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ECONOMIC DEVELOPMENT, CARBON EMISSIONS AND CLIMATE POLICIES

LUCA BETTARELLI, DAVIDE FURCERI, PRAKASH LOUNGANI, JONATHAN D. OSTRY AND LOREDANA PISANO

If economic activity is considered the primary driver of climate change through emissions of carbon dioxide, then supporting economic growth and fighting emissions would appear to be at odds. However, the process of economic development may itself foster complementarity between GDP growth and emissions reductions. Such complementary in the relationship between economic development and emissions reduction might reflect changes in the industrial composition of economic activity, technological advancements or environmental consciousness.

This view is in line with the Environmental Kuznets Curve (EKC) hypothesis: that *per-capita* income growth is associated with increases in carbon emissions up to a certain threshold of economic development, but beyond that threshold, higher *per-capita* incomes are associated with lower emissions per capita. The EKC hypothesis, suggests that economic development is actually a pathway to environmental improvements.

We test the EKC hypothesis for 191 countries over 1989-2022, enabling us to study the overall validity of the EKC hypothesis at global level. Moreover, by interacting GDP *per capita* with an index measuring the stringency of climate policies, we shed light on whether and how climate policies mediate the impact of GDP on emissions. We find that emissions respond to increasing *per-capita* income levels nonlinearly, with a turning point at about $25,000 on average. Importantly, we show that climate policies shape the relationship between income and emissions by making the EKC lower and flatter, thus favouring a decoupling between emissions and economic activity. Our results have important policy implications, as they identify economic development as a pathway to environmental improvements. We also show that environmental policies are an essential ingredient to achieve decoupling of emissions and economic output over the longer term.

Keywords: Environmental Kuznets Curve; Climate Change Policy; Decoupling; Carbon Tax
JEL codes: C33, Q53

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Luca Bettarelli (luca.bettarelli@unipa.it) is an Assistant Professor at the University of Palermo
Davide Furceri (davide.furceri@unipa.it) is a Professor at the University of Palermo
Prakash Loungani (ploungani@jhu.edu) is a Program Director at Johns Hopkins University
Jonathan D. Ostry (jonathan.ostry@bruegel.org) is a Non-resident Fellow at Bruegel and a Professor at the University of Toronto
Loredana Pisano (loredana.pisano@unipa.it) is a researcher at the University of Palermo

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1 Introduction

Global shocks in the twenty-first century so far, including the Global Financial Crisis and the COVID-19 pandemic, have necessitated unprecedented macroeconomic policy support to sustain the momentum of economic activity and prevent another Great Depression. Overlaid on these challenges, the imminence of catastrophic climate tipping points underscores the imperative of strict global efforts to fight climate change and foster a green economic transition.

Is there a tension between meeting these economic and environmental challenges? Many, including the Intergovernmental Panel on Climate Change (IPCC, 2021), have noted that economic activity is the primary driver of climate change through emissions of carbon dioxide. From this perspective, supporting economic growth and fighting emissions would appear to be at odds, constraining the ability of policymakers to achieve economic and environmental targets. Is this tension inevitable? Perhaps not, to the extent that a relationship between economic development and environmental improvements fosters complementarity between GDP and emissions reductions. Such a complementary relationship might reflect changes in the industrial composition of economic activity associated with economic development, technological advancements, or environmental consciousness (Stern, 2004).

This view is in line with the Environmental Kuznets Curve (EKC) hypothesis. The traditional Kuznets inverted U-shaped relationship between income inequality and economic development (Kuznets, 1955) was adapted to environmental issues in the early 1990s (Grossman and Krueger, 1991). The idea behind the EKC is that *per-capita* income is positively associated with increases in (CO2) emissions up to a certain threshold of economic development. Beyond that, higher *per-capita* income leads to lower emissions *per capita*. The validity of the EKC hypothesis is crucial for the climate change debate, as it identifies economic development as a pathway to environmental improvements.

The empirical literature so far – focusing mostly on single-country case studies or rather homogeneous groups of countries, such as in the European Union – provides mixed results. While most authors validate empirically the EKC hypothesis, others do not find evidence of emission reductions with increasing income (see Guo and Shahbaz, 2024, for a recent survey of results). This empirical ambiguity suggests that the impact of economic development on emissions may also depend on other factors, potentially correlated with both emissions and income levels. One such potential factor is climate change policy (CCP).

In recent years, numerous policies have been proposed and implemented to fight climate change. Governments throughout the world have committed to limit the increase in the average global temperature to 1.5 degrees Celsius compared to the pre-industrial period. To achieve that objective, carbon emissions need to fall to zero by around the middle of this century (IPCC, 2018). In this sense, climate change policies should help to foster a decoupling of emissions from economic activity. However, to our knowledge, no studies have investigated the role of climate change policies (CCPs) on the income-emissions relationship.

In this paper, we first empirically test the EKC hypothesis for a large sample of 191 countries over the period 1989-2022. Our rich dataset allows us to study the overall validity of the EKC hypothesis at the global level, and to disentangle the emissions-income relationship in advanced and emerging market economies separately. Moreover, by interacting GDP *per capita* with an index measuring the (country-level) stringency of environmental policies, we shed light on whether and how (different types of) CCPs mediate the impact of GDP on emissions. Finally, we extend the level of granularity of our findings to the regional level, looking at the EKC relationship in 140 (admin 2) regions in four countries (Canada, China, Japan and the United States), for the period 1995-2018.

