this problem is the estimation of EFFICIENCY using import and export trade flows and country-fixed effects. The results can be used to obtain country-level averaged light and, thus, carbon dioxide emissions conditional on the absence of trade.

My results are the following: To ensure that an EKC relationship between light per capita and, thus, carbon dioxide equivalent emissions and income per capita does exist, I test the EKC hypothesis in two different ways. I control the extent to which there is an inverted-U relationship between the per capita income and per capita light emission, and I examine whether the income/light ratio is driven by each nation's sectoral structure. I find evidence that there is an inverted-U shape, as seen in Figure 1. Depending on the regression structure, I find maximum turning points at less than $51,000 which is exceeded by more than 200 observations. In addition, the income/light ratio improves if the share of value added by the agricultural or service sector increases. This finding supports the EKC hypothesis.

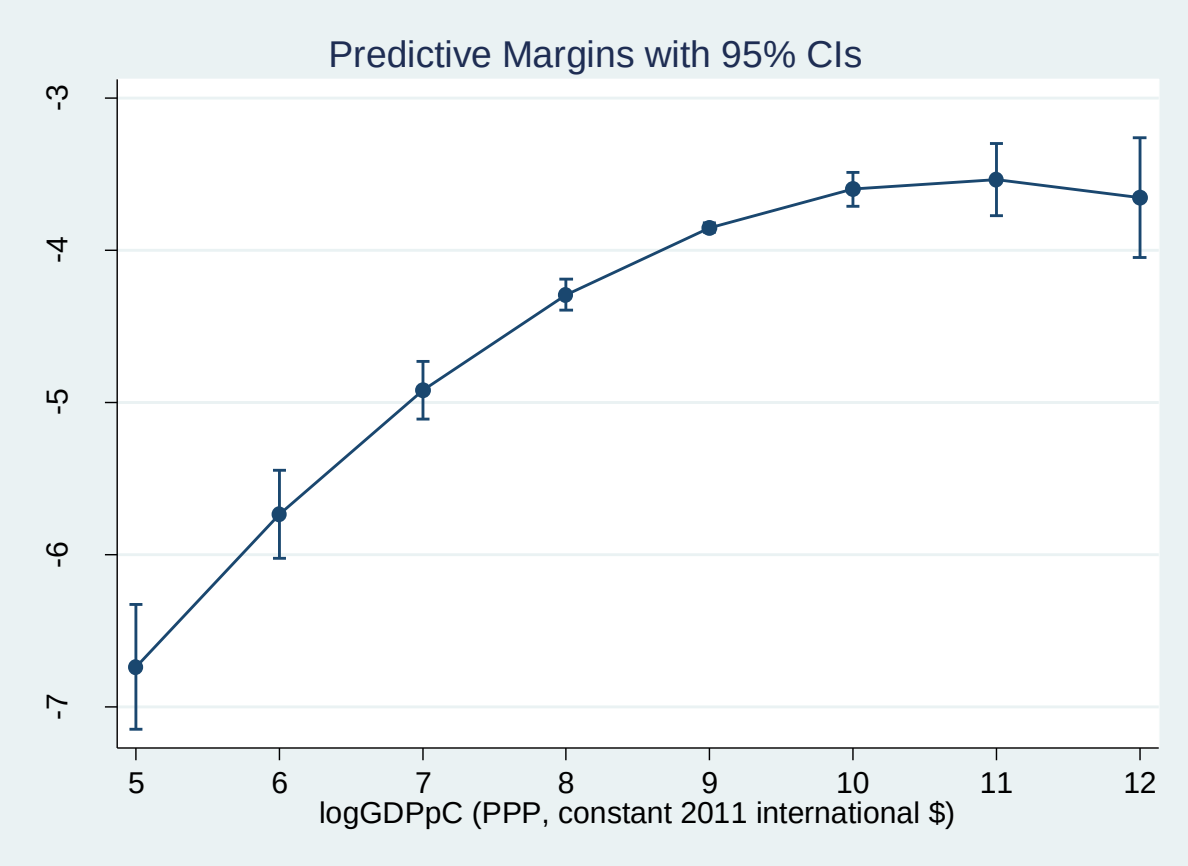

Figure 1: Environmental Kuznets Curve - Predictive Margins

Nevertheless, it remains questionable to what extent the EKC is just a result of international trade. It is possible that comparatively rich countries relocate their dirty production to low-income countries and import those goods afterwards instead of producing them on their own. Thus, I take a closer look at the effect of trade on EFFICIENCY and estimate a new relationship between income and light, controlling for the absence of trade. The results differ dramatically from the originally inverted-U shape. The quadratic term turns slightly insignificant, and I receive maximum turning points at incredibly high income levels of more than US $400,000. Therefore, I assume that the EKC hypothesis has to be rejected if I control for carbon leakage.

The remainder of this paper is structured as follows. In section 2, I take a closer look at the environmental Kuznets hypothesis and present the results of previous studies. Moreover, I note that manmade nighttime lighting is a suitable proxy for greenhouse gas emissions. The data used as basic input are illustrated in section 3. Section 4 examines the EKC hypothesis in the way of the traditional inverted-U shape and looks at the sectoral effects on EFFICIENCY. The effect of trade and carbon leakage on the EKC is the point of concern in section 5. Section 6 concludes.

2 The environmental Kuznets hypothesis and the advantage of light data

The following section serves as a theoretical introduction by explaining the environmental Kuznets hypothesis, and it shows empirical evidence and its misleading assumptions in terms of the EKC approach. Additionally, I explain why nighttime lighting is a suitable proxy for environmental degradation that can be used to test the hypothesis.

2.1 EKC – Theory and existing empirical evidence

The well-known Kuznets (1955, 1963) theory states that there is an inverted-U relationship between income and inequality. A modification of this theory regarding ecological matters is the environmental Kuznets curve (EKC). I put the following reasoning behind the EKC theory in a manner analogous to Panayotou's (1993).

At low levels of income, there is only minor economic activity. The depletion of resources and the amount of pollution and waste is limited by the degree of development. Thus, resource regeneration can catch up with depletion, and the environment's ability to recover exceeds the production of waste. Higher levels of income are linked with increasing economic activity, which comes with two effects. First, agriculture is intensified to satisfy the growing demand. Second, there is a change in the economic structure. Industrialization takes off and workforces change from the first to the second sector. Both processes come with a higher degree of resource depletion and waste generation. Regeneration is not able to catch up with depletion because nature's rate of recovery is not as high as the rate of waste generation; therefore, pollution and degradation are proceeding. As the level of income continues to grow, this process continues until another structural interruption occurs that marks the maximum turning point of the environmental Kuznets. This change compromises three further steps of development. Economic structure shifts from industrial production towards services, production technology becomes more efficient, and public awareness regarding environmental issues increases. What follows is that if the argumentation holds, I will find an inverted-U shape regarding the relationship between the degree of environmental damage and the advance of the economic structure, represented by the average level of income.

The empirical evidence of the inverted-U relationship is mixed. Cole et al. (1997) analyze the degradation-income relationship for a variety of pollutants, energy use and municipal waste. The number of regions and the time period under consideration vary slightly. On the one hand, they find robust EKCs for carbon monoxide, nitrogen dioxide, sulfur dioxide and suspended particulate matter (SPM), which are characterized by maximum turning points at low incomes (e.g., sulfur dioxide: US $5,700) and small standard errors. However, on the other hand, they are not able to figure out reliable turning points for carbon dioxide, total energy use or municipal waste. Indeed, they observe a monotonic increase in carbon dioxide with income. Notably, the chlorofluorocarbon (CFC)-income distribution shows a special feature. Due to the 1987 Montreal Protocol, most nations almost immediately cut their CFCs and halon consumption because of their effect on ozone depletion. The consequence was a tunneling of the EKC. A new EKC with a much flatter trend was achieved.

Shafik and Bandyopadhyay (1992) find similar results regarding the EKC behavior of air pollutants and show that there is a linear relationship between income and carbon dioxide. It is

worth noting that they find a carbon dioxide elasticity of 1.6, which indicates that a one-percent increase in income comes with a 1.6-times strengthened increase in carbon dioxide emissions. In addition, they investigate changes in forest areas and rates of deforestation. Although high investment rates seem to worsen deforestation, both ecological measures tend to improve as income rises. Surprisingly, the access to safe water and the degree of urban sanitation immediately increase as income grows. Thus, there is a distinct positive effect of development.

Panayotou (1993) investigates the per capita emissions of nitrogen oxides, sulfur dioxide, SPM and analyses the rate of deforestation. Each of the four degradation criteria follows an inverted-U shape. The field of maximum turning points ranges from US $820-$5,500.

The explanations for and causes of a biased formation or partial absence of the inverted-U relationship are numerous. Stern et al. (1996) mention crucial aspects of hypothesis testing within the context of the EKC. They argue the theory of the EKC is based on the assumption of an economy in that production is independent of environmental conditions. Therefore, even high levels of pollution or resource depletion do not have harmful effects on production possibilities. Thus, income maximization seems to be a solution to cure all environmental issues. In fact, there is feedback from environmental conditions towards production possibilities, particularly if exhaustible resources are taken into account. A shift in resource extraction towards early generations for the sake of rapid growth may even lead to over extraction and cause a mid- and long-term decrease in income (see Solow (1974)). Consequently, the authors caution that assuming a unidirectional influence of economy on environment is not a suitable way to test the EKC hypothesis because simultaneity causes inconsistent estimates in single-equation ordinary least-square regressions.

Furthermore, they note that most studies either assume that international trade has no effect on the degradation income relationship or fully neglect the influence of trade. This is problematic in two ways. First, because of comparative cost advantages, developing countries focus on the production of labor and resource-intense goods, whereas developed countries specialize in capital-intense goods. Because labor and resource-intense production is usually linked with higher ecological damage, the inverted-U shape may be a result of highly developed countries' 'export' of their degradation to developing countries. Second, this effect can be enforced by environmental legislation in developed countries that favors the 'export' of pollutants and depletion towards less developed countries that have no legal restrictions. Thus, it is questionable whether there is a positive effect of growth on the environment on global scale at all.

A third criticism regards the data. Stern et al. (1996) argue that particularly in developing countries, data on environmental problems such as carbon dioxide-equivalent emissions are of poor quality. Consequently, the consolidation of data from different sublevel aggregations may cause heteroscedasticity. Additionally, if data are available, they are often unsuitable for testing the EKC hypothesis because the effects measured by the data cover only parts of the total effect on degradation. This argument becomes clear if one considers the difference between stock and flow data. Obviously, even in cases of an existing inverted-U relationship between flow and income, it does not automatically lead to the same U shape if the stock is considered instead.

This fact is of high importance because stock is the real cause of environmental pollution and degradation.

2.2 Light as a degradation figure

One way to avoid the arising problems is the use of manmade nighttime lighting as a measure of carbon dioxide-equivalent emissions. Its superiority to other measures arises from many points.

First, the usefulness of light emissions as a proxy for carbon dioxide emission has already been shown in the literature. Whereas Doll et al. (2000) figure out that carbon dioxide emissions have a significantly high correlation with the total lit area of countries, Ou et al. (2015) use the local light emissions to estimate a global high-resolution fossil fuel combustion carbon dioxide map. In addition, Coscieme et al. (2013) investigate the light-emergy relationship. Emergy is a solar energy equivalent that can be divided into a renewable and a non-renewable component. Their results are the following. The sum of lights within each country is highly correlated with the non-renewable component but shows no alliance to the renewable part. Similarly, I find that light emissions per capita are highly positively correlated with primary energy use (kg oil equivalent per capita) in all World Bank income categories. Furthermore, carbon dioxide equivalent emissions (tons per capita) and electricity consumption (kWh per capita) are also positively correlated with light emissions, although they suffer from low significance in the high-income OECD and high-income non-OECD categories, respectively (see Table A 1). Therefore, it is plausible to assume that the intensity of nighttime lighting is an appropriate proxy for real carbon dioxide-equivalent emissions.

Second, it can be assumed that there is no direct feedback from lighting towards production possibilities. This absence of simultaneity allows for single-equation regression without risking inconsistent estimates.

Third, the data on nighttime lighting are available on high resolution (almost) all over the world. Thus, I do not risk errors that arise from different sublevel aggregations. In addition, many countries have incentives to manipulate their total emission reports, which may lead to biased results. Using comparatively unbiased light data, I also avoid errors that come from purposely skewed carbon dioxide-emission reports. Consequently, I have reliable data for a full set of countries, including developing countries.

2.3 Income/light ratio – state of knowledge

Whereas most economic literature estimates a linear income-light ratio to use nighttime lighting as proxy for estimating gross domestic product (GDP) at the national or subnational scale (Elvidge et al. (1997), Chen and Nordhaus (2011), Lessmann and Seidel (2015)), its constituents (Wu et al. (2013)), or its growth rates (Henderson et al. (2012)), less effort has been spent on extending the perspective beyond the linear light-income relationship.

Elvidge et al. (2013) take a closer look at the correlations between sum of lights (SOL) and GDP and SOL and population. They find an Antipole group that consists of twelve countries where both correlation coefficients are negative, and they reason the appearance of this group is shaped by improved lighting efficiency and by local regulation, which are designed to reduce nighttime light pollution. However, Gallaway et al. (2009) find evidence of correlation between

economic activities and light pollution. They measure light pollution as the portion of manmade light in the total brightness of the sky at night. Their logit-regression model provides the first evidence of a non-linear relationship between GDP and light pollution, which is consistent with demand- and supply-side factors that may yield an EKC. Wu et al. (2013) provide additional evidence for the existence of a lighting EKC. They figure out that there is a quadratic relationship between light consumption per capita and GDP per capita, but they do not perform further analyses. Consequently, the EKC regarding light as a measure of environmental degradation needs further investigation to make a statement on its existence and influencing factors.

3 Data

Satellite nighttime imagery

Using satellites is the only appropriate way to detect visible nighttime lighting on high resolution. Until recently, two types of satellite sensors have existed. The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument, carried by the Suomi National Polar Partnership (SNPP) satellite, has been in service since 2011. It is superior to the Operational Linescan System (OLS), which is flown by the US Air Force Defense Meteorological Satellite Program (DMSP), in terms of resolution, accuracy, and frequency of measurements, and it does not suffer from saturation. Nevertheless, I use the DMSP OLS data because of the existence of 34 satellite years, covering the years 1992-2013, which give us a wide band of observations.[2]

US Airforce weather satellites circle the earth within 102 minutes, recording the light intensity of each location on a 30 arc-second grid between 8:30 and 10:00 pm. Hence, resolution increases with latitude. Because the imagery spans a longitude of -180 to 180 degrees and a latitude of -65 to 75 degrees, most land area—except some small regions of Canada and Russia and some tiny islands—is observed (see Figure 2).

[2] Recently, there have also been unsaturated radiance-calibrated DMSP OLS products, but only a few images are available at this time.