We find that (CO2) emissions respond to increasing *per-capita* income levels nonlinearly, with a turning point at about $25,000 on average, a value similar to findings in previous literature (Galeotti, 2006; Churchill *et al*, 2018; Xu and Yang, 2024). Results are robust to several sensitivity checks, including: (i) a Weighted Least Squares (WLS) model, with weights equal to population size; (ii) adding controls to the baseline specification; (iii) alternative sets of fixed effects and standard errors; (iv) different data sources; (v) removing one country at a time to control for outliers; and (vi) splitting the sample into sub-periods.

Importantly, we show that CCPs matter in shaping the relationship between income and emissions: CCPs make the EKC lower and flatter, thus favouring a decoupling between emissions and economic activity. The impact on the EKC is greater for market-based CCPs, such as emissions trading systems and (particularly) carbon taxes. Results using regional data are qualitatively similar to macro-level results, further corroborating the validity of our findings.

The rest of the paper is structured as follows: section 2 provides a review of the literature, also identifying how we contribute to it; section 3 introduces the data and the empirical methodology; section 4 discusses the results and section 5 concludes.

2 Literature review

In the last decades, the trade-off between economic growth and environmental quality has led to an intense debate. Some scientists (Meadows *et al*, 1972) have argued that economic growth cannot come without extensive exploitation of energy, leading to large emissions, but others (Beckerman, 1992; Bhagwati, 1993) have suggested that economic growth could improve environmental quality in the long run (World Bank, 1992). This may happen thanks to factors such as changes in the composition of output, the introduction of cleaner production technology and greater public demand for stricter controls on emissions and increased environmental awareness (Grossman and Krueger, 1995; Andreoni and Levinson, 2001). Thus, rising *per-capita* income may be associated with declining pollution, engendering an inverted-U relationship between economic growth and environmental damage (Grossman and Krueger, 1991) that was named Environmental Kuznets Curve (EKC) for the first time by Panayotou (1993). Since then, the debate about the validity of the EKC has grown exponentially, also thanks to the availability of environmental data (World Bank, 1992; Holtz-Eakin and Selden, 1995; Leal and Marques, 2022).

Empirical studies so far have provided mixed results. Several surveys – see, for instance, Stern (2004), Kaika and Zervas (2013) and more recently Guo and Shahbaz (2024) – review approximately 200 articles, most of them (about 80 percent) validating the EKC hypothesis. These authors also highlight specific issues with empirical estimations of the EKC, potentially driving results.

A first issue is the sample selection. Many articles (about 40 percent) analyse a single country; one out of four is China (eg Luan *et al*, 2022; Xu *et al*, 2022; Zhang *et al*, 2022). Forty percent of the studies focus on a restricted number of countries (<10) or homogeneous groups of countries (eg EU, OECD, MENA, ASEAN, BRICS, Central and Eastern Europe, Central America) (Atici, 2009; Acaravci and Ozturk, 2010; Saboori and Sulaiman, 2013; Heidari *et al*, 2015; Sun *et al*, 2020). Only a few studies investigate larger samples of countries (>50), including both advanced and emerging market economies (Al-Mulali *et al*, 2015; Allard *et al*, 2018; Farooq *et al*, 2022; Wang *et al*, 2023).

This has two implications. Empirically, as most studies use country and time fixed effects, the estimated parameters are conditional on the country and time effects in the selected sample of data (Hsiao, 1986). In addition, emissions reductions in one country may be due to pollution transfer to neighbouring countries, in line with the 'race to the bottom' hypothesis. In this regard, our paper considers a large sample of 191 countries, and provides heterogeneity tests distinguishing between advanced and emerging market economies. Moreover, we extend the level of granularity to the sub-national level for a sample of 140 regions in four countries. Very few studies have provided evidence of the EKC at the sub-national level; those that have have mainly focused on China or the United States (Zhou *et al*, 2020; Dai *et al*, 2023).

A second issue is related to the selection of the proxy for environmental degradation, as the EKC hypothesis does not explicitly state the basis for the selection of environmental pollution indicators. According to Stern (2004), earlier EKC studies suggested that local pollutants (eg SO2, PM10) are more likely than global pollutants (CO2) to have an inverted U-shaped relationship with income (Lopez, 1994; Stern *et al*, 1996; Panayotou, 1997). However, large emissions of global pollutant CO2 are the main cause of climate change (Narayan and Narayan, 2010; Jaunky, 2011), thus suggesting that researchers should test the validity of the EKC hypothesis in relation to the use of global pollutants as indicators of environmental degradation. Accordingly, our paper focuses on CO2 emissions as the dependent variable.

A third issue relates to the set of controls used in empirical specifications. Many researchers have included various control variables in the standard relationship between income and emissions. These include for example the output structure (eg Panayotou, 1997), trade openness (eg Suri and Chapman, 1998), globalisation (Dasgupta *et al*, 2022), financial development (Seker *et al*, 2015), urbanisation (Iwata *et al*, 2010), population density (Ahmed *et al*, 2022), education (Zhang *et al*, 2022) and sectoral specialisation (Guo *et al*, 2022). Testing the effect of different controls individually is subject to the problem of omitted variables (Stern, 2004). Thus, we simultaneously consider a large set of controls, including the share of manufacturing and services over GDP, population density, human capital and economic openness.