Figure 2: Satellite imagery range

Their low light-imaging limit is $5 \cdot 10^{-10} W/cm^2/sr$, which allows for detecting even less lit areas. Before distributing the raw DMSP OLS data to public, several adjustments—depending on the type of product—are performed. Because I use Stable Lights, the following explanation focuses on the processing of this type of imagery. Scientists at the National Oceanic and Atmospheric Administration (NOAA) and National Geophysical Data Center (NGDC) remove, among other things, ephemeral events and cloudy observations based on identification by thermal-band data and surface-temperature grids. Sunlit data and glare are excluded based on information on the solar-elevation angle. Moonlit data and auroral activities are also removed. Consequently, the imagery contains only manmade light. In contrast to some other studies, I keep light emitted by gas flares in the data because it is unavoidably linked with environmental effects. All valid observations of each 30 arc-second pixel are averaged on a calendar-year basis, producing a satellite-year dataset.

The light intensity of each grid pixel is reported as a 6-bit digital number (DN) ranging between 0 (no light, rural areas) and 63 (densely populated and rich areas). Unfortunately, because they report censored integer values, the DMSP OLS data do not conform to the true radiance emitted on the earth's surface. Thus, two problems arise that have previously been discussed in detail in the literature. Due to sensor saturation, the data are top coded at 63. This censoring is problematic particularly at regional scale because it is not possible to distinguish lighting intensity in large cities that do have significant socioeconomic and ecological differences, such as Berlin and Beijing. Therefore, I assume that light is not a suitable measure to detect ecological effects on a regional scale, and consequently, I focus on country-level data in my analysis. Because less than 0.1 percent of all lit pixels are top coded, estimation errors resulting from censoring can be neglected at the country level. A second aspect that needs to be considered is the absence of on-board calibration and the existence of different sensor technologies. Satellites are calibrated on earth before take-off, and gain settings are not recorded in data. Furthermore, sensor settings might vary over time because of aging effects. Thus, it is

not possible to simply compare the DN for two different satellites. Although Elvidge et al. (2013a) provide a method for inter-calibrating satellite data, I refrain from doing so because this method comes with severe accuracy problems in rural areas. Therefore, I use satellite-year dummies instead.

National Boundaries

National boundaries are taken from the Global Administrative Areas (GADM) project. It is a spatial database that contains the location of the world's administrative areas. Administrative areas are provided at different administrative levels and contain additional information regarding size in square kilometers (sq km), population density and affiliation to certain income groups according to World Bank data. I use the level-0 sub-division, which equals the country level in my analysis, to minimize errors caused by top coding.

To process satellite data and national boundaries, I use QGIS Desktop 2.8.2. An additional plugin, called Zonal Statistics 0.1, is used to determine the sum of lights and the mean nighttime light intensity within each country.

After processing the data, I remove all countries and administrative subunits smaller than 1000 sq. km, except Malta, Bahrain, Singapore and Liechtenstein. Furthermore, I exclude countries with less than 100.000 inhabitants and a sum of lights smaller than 1000. Finally, the light dataset contains 181 countries. Most of them are available for every satellite-year observation.

Economic and ecological data

To test the usual EKC hypothesis and other factors that may influence the relationship between income and light (and, thus, the carbon dioxide-equivalent emission), it is of high relevance to have reliable income and trade data and a variety of other ecological figures. The World Bank provides the World Development Indicators (WDI) database, which includes several income measures and a variety of other economic and ecological data, such as sectoral structure, carbon dioxide emissions or primary energy use on the country level. Most figures are calculated on an annual basis. Although there may be high deviation in data accuracy, particularly for less developed countries, all economic and ecological data in this paper are taken from this database.

4 Existence of the environmental Kuznets curve

In this section, I provide evidence of the existence of the EKC. To do so, I first investigate the general income-light relationship, which is assumed to be inverted-U shaped. Furthermore, I analyze the income/light ratio because the EKC hypothesis suggests that this ratio depends on the state of economic development, and it is of high relevance in the context of carbon leakage.

4.1 General Setup

To make statements on the existence of the EKC, it is appropriate to look at the traditional income-light relationship in the first step. As an income measure, I use gross domestic product per capita (GDPpC) in constant 2011 US-$, purchasing power adjusted. To get an idea of the total amount of light emitted per capita and to avoid huge problems that arise from different

pixel sizes, I calculate the following figure:[3] I multiply the average DN within a country with its size and divide the results by the total population. From now on, I simply call this figure "LIGHT". Because GDPpC and LIGHT span wide ranges, I logarithmize both figures. This procedure also helps minimize the risk of heteroscedasticity but unfortunately does not avoid heteroscedasticity in the end. A glance at the simple graphical mapping of all logGDPpC and logLIGHT observations provides first evidence of the existence of the EKC (see Figure 3).

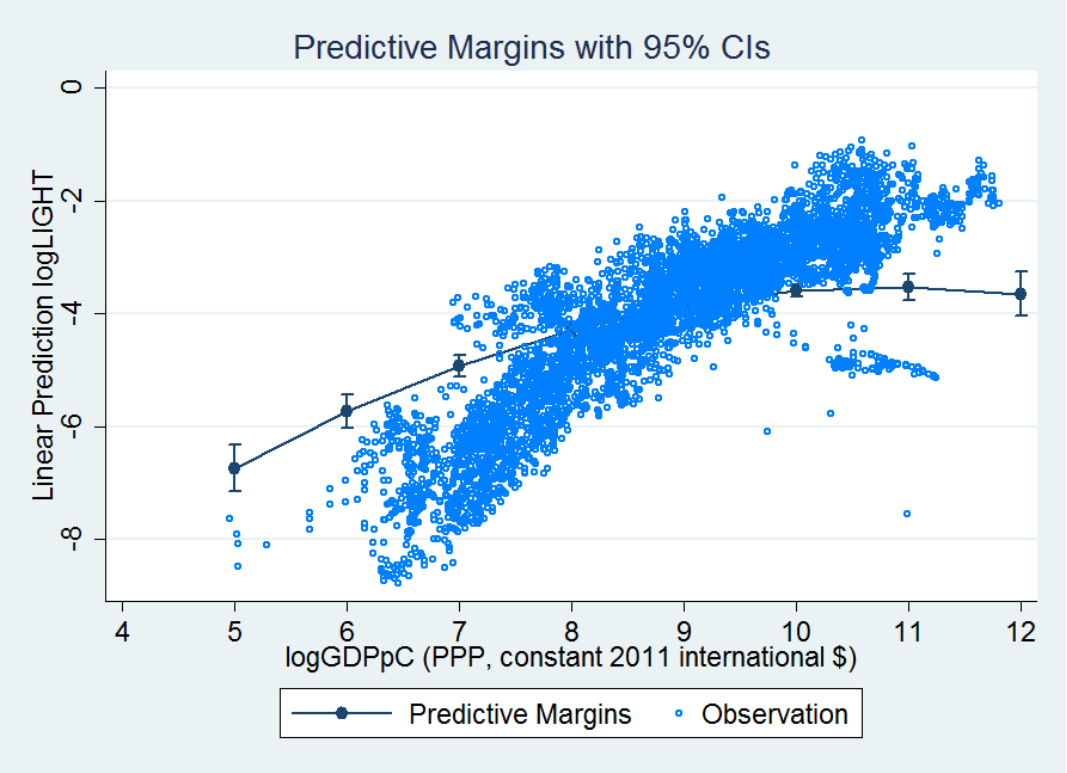

Figure 3: Environmental Kuznets curve in raw data vs. predictive margins[4]

In addition to the graphical analysis, I estimate the following pooled linear regression model:

$$logLIGHT_{i,t} = \beta_0 + \beta_1 logGDPpC_{i,t} + \beta_2 logGDPpC_{i,t}{}^2 + \beta_3 logGDPpC_{i,t}{}^3 + \theta_i + \mu_{k,t} + \epsilon_{i,t} \quad (1)$$

where θ_i (i=1,2,…,I) is the time-invariant country-fixed effect, $\mu_{k,t}$ is the satellite/year/satellite-year fixed effects of satellite k (k=1,2…,K) in year t (t=1,2,…,T), and $\epsilon_{i,t}$ is the error term. I calculate robust standard errors because Breusch-Pagan tests indicate the existence of heteroscedasticity. I refrain from reporting fixed-effects panel-data models, for two reasons. First, the results obtained from fixed-effects models are almost identical to the pooled model. Second, the overlap of nighttime imagery produced by two different satellites simultaneously

[3] I assume that pixel sizes are identical within each country. This is not certainly true, but errors are negligible.
[4] Estimated by equation (1), column (4).

allows for a slightly implicit intercalibration using satellite/satellite-year fixed effects.[5] The model contains 5.508 observations. Estimates of different specifications of the linear model are reported in Table 1.

In column (1), I perform a simple model in which I regress the light figure on the income per capita in linear and quadratic terms. Despite using robust standard errors, both coefficients of income are statistically significant. The coefficient signs are positive for the linear term and negative for the quadratic term and, thus, imply the expected inverted-U shape. The maximum turning point is located at a per capita income of approximately US $143,000. Column (2) additionally considers country-fixed effects, which are important because they serve as a criterion for the level of economic development. This specification yields an R-squared of 0.97 and coefficients that are also statistically significant. It is worth noting that the estimated maximum turning point is still a very high level of approximately US $121,000. Columns (3)-(5) add step-by-step satellite, year and satellite-year fixed effects. Consequently, I implicitly control for different satellite-sensor calibrations and technological progress in lighting efficiency. I do not find a noticeable increase in R-squared, and all estimated coefficients are the same size, implying a maximum turning-point range of US $32,000 to US $51,000. Because this point is exceeded by at least 211 observations, I conclude that the descending part of the EKC indeed exists. As a robustness check, I control for a third-order term of the income measure in column (6). I find that all income coefficients turn insignificant. This result confirms the existence of an inverted-U shape.

Although I aggregate light data on the country level, one could argue that the inverted-U shape is caused by satellite-sensor saturation and is not a consequence of the EKC hypothesis. Although Wu et al. (2013) use different light figures, they prove this argument wrong. They exclude observations where saturated areas are more than 0.5% and 0.01%, respectively, but nonetheless find an inverted-U shape. To verify the EKC, the following section provides a different view on the light-income relationship.

[5] I am aware of the fact that this procedure also increases the coefficient´s variation.

Table 1: Regression results of general EKC setup

	(1) logLIGHT	(2) logLIGHT	(3) logLIGHT	(4) logLIGHT	(5) logLIGHT	(6) logLIGHT
logGDPpC	4.155***	2.168***	2.115***	2.035***	2.035***	1.674
	(32.60)	(11.27)	(12.02)	(12.20)	(12.22)	(1.80)
logGDPpC²	-0.175***	-0.0926***	-0.102***	-0.0938***	-0.0938***	-0.0502
	(-24.70)	(-8.55)	(-10.01)	(-9.53)	(-9.56)	(-0.44)
logGDPpC³						-0.0017
						(-0.38)
Country FE	NO	YES	YES	YES	YES	YES
Satellite FE	NO	NO	YES	YES	YES	YES
Year FE	NO	NO	NO	YES	YES	YES
Satellite-year FE	NO	NO	NO	NO	YES	NO
Constant	-26.84***	-16.82***	-16.13***	-16.02***	-16.02***	-15.04***
	(-47.4)	(-19,95)	(-21.03)	(-21.79)	(-21.84)	(-5.98)
#Observations	5508	5508	5508	5508	5508	5508
R-squared	0.7987	0.9714	0.9765	0.9797	0.9804	0.9797

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.2 EFFICIENCY

In addition to the traditional EKC perspective, I investigate the ratio of income and lighting. According to the EKC hypothesis, environmental degradation depends on the state of economic development and, thus, on the share of each sector in overall production. If the EKC holds, I assume that agricultural production and services are less energy and light intense than manufactural production. To test this assumption, I take a closer look at the logarithmized ratio of income and light (log(GDPpC/LIGHT)). Because this ratio describes the productivity of light, I call this figure EFFICIENCY. EFFICIENCY is supposed to be high in countries with a high share of the agricultural sector and/or the service sector in GDP, and it will be low if most production is located in manufacturing industries. Consequently, I expect the EFFCIENCY-income ratio to be (inverted-)U shaped because particularly in highly and low developed countries, the share of agriculture and/or service in GDP is comparatively high.

In the first step, I draw an EFFICIENCY boxplot for each income category according to the World Bank (see Figure 4). Because both the medians and the 50% quintiles follow the expected inverted-U shape, I further analyze the effect of economic sectors on EFFICIENCY because it is of high relevance in the context of the EKC hypothesis and carbon leakage.

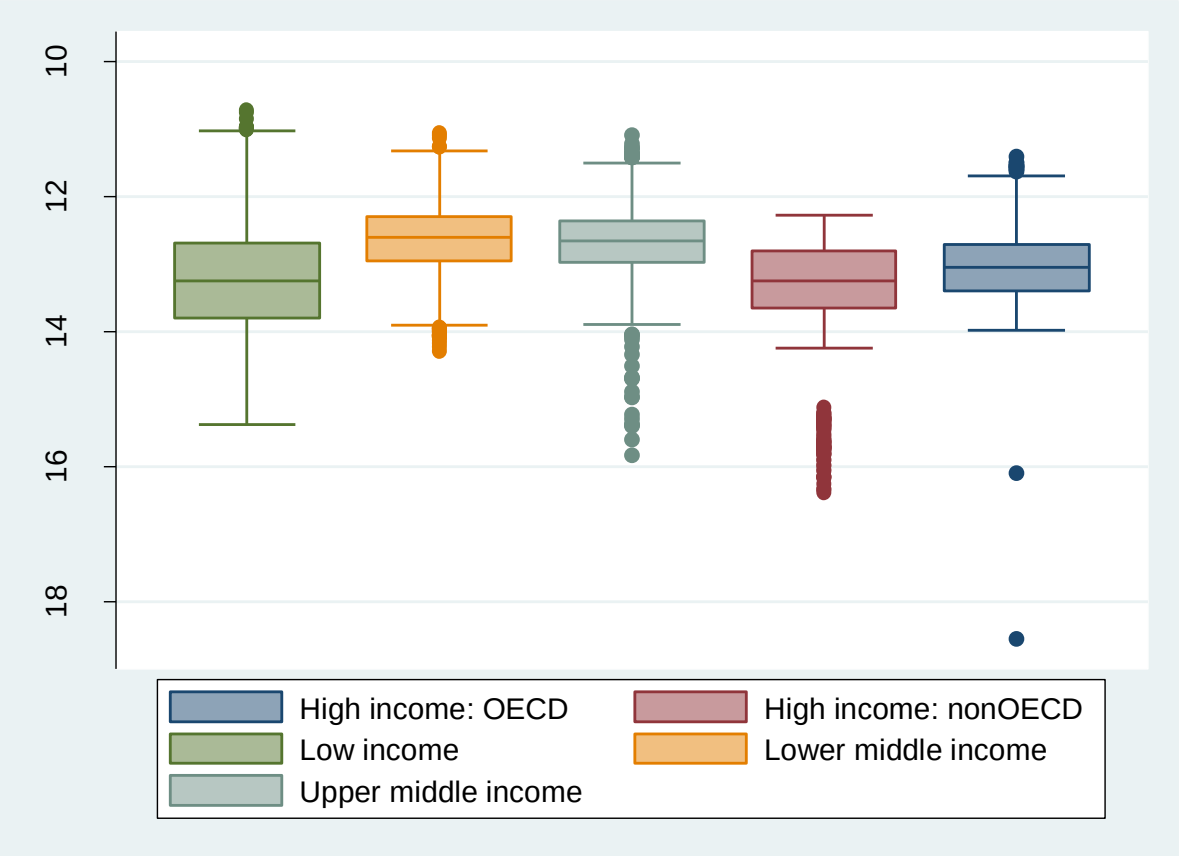

Figure 4: EFFICIENCY boxplots[6]

[6] The scale is inverted to illustrate the inverted-U shape.