Very few studies have analysed the role of mediating factors in the EKC relationship. Udeagha and Breitenbach (2023) showed that financial development attenuates the detrimental impacts of economic growth on emissions. Joshi and Beck (2018) focused on the impact of political and economic freedom and found that political freedom exacerbates the negative impact of economic activity on environmental quality, possibly because interest groups and industries place pressure on governments to reduce regulation of pollutants. Closer to our study is Panayotou (1997), who used a set of indicators of the quality of institutions – respect/enforcement of contracts, efficiency of bureaucracy, the efficacy of the rule of law, the extent of government corruption and the risk of expropriation – to investigate how institutional quality affects the income-emissions relationship, for a sample of 30 countries for the period 1982-94. Consistent with our findings, the author showed that better institutions are associated with a more favourable EKC. However, to the best of our knowledge, the literature has not specifically investigated the role of the degree of stringency of (different types of) climate change policy on the EKC relationship.

In this regard, we also link to the literature analysing the impact of CCPs on emissions and the economy (IPCC, 2018). Empirical work predominantly finds that CCPs are associated with reductions in emissions (Zhao *et al*, 2015; Shapiro and Walker, 2018; Neves *et al*, 2020). The literature also suggests that emissions may fall after CCPs are put in place because of a slowdown in economic activity (Bettarelli *et al*, 2024a, 2024b; OECD, 2021). However, the negative impact of CCPs on the economy seems to be temporary (Porter and Van der Linde, 1995). In the medium term, CCPs are more likely to induce firms to modernise their production techniques and switch to more energy-efficient production processes (Deb *et al*, 2023). Recent studies (Cohen *et al*, 2022; Bettarelli and Yarveisi, 2023; Naqvi, 2021) have shown empirically that CCPs favour decoupling in the medium-term (approximately three years after the introduction of the policy), with a reduction in emissions and a positive impact on economic activity. In line with these findings, we expect that CCPs would significantly affect the EKC relationship: CCPs should lower the EKC by reducing the level of emissions for any given level of *per-capita* GDP. In addition, CCPs should result in a flattening of the EKC by decoupling emissions from economic activity.

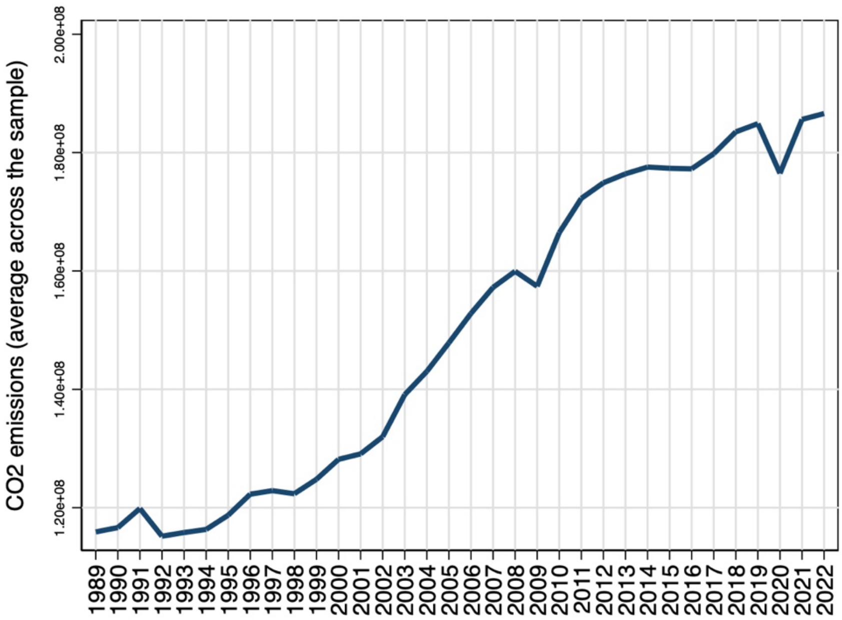
Finally, we also align with the literature recognising that not all types of CCP have the same effect on emissions and the economy. Chang *et al* (2020) found that carbon pricing is the most effective measure to meet emission reduction targets. Bettarelli and Yarveisi (2023) demonstrated that although market-based policies have more traction in reducing emissions, they also cause greater economic damage. Thus, in our empirical analysis, we distinguish between market- and non-market-based CCPs.

3 Data and methodology

3.1 Data

Our main source of emissions data is Our World in Data (OWD), from which we extract information on *per-capita* CO2 emissions at the country-year level for 191 countries from 1989 to 2022[1]. We look at annual total emissions of carbon dioxide (CO2), excluding land-use change, measured in tonnes per person. Data is based on territorial emissions, which do not account for emissions embedded in traded goods. Figure 1 shows the evolution of the level of CO2 emissions by year on average across the sample of 191 countries: emissions increase steadily with time, particularly since 2000, with sudden reductions related to major global shocks, such as the COVID-19 pandemic. As a robustness check, we also consider country-level GDP (instead of population) to 'weight' CO2 emissions as well as cumulative *per-capita* CO2 emissions, which sum up country-level emissions over the years.

Figure 1: Level of CO2 emissions (average by year across a sample of 191 countries)



Source: authors' calculations based on Our World in Data.

To provide further robustness checks, we collect *per-capita* CO2 emissions data from two sources: the European Commission's Emissions Database for Global Atmospheric Research (EDGAR) and the OECD. The correlation between the three sources (OWD plus EDGAR plus OECD) is above 0.9, even if the coverage of OECD data is lower than other sources.

[1] OWD provides information on (different types of) pollutants for most countries from 1750 on, extracted from the Global Carbon Budget (2023). For more information, see Hannah Ritchie, Pablo Rosado and Max Roser, 'CO_2 and Greenhouse Gas Emissions', *Our World in Data*, undated, https://ourworldindata.org/co2-and-greenhouse-gas-emissions. We restrict our analysis to the time-period available for CCP data.

Data on *per-capita* GDP (in 2015 US dollars) at the country-level is drawn from the World Bank's WDI database. From the same source, we also collect data on the share of manufacturing and services in GDP, trade over GDP, human capital and population density. As a measure of the country-level degree of globalisation, we use the KOF index from the Swiss Economic Institute[2], measuring the social and political dimensions of globalisation.

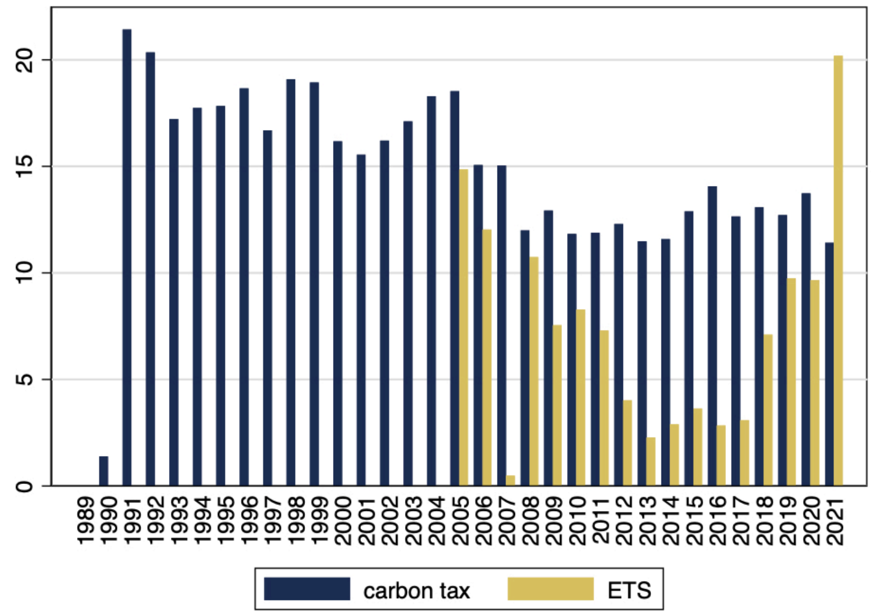
Data on *per-capita* emissions and *per-capita* GDP at regional level is drawn from the OECD. They cover 140 regions in four countries (Canada, China, Japan and the US) for the period 1995-2018[3].

Climate change policies data comes from different sources. The most comprehensive in terms of coverage and granularity is Dolphin (2022). This database provides emission-weighted carbon price (ECP) data, including carbon taxes, emissions trading schemes (ETS) and the combination of both, for 198 countries, over the period 1989-2022. Importantly, the ECP considers both price and coverage of carbon pricing instruments, as most of the schemes implemented globally entail partial coverage, because of sectoral or fuel-based exemptions. The ECP index is assembled at the sector-fuel level considering: the coverage of carbon pricing mechanisms; carbon pricing mechanisms' associated price of emissions (expressed in 2019 US$/tCO2); and verified (sector-fuel) CO2 emission data. Sectoral data is then aggregated to the economy-wide level as a weighted average of the sectoral carbon rates. In the case of a carbon tax, the ECP indicates the emissions-weighted average price on emissions covered by a carbon tax. Figure 2 reports the evolution of both emissions-weighted carbon taxes and ETS, on average across countries. It shows that the application of carbon-tax mechanisms decreased slightly when ETS instruments were introduced in 2005. Recently, countries have favoured the implementation of ETS rather than carbon taxes.

[2] See https://kof.ethz.ch/en/.

[3] The set of countries is limited by data availability. At the regional level, only an aggregate index of greenhouse-gas emissions is available.

Figure 2: Evolution of carbon taxes and ETS (average across countries)



Source: Dolphin (2022).

To compare different types of CCPs, we also collect data from the OECD Environmental Policy Stringency (EPS) index. The database provides information on the degree of stringency of CCPs for a sample of 40 countries over the period 1990-2020. The index ranges from zero to six, with higher values corresponding to stricter policy measures. The dataset provides both an aggregate indicator and a score for sub-indicators for different market-based, and non-market-based policies. Market-based policies include CO2 and renewable energy trading schemes, and carbon tax; non-market-based policies include emission limits. This dataset allows us to evaluate if the impact of CCPs on the relationship between economic activity and emissions changes, depending on the type of CCP implemented.

3.2 Empirical model

As a baseline, we use a standard EKC model of the following form:

$$lnCO2pc_{i,t} = \beta\ lnGDPpc_{i,t} + \gamma\ lnGDPpc_{it}^{2} + \ \delta_i + \eta_t + \varepsilon_{i,t} \qquad (1)$$

where both emissions and GDP are *per capita* and in log. Subscripts *i* and *t* indicate country and year, respectively. Equation (1) is estimated including country and year fixed effects, and heteroskedasticity-robust standard errors[4]. Even if we keep the baseline equation parsimonious, we add controls for robustness checks, including: the share of the Gross Value Added (GVA) of

[4] Note that we also try to estimate Equation (1) using a third-order polynomial to test the existence of a N-shaped relationship income-emissions, but we do not detect a significant coefficient of the cube term of income *per capita*.

manufacturing and service sectors over total GVA; human capital; population density; trade openness; and the globalisation index. Additional robustness checks include different sets of fixed effects (ie only country, only year, no fixed effects), and standard errors (ie clustered at the country level or Discroll-Kraay, 1998).