To do so, I run the following pooled linear regression models:

$$EFFICIENCY_{i,t} = \gamma_0 + \gamma_1 AG_{i,t} + \gamma_2 SV_{i,t} + \theta_i + \mu_k + \eta_t + \epsilon_{i,t} \quad (2)$$

$$EFFICIENCY_{i,t} = \delta_0 + \delta_1 M_{i,t} + \theta_i + \mu_k + \epsilon_{i,t} \quad (3)$$

where $AG_{i,t}$ is the share of agricultural production in GDP [%] of country i (i=1,2,…,I) in year t (t=1,2,…,T), $SV_{i,t}$ is the share of value added by services in GDP [%], $M_{i,t}$ is the percentage of manufacturing in total value added, θ_i is the country-fixed effects, μ_k is the satellite-fixed effects of satellite k (k=1,2…,K), η_t is the year-fixed effects, and $\epsilon_{i,t}$ is the error term. The equations contain 5050 (2) and 4835 (3) observations, respectively. I again use robust standard errors because of heteroscedasticity in the data.

The regression results of equation (2) are reported in Table 2. In column (1), I refrain from using any fixed effects, and I add satellite-fixed effects and year-fixed effects stepwise in columns (2) and (3). The coefficients of share of service and share of agriculture are both positive, statistically significant and almost of the same magnitude in all three regressions. The interpretation of the coefficients is not straightforward. Because I exclude the share of value added by manufacturing in equation (2), I can say that, e.g., substituting one percent of manufacturing value added by one percent of agriculture value added increases EFFICENCY by 0.014. In column (4), I also control for country-fixed effects. Coefficients differ slightly in significance in comparison to the first three runs. This finding is conclusive because sectoral effects are captured by country-fixed effects, and the variation of sector shares within each country is low. Nevertheless, even this setting supports my hypothesis that service and agriculture are more light and, thus, *more* carbon dioxide efficient than manufacturing.

Equation (3) is used as a robustness check of equation (2). The results are reported in Table 3. I also control for satellite-, year- and country-fixed effects. In all regressions, the coefficient of the share of manufacturing is negative and statistically significant. This finding confirms the results of equation (2).

This analysis of EFFICINCY provides additional evidence for the existence of the EKC in terms of light. I conclude that manufacturing production is comparatively light and, thus, emission intense, whereas agriculture and services are more efficient. However, I still do not know anything about the effect of trade on the light-income relationship. Consequently, the following section takes a closer look at trade between high- and low-income countries.

Table 2: Effect of agriculture and service on EFFICIENCY

	(1) EFFICIENCY	(2) EFFICIENCY	(3) EFFICIENCY	(4) EFFICIENCY
Share of Service	0.00522***	0.00505***	0.00514***	0.00433***
(% of GDP)	(5.38)	(5.27)	(5.39)	(4.29)
Share of Agriculture	0.0133***	0.0138***	0.0140***	0.00323*
(% of GDP)	(14.67)	(15.22)	(15.57)	(2.36)
Satellite FE	NO	YES	YES	YES
Year FE	NO	NO	YES	YES
Country FE	NO	NO	NO	YES
Constant	12.45***	12.44***	12.53***	12.98***
	(208.05)	(180.00)	(143.99)	(125.34)
#Observations	5050	5050	5050	5050
R-squared	0.0447	0.0637	0.0855	0.9168

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Effect of manufacturing on EFFICIENCY

	(1) EFFICIENCY	(2) EFFICIENCY	(3) EFFICIENCY	(4) EFFICIENCY
Share of Manufacturing (% of GDP)	-0.0154***	-0.0154***	-0.0152***	-0.00806***
	(-10.42)	(-10.43)	(-10.37)	(-5.51)
Satellite FE	NO	YES	YES	YES
Year FE	NO	NO	YES	YES
Country FE	NO	NO	NO	YES
Constant	13.17***	13.26***	13.38***	13.42***
	(540.38)	(305.07)	(198.97)	(186.53)
#Observations	4835	4835	4835	4835
R-squared	0.0240	0.0394	0.0601	0.9165

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5 Influence of Trade

It remains questionable whether the inverted U-shape is just a consequence of high-income countries' relocation of light and, thus, energy-intense production to low-income countries. This 'export' of pollution is known in the context of carbon leakage. There, it is assumed that environmental policies cause leakage in two ways. First, lower world prices of energy that come from decreasing demand in regulative countries cause a substitution of carbon dioxide-intense energy towards non-regulative countries. Second, energy-intense production is relocated to non-regulative countries that export those goods back to regulative countries. Because the literature finds leakage rates between 10 and 130% (see Paltsev (2001), Felder and Rutherford (1992), Babiker (2005)), using general equilibrium models, I have to investigate trade flows between countries of different income levels in terms of EFFICIENCY and control for trade in the traditional EKC perspective.

Effect of trade on EFFICIENCY

Due to different origins of light—either the consumption or production of goods—the effect of trade on EFFICIENCY is ambivalent and needs explanation. If trade has no effect on the EKC because the light intensity of imports equals the intensity of exports, I expect, on the one hand, that imports decrease EFFICIENCY because pure consumption of imported goods emits light, whereas imports do not increase income. On the other hand, exports are supposed to improve EFFICIENCY because income increases, but light caused by consumption is relocated to other countries. Additionally, to avoid problems of interpreting the following results, I focus on imports and exports of merchandise goods and services. To make a statement on the effect of trade, I use the following linear model:

$$EFFICIENCY_{i,t} = \kappa_0 + \kappa_1 IM_{i,t} + \kappa_2 EX_{i,t} + \theta_i + \mu_k + \eta_t + \epsilon_{i,t} \quad (4)$$

where $IM_{i,t}$ is the ratio of merchandise imports to GDP of country i (i=1,2,…,I) in year t (t=1,2,…,T), $EX_{i,t}$ is the ratio of merchandise exports to GDP, θ_i are the country-fixed effects, μ_k is the satellite-fixed effects of satellite k (k=1,2…,K), η_t are the year-fixed effects, and $\epsilon_{i,t}$ is the error term. I report robust standard errors because the data suffer from heteroscedasticity.

The results of equation (4) can be seen in Table 4. In column (1), I take a look at all available observations. The coefficients of imports and exports are both statistically significant and confirm my expectation that trade is neutral. To test the effect of trade on the EKC hypothesis, I divide the sample into 5 subgroups depending on their World Bank income classification and run the same regression. The results for each subsample are reported in columns (2)-(6). Despite the overall neutral effect, I find evidence that trade has an influence on the EKC. Taking only low-income countries into account, the coefficient's signs are inverted. Because the coefficient of exports is statistically significant and negative, it becomes obvious that low-income countries export goods that are linked with a comparatively light-intense production. As seen in columns (5) and (6), I find a statistically significant coefficient for neither imports nor exports in high-income countries. This result can also be seen as a lead that high-income countries tend to relocate light- (and energy-) intense production and import these goods instead of producing them on their own. Notably, the middle-income countries reported in columns (3) and (4)

behave as if trade is neutral. A suitable way to reason this outcome in terms of the EKC is to say that middle-income countries do not need to grow at any price, but they have not yet reached a stage yet degradation matters. Thus, their total light or energy trade balance is sane.

Because the impact of trade on the EKC is a crucial issue, I perform several robustness checks to verify the relationship between trade and EFFICIENCY. As a first check, I use the data to estimate a first-differences[7] and a fixed-effects model in a similar fashion as that implied by equation (4) to control for additional unobserved effects and/or trends in the data. Therefore, I generate a panel by collapsing the light observations, and I create new satellite configuration dummies. The results of the fixed-effects and first-difference models are reported in Table A 2 and Table A 3 in the Appendix. Both models confirm the assumption that trade plays an important role in the discussion on the EKC because the coefficients behave in the expected way even though they are less statistically significant. Furthermore, I run a Dickey-Fuller test with different specifications to control for the stationarity of EFFICIENCY. The results of some specifications can be seen in Table A 4. All tests reject the null hypothesis that all panels contain unit roots. This result suggests that it can be assumed that EFFICIENCY is stationary and OLS estimates are reasonable.

In addition, I split up the merchandise import and export variables into their constituents and run the same pooled regressions as in the basic model. The results are reported in Table 5. It becomes obvious that in particular, the export of fuel and manufactures deteriorates EFFICIENCY in low-income countries. The EEFICIENCY of other income categories tends to be positively affected by exports (except exports of agricultural raw materials) if statistically significant coefficients are considered. Furthermore, the import of products such as fuel, manufactures and metals is unlikely to change EFFICIENCY for the worse in high-income countries. This fact seems to confirm the assumption that high-income countries import goods that come with light-intense production and refrain from producing them on their own. Thus, the detailed examination of the effect of merchandise imports and exports on EFFICIENCY verifies the basic model.

[7] The use of a first-difference model is consistent with Henderson et al. (2012), who argue that nighttime lighting is best for measuring differences in growth rather than absolute values.

Table 4: Effect of trade on EFFICIENCY

All regressions contain Satellite, Year, Country FE	(1) EFFICIENCY World	(2) EFFICIENCY Low income	(3) EFFICIENCY Lower middle	(4) EFFICIENCY Upper middle	(5) EFFICIENCY High income non OECD	(6) EFFICIENCY OECD
Merch. Imports (% of GDP)	-0.320***	0.136	-0.508***	-1.445***	0.135	-0.0808
	(-3.33)	(1.84)	(-5.43)	(-4.30)	(1.00)	(-0.21)
Merch. Exports (% of GDP)	0.235**	-0.188***	0.590***	1.342***	0.00233	0.0401
	(2.62)	(-3.36)	(6.23)	(3.78)	(0.02)	(0.13)
Constant	13.37***	13.27***	13.17***	12.16***	12.52***	13.07***
	(171.81)	(176.79)	(161.29)	(86.52)	(127.48)	(288.34)
#Observations	5370	1749	1506	892	420	803
R-squared	0.9016	0.9304	0.8914	0.7259	0.9825	0.7515

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Constituents of merchandise trade

All regressions Contain Satellite Country, Year FE	(1) EFFICIENCY World	(2) EFFICIENCY Low income	(3) EFFICIENCY Lower middle	(4) EFFICIENCY Upper middle	(5) EFFICIENCY High income Non-OECD	(6) EFFICIENCY OECD
Agricultural IM	1.968	3.352*	-7.953**	14.58**	-11.99	22.30***
(% of GDP)	(1.53)	(2.42)	(-2.99)	(3.00)	(-1.80)	(3.34)
Food IM	-1.286***	-0.874	-0.0154	0.535	-3.842***	-5.623
(% of GDP)	(-3.66)	(-1.82)	(-0.02)	(0.45)	(-3.85)	(-1.23)
Fuel IM	-0.225	-1.298***	-1.259***	0.393	1.242***	2.100
(% of GDP)	(-1.26)	(-3.64)	(-4.99)	(0.94)	(4.94)	(1.81)
Manufactures IM	0.0509	0.273	-0.862***	0.923***	0.0788	-0.785
(% of GDP)	(0.54)	(1.53)	(-4.69)	(5.36)	(0.45)	(-1.32)
Ores and Metals IM	-1.296*	-1.705*	3.789***	-9.601***	1.933	3.460
(% of GDP)	(-2.33)	(-2.52)	(4.43)	(-4.70)	(1.50)	(1.42)
Agricultural EX	0.860*	1.050*	-0.237	-0.867	-10.48**	-10.68***
(% of GDP)	(2.12)	(2.37)	(-0.18)	(-1.38)	(-3.03)	(-3.65)
Food EX	0.0381	-0.600*	0.625***	-0.956***	6.472***	1.971
(% of GDP)	(0.29)	(-2.13)	(3.68)	(-4.96)	(6.28)	(0.74)
Fuel EX	0.293**	-1.253***	1.228***	-0.271	-0.352*	1.577*
(% of GDP)	(2.76)	(-3.98)	(7.13)	(-1.33)	(-2.37)	(2.01)
Manufactures EX	0.106	-0.991***	0.498***	-0.00414	-0.0566	0.191
(% of GDP)	(1.27)	(-4.53)	(4.24)	(-0.03)	(-0.36)	(0.54)
Ores and Metals EX	-0.111	-0.201	0.136	-0.476	-0.183	-2.019
(% of GDP)	(-0.73)	(-0.88)	(0.58)	(-1.75)	(-0.60)	(-1.21)
Constant	12.90***	13.86***	13.17***	11.73***	12.61***	13.16***
	(256.91)	(175.23)	(187.96)	(107.20)	(104.62)	(183.34)
#Observations	4181	1043	1187	796	352	803
R-squared	0.9119	0.9457	0.9037	0.8171	0.9911	0.7581

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

As another robustness check, I generate three new subgroups depending on their income, and I reexamine the influence of trade on total terms. The first subgroup, called HIGH, contains all observations whose incomes exceed US $40,000, which can be seen as the average maximum turning point of the EKCs calculated in chapter 4.1. The second subgroup, called MIDDLE, contains observations with incomes between US $5,000-$40,000. The last income class, labelled LOW, consists of observations whose incomes are less than US $5,000. Because this classification diverges vastly from the basic model (in which I use the World Bank income classification), I can draw robust conclusions on the effect of trade on EFFICIENCY if I obtain similar results in the regressions. The results of the diverging sub-divisions are reported in Table 6. Despite the broader sample of the LOW category, column (1) shows that the effect of exports is still statistically significant and indicates that these countries export goods that come with comparatively light-intense production. In column (2), I report the regression results for the MIDDLE-income subgroup. This category contains the most observations, and the coefficients behave as if trade is neutral, although they are less significant than in the basic model. Column (3), on the contrary, takes a closer look at HIGH-income countries. Although the HIGH sample consists of only 498 observations, less than half of the high-income sample in the basic model, no trade coefficient is statistically significant. This result is also similar to the basic model.

Table 6: Robustness check using different subgroups

All regressions contain Satellite, Year, Country FE	(1) EFFICIENCY LOW	(2) EFFICIENCY MIDDLE	(3) EFFICIENCY HIGH
Merch. Imports (% of GDP)	0.111	-0.321*	0.0524
	(1.58)	(-2.58)	(0.29)
Merch. Exports (% of GDP)	-0.144**	0.243**	0.0232
	(-3.06)	(3.17)	(0.15)
Constant	13.29***	12.88***	13.22***
	(206.02)	(242.95)	(66.52)
#Observations	2077	2795	498
R-squared	0.9344	0.8813	0.8989

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Based on these results, I can conclude that the effect of imports and exports on the EKC is not neutral. In addition, I find evidence that high-income countries relocate light-intense production to low-income countries. However, is it not yet obvious to which extent the traditional inverted-U shape is just caused by trade and the accompanied light and, thus, carbon leakage. I therefore investigate the traditional EKC perspective with respect to trade.