Next, to investigate the role of CCPs in mediating the income-emissions link, we empirically interact the (log of) GDP (level and squared) with an indicator of the stringency of (different types of) CCPs:

$$lnCO2pc_{i,t} = \beta\ lnGDPpc_{i,t} + \gamma\ lnGDPpc_{it}^2 + \rho\ lnGDPpc_{i,t} \times\ CCP_i + \phi\ lnGDPpc_{it}^2 \times\ CCP_i + \delta_i + \eta_t + \varepsilon_{i,t} \qquad (2)$$

To reduce endogeneity due to the correlation between CCP and income levels, we consider the country-level mean of CCP across the sample period[5]. As described above, CCPs are: carbon tax and emission trading systems (ETS) (or the combination of both) from Dolphin (2022); the OECD's Environmental Policy Stringency Index (EPS), including aggregate EPS, market-based EPS, non-market-based EPS

At the regional level, we estimate Equations (1) and (2) for a sample of 140 regions in four countries for the period 1995-2018. For the regional analysis, we alternatively include either country and year fixed effects, or region and year fixed effects, to provide robustness checks. In estimating Equation (2) at the regional level, we interact regional income by the country-level indicator of CCP from Dolphin (2022), combining ETS and carbon tax.

4 Results

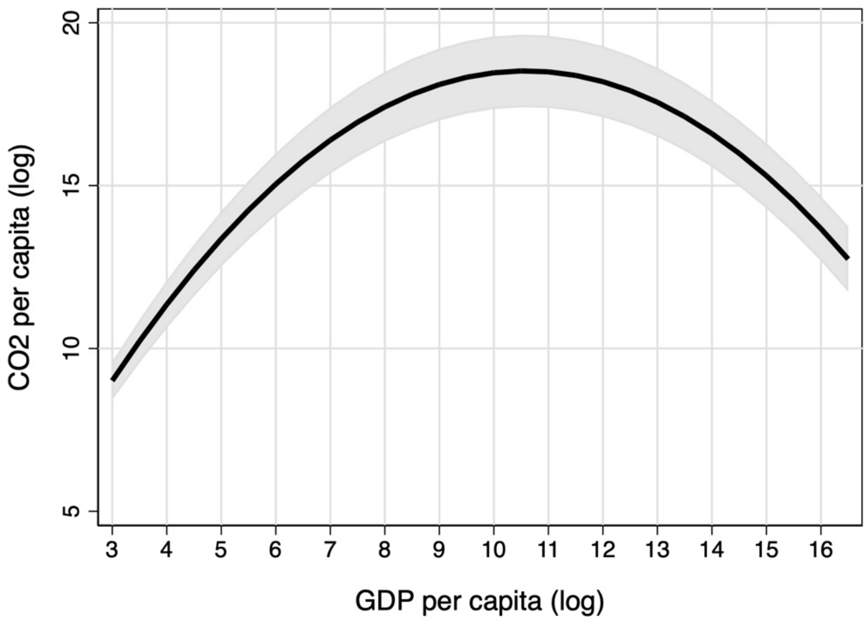
4.1 The EKC hypothesis at the global and regional level

Estimating Equation (1) for a large sample of 191 advanced and emerging market economies, for the period 1989-2022, we find that, on average, the EKC hypothesis is validated by our data. Figure 3 plots the effect of *per-capita* GDP on *per-capita* CO2 emissions, for different values of *per-capita* GDP[6]. Emissions rapidly increase when income increases, up to a threshold of economic development, which corresponds to approximately $25,000 on average in our sample[7]. Afterwards, higher *per-capita* GDP leads to lower emissions, as put forward by the EKC. The threshold varies greatly across countries, as already stressed by the previous literature (Wang *et al*, 2023). While advanced economies (eg Australia, Canada, France, the US) register a turning point at about $35,000-$50,000, emerging-market countries, such as India, the Middle East and North African countries, and South Africa, switch to a negative income-emissions relationship when income exceeds $5,000-$18,000[8]. These values imply that many countries – including major economies China and India – are still in the upward-sloping segment of the EKC, with emissions increasing as *per-capita* incomes rise. In contrast, most advanced

[5] Results are qualitatively identical if we use the median.
[6] All variables are in log.
[7] Full regression results are available on request. Threshold is computed as $\exp(-\frac{\beta}{2\gamma})$.
[8] Turning points for individual countries are based on estimation of Equation (1) for each country separately, without the inclusion of year FE.

economies, including in North America and Europe, reached the EKC inflection point during the mid-1990s.

Figure 3: Baseline results (country-level analysis)



Source: authors' calculations. Note: chart reports the effect of the (log of) GDP *per capita* on the (log of) emissions, for different levels of the (log of) GDP *per capita*. Shaded area represents 90 percent confidence band. Estimate is based on a sample of 191 countries, over the period 1989-2022. OLS model with country and year fixed effects. Heteroskedasticity robust standard errors.

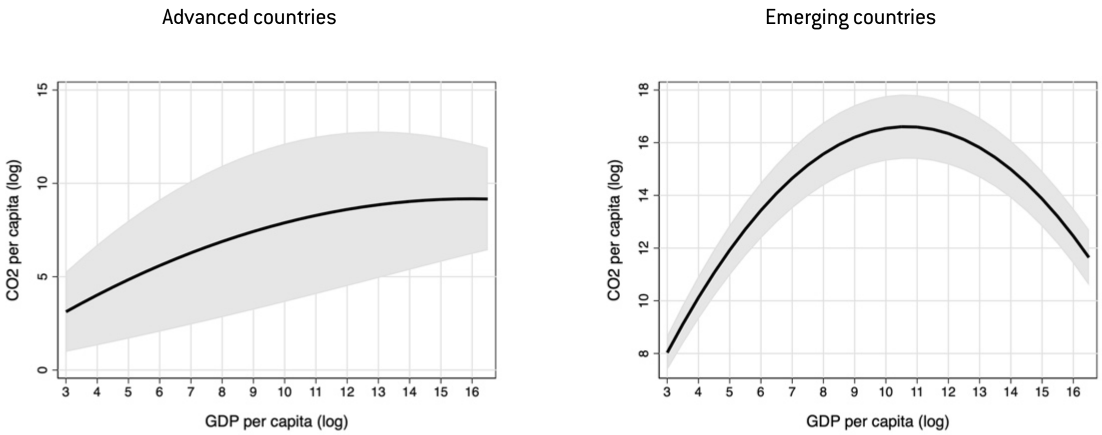
To expand slightly on these points, there is an evident trend among the advanced economies toward a decoupling between *per-capita* emissions and *per-capita* incomes, while for non-advanced economies, that trend is not yet evident. Most advanced economies are near the peak of the EKC but a number are already in the downward portion (examples are the Nordic countries and Switzerland), ie they have higher *per-capita* incomes and lower *per-capita* emissions than poorer countries. These findings are extremely robust, and hold irrespective of the source of the emissions data or the *per-capita* income data. To make the point slightly differently, *per-capita* emissions have been declining in the advanced economies as a whole for more than a decade, while *per-capita* incomes have obviously continued to increase: decoupling. The emerging market and developing economies are not yet at the decoupling stage.

For the United States, which holds special interest, carbon emissions *per capita* began a steep and durable decline in the early 2000s. This persists throughout the remainder of our sample period. Emissions per unit of GDP began a steep decline long before this, and that trend persists as well. This does not mean, of course, that the United States does not remain the second largest emitter in the world. All told, the estimated EKC fits closely the actual country-level data in our dataset.

We test the robustness of our baseline result to numerous sensitivity checks: (i) using a Weighted Least Squares (WLS) model, with weights equal to population size; (ii) adding as controls to the baseline specification the share of manufacturing/service over GDP, population density, the globalisation index, human capital, trade openness; we include these controls one by one in Equation (1) and also all together; (iii) trying alternative sets of fixed effects (only country, only year, no fixed effects) or standard errors (clustered at the country level or Discroll-Kraay); (iv) using different data sources, as described in section 3; (v) removing one country at time to control for the presence of outliers; (vi) splitting the sample in sub-periods, ie pre- and post-2005[9]. Results of robustness checks are qualitatively identical to baseline one.

In a next step, we recognise that results for the sample as a whole may be heterogeneous according to the development level (*per-capita* income) (Dasgupta *et al*, 2002). Thus, we estimate Equation (1) separately for the groups of advanced and emerging countries. Results reported in Figure 4 show that the EKC more closely adheres to the hypothesised shape in the case of emerging countries, where emissions decline with economic development. In the sub-group of advanced economies, the slope of the EKC only flattens partially, suggesting that other factors may contribute to shaping the EKC. If we limit the estimation of Equation (1) to the top-four emitters within each income group, the results corroborate the findings in Figure 4.

Figure 4: Heterogeneity: advanced vs. emerging countries

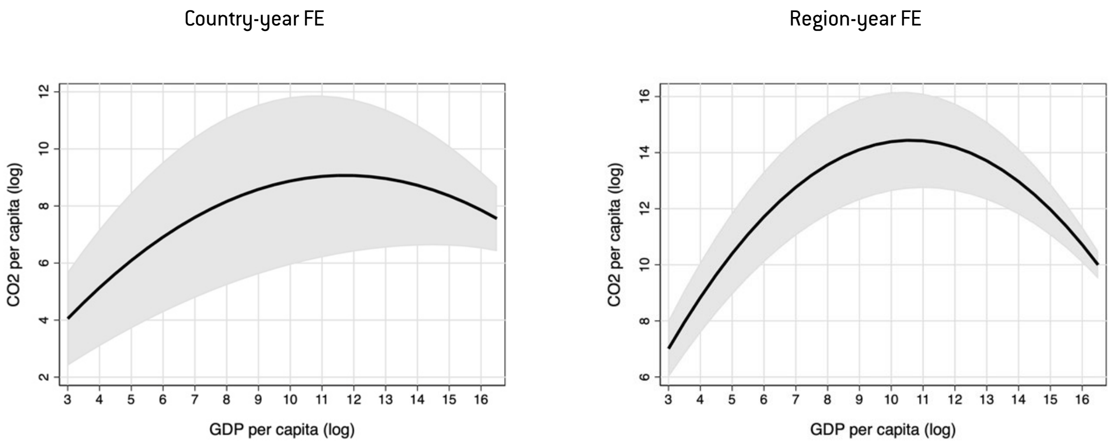


Source: authors' calculations. Note: charts report the effect of the (log of) GDP per capita on the (log of) emissions, for different levels of the (log of) GDP *per capita*. Shaded area represents 90 percent confidence band. Estimate is based on a sample of 39 advanced countries (left), and 152 emerging market economies (right), over the period 1989-2022. OLS model with country and year fixed effects. Heteroskedasticity robust standard errors.

[9] In fact, 2005 is a key year for climate change policy: it was when the Kyoto Protocol entered into force and the EU ETS was set up.