Effect of trade on the traditional EKC

Because coefficients in regression models reflect ceteris paribus changes, it is not possible to simply add exports and imports to equation (1). Therefore, I need another approach to examine the traditional EKC. In the previous part of this section, I investigated the effect of merchandise imports and exports on EFFICIENCY. In doing so, I casually included country-fixed effects, which can now be used to estimate the traditional EKC. The country-fixed effects in connection with the constant terms represent the average EFFICIENCY of each country during the period of interest on the condition that the share of merchandise imports and exports in GDP equals zero. Thus, I can calculate the average light emissions (ALIGHT) of each country on the condition that there is no merchandise trade, using the average income in the following way:

$$ALIGHT_i = \frac{AGDPpC_i}{e^{(\kappa_{0j}+CFE_{i,j})}} \tag{5}$$

where $AGDPpC_i$ is the average income per capita of country i (i=1,2,…,I), κ_{0j} is the constant coefficient of the regression of subgroup j (j=1,2,…,J), and $CFE_{i,j}$ is the country-fixed effects. A plot of the logarithmized ALIGHT (which is calculated based on the basic model of the previous section) and the logarithmized average income per capita shows that the inverted-U shape is still existent (see Figure 5). To make a more satisfying statement, I perform the following OLS model:

$$logALIGHT_i = \tau_0 + \tau_1 logAGDPpC_i + \tau_2 logAGDPpC_i^2 + \tau_3 logAGDPpC_i^3 + \epsilon_i \tag{6}$$

The outcomes of different settings of equation (6) are reported in Table 7. In column (1), only the linear and the quadratic term of the average income per capita are taken into account. Both coefficients are statistically significant and indicate the expected inverted-U shape. Although the EKC is still existent, it should be mentioned that the absence of trade moves the maximum turning point to an incredibly high level of approximately US $680,000, which is not exceeded by a single observation. In column (2), I perform the same regression but exclude five countries that have the highest incomes and indicate the beginning of a new upwards slope.[8] The regression yields statistically significant coefficients and a maximum turning point of US $470,000, which is far below the turning point estimated in column (1) but still not exceeded by any observation. In column (3), I test the existence of another upwards slope if these five countries are again included. To do so, I include the third-order term of income in the regression. Because no coefficient is statistically significant, I can conclude that there is no evidence of an N-shape in the data. Furthermore, it can be stated out that trade does not suspend the traditional EKC, but it has a major effect on the location of the maximum turning point because the comparatively good EFFICIENCY of high-income countries is primarily caused by relocating light-intense production.

[8] Brunei, Kuwait, Luxembourg, Qatar and UAE.

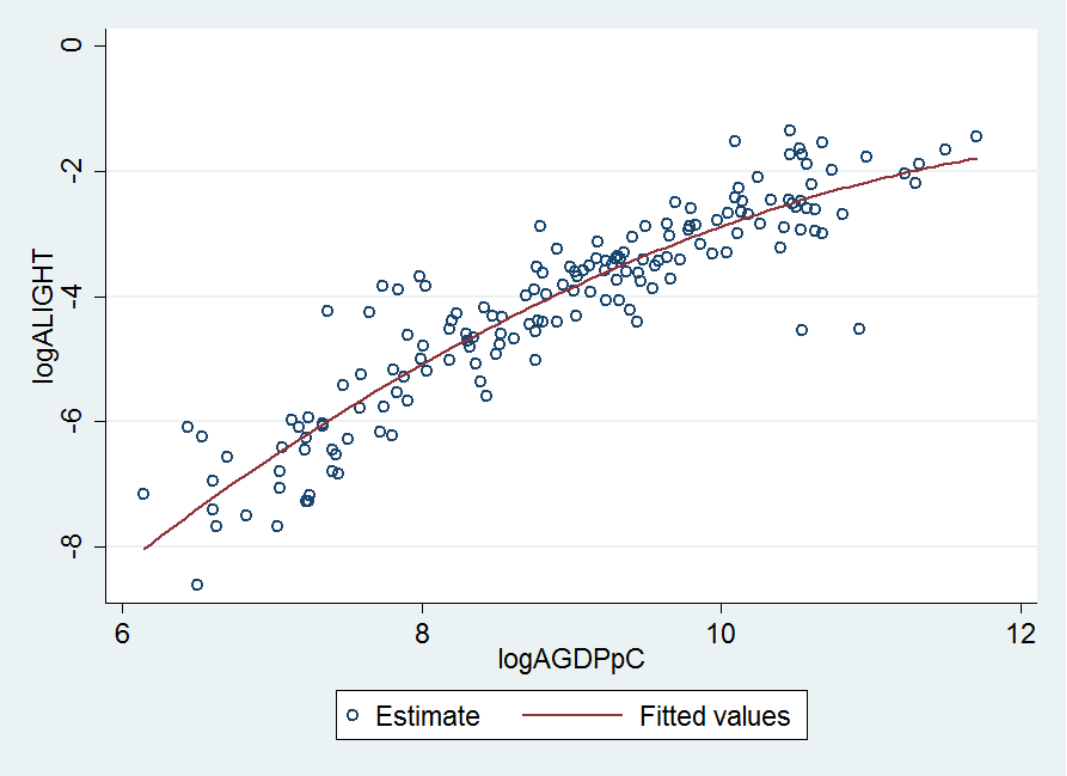

Figure 5: EKC conditional on the absence of trade

Table 7: Traditional EKC on the condition of the absence of trade

	(1) logALIGHT	(2) logALIGHT	(3) logALIGHT
logAGDPpC	3.360***	3.528***	0.420
	(6.03)	(4.57)	(0.08)
logAGDPpC²	-0.125***	-0.135**	0.210
	(-4.06)	(-3.06)	(0.37)
logAGDPpC³			-0.0125
			(-0.60)
Constant	-23.94***	-24.63***	-15.47
	(-9.60)	(-7.37)	(-1.01)
#Observations	164	159	164
R-squared	0.8490	0.8387	0.8494

To verify this finding, I estimate ALIGHT with constants and country-fixed effects that result from the more detailed model in the previous section and run the same regression as described

in equation (6). The results are reported in Table 8 and confirm my assumption that trade is not neutral. Notably, the willful neglect of the five highest-income observations causes an increase in the maximum turning point income level (approximately US $460,000 instead of US $390,000). Furthermore, in column (3), I find a slightly statistically significant coefficient for the third-order income variable. This finding indicates that there might be an inverted-N shape relationship between income and light at all. The inverted-N function has a maximum turning point at less than US $80,000, which is far below the turning points of the trade-restricted inverted-U shapes but still higher than the results calculated in section 4.1.

Table 8: Robustness check of traditional EKC on the condition of the absence of trade (detailed perspective)

	(1) logALIGHT	(2) logALIGHT	(3) logALIGHT
logAGDPpC	3.626***	3.547***	-6.828
	(6.82)	(5.55)	(-1.36)
logAGDPpC²	-0.141***	-0.136***	1.040
	(-4.75)	(-3.76)	(1.84)
logAGDPpC³			-0.0438*
			(-2.09)
Constant	-25.11***	-24.79***	5.299
	(-10.67)	(-8.91)	(0.36)
#Observations	152	147	152
R-squared	0.8462	0.8378	0.8506

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

One could argue that the results are biased because the light figure includes light emitted by the burning of gas flares, and the share of merchandise imports and exports is insufficient to capture this effect. This assumption would imply that the true maximum turning point is located at lower income levels because the light emittance of primarily high-income countries that profit greatly from fossil fuels is overestimated. To disprove this argument, I run regressions of equation (4) considering only observations whose share of fuel exports is less than 15% of all merchandise exports.[9] Then, I employ the outcomes to calculate ALIGHT in the same way as described above and run equation (6) without using the third-order income term. The results of the regression and the appendant diagram can be seen in Figure 6.

[9] Coefficients of merchandise imports and exports are almost the same as those reported in Table 4.