In Figure 5, we re-estimate Equation (1) for a sample of 140 regions in four countries for the period 1995-2018.The sample includes regions in Canada, China, Japan and the US. The left-panel includes country and year fixed effects; the right-panel includes region and year fixed effects. Regardless of the specification, results at the regional level confirm the validity of the EKC hypothesis. At early stages of economic development, increasing income results in more emissions, up to a threshold of about $40,000. Beyond that, emissions decline with income, confirming the EKC.

Figure 5: Baseline results (regional-level analysis)



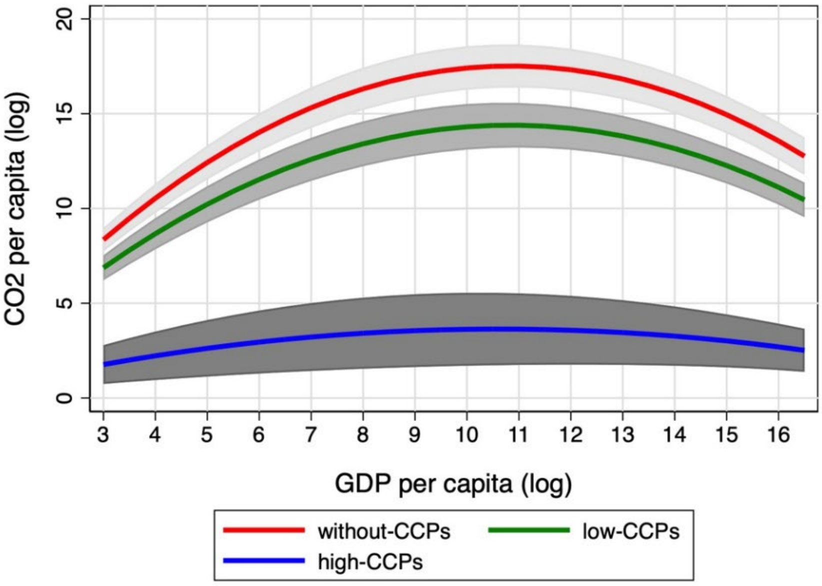
Source: authors' calculations. Note: charts report the effect of the (log of) GDP per capita on the (log of) emissions, for different levels of the (log of) GDP *per capita*. Shaded area represents 90 percent confidence band. Estimate is based on a sample of 140 regions in four countries (United States, China, Japan and Canada), over the period 1995-2018. OLS model with country and year fixed effects (left), and region and year fixed effects (right). Heteroskedasticity robust standard errors.

4.2 The role of environmental regulation

As already stressed, we expect CCPs to lower the EKC (for any income level, emissions should fall due to more stringent CCPs), and make it flatter (ie CCPs contribute to decoupling emissions from economic activity).

Figure 6 reports results from estimation of Equation (2) when we use CCP data from Dolphin (2022), combining emissions trading systems (ETS) and carbon taxes. The red-line plots the baseline relationship; the green-line plots the interaction between *per-capita* GDP (level and squared) and low stringency of CCPs (at the 25th percentile of the distribution of the CCP index across the sample); the blue-line plots the interaction between *per-capita* GDP (level and squared) and high stringency of CCPs (at the 75th percentile of the distribution of the CCP index across the sample).

Figure 6: The mediating role of CCPs: index combining carbon tax and ETS



Source: authors' calculations. Note: chart reports the effect of the (log of) GDP *per capita* on the (log of) emissions, for different levels of the (log of) GDP *per capita*, interacted with a climate change policy (CCP) index drawn from Dolphin (2022), including carbon tax and emissions trading systems. Red-line reports coefficient of the non-interacted model; green-line reports coefficient of interacted model, with CCP at 25th percentile of its distribution (only considering positive values of CCP); red-line reports coefficient of interacted model, with CCP at 75th percentile of its distribution (only considering positive values of CCP). Shaded areas represent 90 percent confidence band. Estimate is based on a sample of 191 countries, over the period 1989-2022. OLS model with country and year fixed effects. Heteroskedasticity robust standard errors.

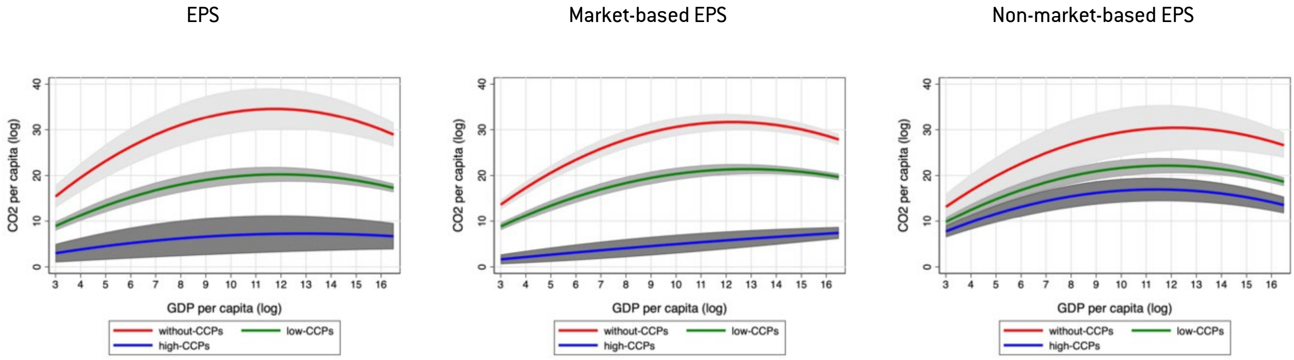
Results confirm our conjectures: the income-emissions relationship tends to disappear as CCPs become stricter. In fact, high stringency of green regulation (ie a carbon tax of at least $6/tCO2 or ETS price of $5.5/tCO2, corresponding to the 75th percentile of their (country-average) distribution[10]) contributes to lowering and flattening the EKC[11]. In fact, delving a bit deeper, one can show that the findings in Figure 6 are mostly driven by carbon taxes, in line with some findings in earlier literature (eg Bettarelli and Yarveisi, 2023), which highlight that a carbon tax is the most effective climate policy in reducing emissions.