	(1) logALIGHT
logAGDPpC	1.792**
	(2.90)
logAGDPpC²	-0.0454
	(-1.30)
Constant	-16.22***
	(-5.99)
#Observations	119
R-squared	0.8152

t statistics in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

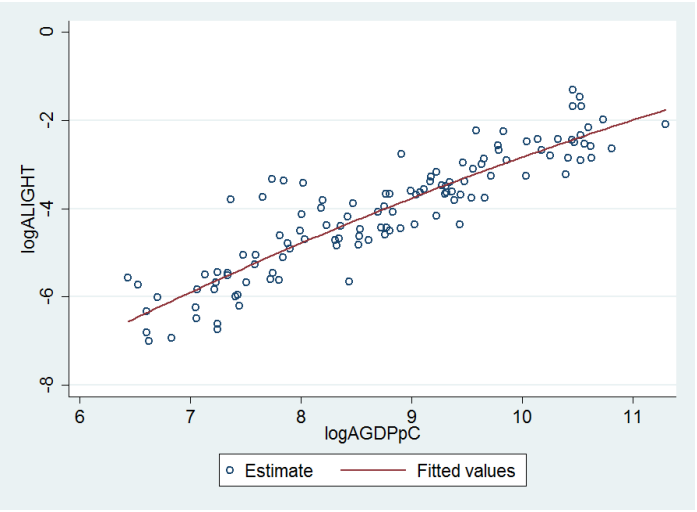

Figure 6: Traditional EKC on condition of the absence of trade and fuel-exporting countries

The omission of those countries does not improve the maximum turning point. Instead, the quadratic term turns insignificant. Because only the linear-income term stays statistically significant, this finding makes the EKC hypothesis implausible. Higher incomes certainly come with intensified light emissions. There is absolutely no downward slope of this curve. Consequently, I can reject the argument of a strongly biased light figure.

Although the EKC relationship is persistent, I can conclude that it is safe to say that trade is a driving force of the course of the light-income relationship. The worldwide economy has not yet reached a point where the total level of degradation is in decline. Nonetheless, improvements in environmental pollution levels in high-income countries are primarily caused by the relocation of production and the subsequent trade of so-called ‘dirty’ goods.

6 Conclusions and policy implications

In this paper, I have shown that manmade lighting is a crucial and unbiased figure in terms of environmental degradation and that it allows for the analysis of a full set of countries. Therefore, I used satellite nighttime imagery as a proxy for carbon dioxide-equivalent emissions and took a closer look at the existence of an environmental Kuznets curve. My results suggest the following: It is most likely that the light-income relationship follows an inverted-U shape. Additionally, it is obvious that the economy’s sectoral structure influences the light-output ratio. This finding also supports the existence of an EKC. Unfortunately, the inverted-U shape vanishes almost completely if I control for international trade. Similarly to the carbon leakage phenomenon, this result suggests that high-income countries export their energy-intense production to less developed countries.

These results lead to the necessity of global environmental policies because only comprehensive legislation and global conventions may have the power to reduce the total amount of greenhouse

gas emissions. Regulations that become operative in only one part of the world fail because they can be flouted by trade and cause an apparent EKC that suffers from an increase in the global level of carbon dioxide leaks. In fact, local environmental activities can succeed only with the support of suitable taxation systems that are able to gather the energy or pollution intensity of each traded good to adapt the tax based on the good's ecological fingerprint, which is impossible indeed.

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I hereby declare that there are no competing financial interests linked with this paper.

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Appendix

Table A 1: LIGHT – Energy/Emission correlation[10]

	(1) logLIGHT World	(2) logLIGHT Low income	(3) logLIGHT Lower middle	(4) logLIGHT Upper middle	(5) logLIGHT High income Non-OECD	(6) logLIGHT OECD
logCO_2eqpC	0.796***	0.380**	0.735***	0.616***	0.687**	0.249
# Countries	135	33	41	25	12	24
logEnergyUsepC	0.796***	0.390***	0.713***	0.533***	0.440	0.602***
# Countries	151	38	48	28	13	24
logElectrConspC	0.878***	0.746***	0.734***	0.577***	0.258	0.720***
# Countries	136	33	41	26	12	24

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

[10] Light, energy and emission data are averaged at country level.

Table A 2: Fixed-effects model

FE regressions contain Year and Satellite configuration FE	(1) Efficiency World	(2) Efficiency Low income	(3) Efficiency Lower middle	(4) Efficiency Upper middle	(5) Efficiency High income Non-OECD	(6) Efficiency OECD
Merch. Imports	-0.343***	0.151*	-0.534***	-1.547***	0.106	0.154
(% of GDP)	(-6.61)	(1.98)	(-6.41)	(-9.51)	(0.83)	(0.35)
Merch. Exports	0.237***	-0.188**	0.596***	1.506***	0.0166	-0.151
(% of GDP)	(5.60)	(-3.30)	(6.58)	(8.97)	(0.11)	(-0.40)
Constant	13.11***	13.34***	12.94***	12.82***	13.30***	12.93***
	(560.24)	(340.39)	(326.64)	(157.37)	(191.94)	(187.91)
#Observations	3464	1128	972	573	270	521
#Countries	164	53	47	27	13	24
R-squared within	0.2584	0.2672	0.4176	0.3587	0.4700	0.3211
R-squared between	0.0018	0.0118	0.0579	0.0349	0.7463	0.0304

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A 3: First-difference model

	(1) ΔEFFICIENCY World	(2) ΔEFFICIENCY Low income	(3) ΔEFFICIENCY Lower middle	(4) ΔEFFICIENCY Upper middle	(5) ΔEFFICIENCY High income Non-OECD	(6) ΔEFFICIENCY OECD
ΔMerch. Imports	-0.0673	-0.0490	-0.104	-0.281	-0.102	0.105
(% of GDP)	(-1.19)	(-0.70)	(-0.97)	(-1.82)	(-0.84)	(0.13)
ΔMerch. Exports	-0.0515	-0.136**	0.278*	0.463*	0.298*	0.239
(% of GDP)	(-1.23)	(-3.04)	(2.37)	(2.46)	(2.33)	(0.30)
ΔSatellite	-0.141***	-0.162***	-0.154***	-0.154***	-0.0686***	-0.117***
Configuration	(-22.82)	(-15.84)	(-15.69)	(-9.59)	(-6.33)	(-4.89)
Constant	0.0483***	0.0506***	0.0481***	0.0555***	0.0391***	0.0424**
	(11.38)	(7.16)	(7.13)	(5.09)	(5.43)	(2.74)
#Observation	3297	1075	922	546	257	497
R-squared	0.1425	0.2058	0.2137	0.1519	0.1400	0.0495

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A 4: Dickey-Fuller tests

```
Fisher-type unit-root test for Efficiency
Based on augmented Dickey-Fuller tests
---------------------------------------
Ho: All panels contain unit roots           Number of panels       =    164
Ha: At least one panel is stationary        Avg. number of periods =  21.12

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Not included
Drift term:   Included                      ADF regressions: 2 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(328)  P       935.0600       0.0000
 Inverse normal            Z       -19.2144       0.0000
 Inverse logit t(824)      L*      -19.3508       0.0000
 Modified inv. chi-squared Pm       23.7017       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
------------------------------------------------------------------------------
```

```
Fisher-type unit-root test for Efficiency
Based on augmented Dickey-Fuller tests
---------------------------------------
Ho: All panels contain unit roots           Number of panels       =    164
Ha: At least one panel is stationary        Avg. number of periods =  21.12

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Not included
Drift term:   Included                      ADF regressions: 3 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(324)  P       917.5296       0.0000
 Inverse normal            Z       -18.9134       0.0000
 Inverse logit t(814)      L*      -18.9862       0.0000
 Modified inv. chi-squared Pm       23.3160       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
------------------------------------------------------------------------------
```