[10] These values are computed excluding countries without CCPs implemented.

[11] To get a sense of how the stringency of CCPs influences the EKC, at the average *per-capita* income in the sample, the elasticity of CO_2 *per capita* with respect to GDP *per capita* falls from about 1.41 to 1.07 when climate policy stringency increases by one standard deviation. This represents a reduction of roughly 24 percent in carbon-emission responsiveness. Interpreted in terms of the impact of a 1 percent increase in *per-capita* GDP, this reduced responsiveness implies that the increase in CO_2 emissions *per capita* following a 1 percent increase in GDP *per capita* declines from 1.41 percent to 1.07 percent when environmental policy stringency improves. Given that average CO_2 *per capita* in the sample is around 1.8 tonnes, this corresponds to a difference of roughly 0.006 tons (about 6 kilogrammes) of CO_2 per person for each 1 percent increase in *per-capita* income. To give a sense of scale, this amounts to about 500,000 tonnes less CO_2 for Germany's population, 400,000 tonnes for the UK, just over 2 million tonnes for the United States and around 8.6 million tonnes for China, for every 1 percent increase in GDP *per capita*.

In Figure 7, we study whether the mediating effect of CCPs also materialise in the case of non-market-based CCPs, such as emission limits. In so doing, we make use of data from the OECD, as described in section 3. We consider the aggregate environmental policy stringency (EPS) index, and the two sub-components: market-based CCPs and non-market-based CCPs. Estimations are based on a sample of 40 countries over the period 1990-2020. First, aggregate results using the EPS index confirm the previous baseline findings (left panel): the implementation of stricter CCPs (ie at the 75th percentile of the EPS distribution in our sample) makes the EKC significantly lower and flatter. Second, we show that the aggregate effect is mostly driven by market-based CCPs (centre panel); for any given level of income, the reduction in emissions is greater when market-based CCPs are implemented, than when non-market-based CCPs (right panel) are used. However, although smaller, the effect on the EKC also materialises in the case of non-market-based CCPs[12].

Figure 7: The mediating role of CCPs: EPS, market-based EPS, non-market-based EPS



Source: authors' calculations. Note: charts report the effect of the (log of) GDP *per capita* on the (log of) emissions, for different levels of the (log of) GDP *per capita*, interacted with a climate change policy (CCP) index drawn from OECD, ie aggregate Environmental Policy Stringency (EPS) index (left); market-based EPS (centre); non-market-based EPS (right). Red-line reports coefficient of the non-interacted model; green-line reports coefficient of interacted model, with CCP at 25th percentile of its distribution; red-line reports coefficient of interacted model, with CCP at 75th percentile of its distribution. Shaded areas represent 90 percent confidence band. Estimate is based on a sample of 40 countries, over the period 1990-2020. OLS model with country and year fixed effects. Heteroskedasticity robust standard errors.

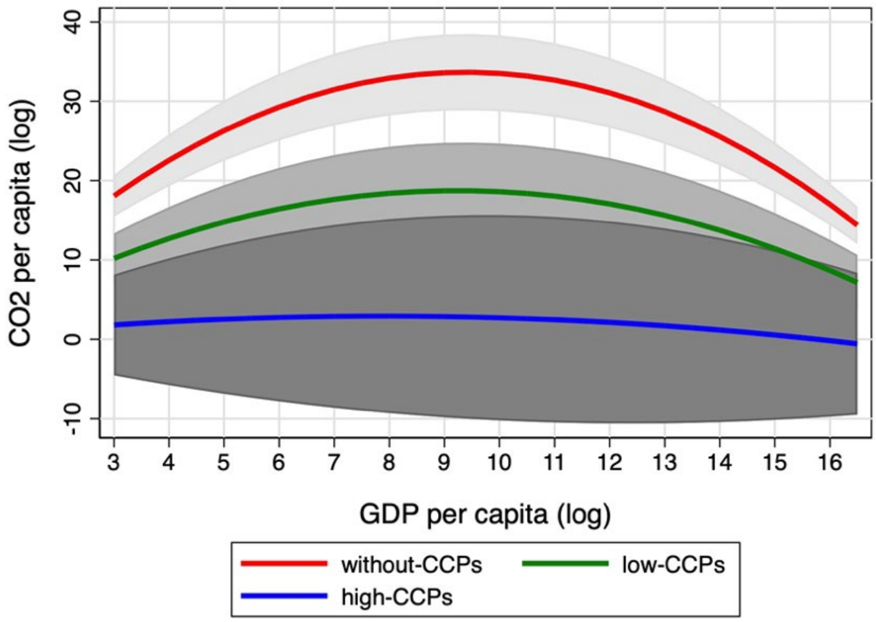
The findings from the estimation are also supported by numerous country examples, which are beyond the scope of this paper, which is concerned with the global evidence from a large panel of cross-country data. That said, a few country examples can be mentioned – cases of green regulations taken by particular countries contributing to evident decoupling. One example is the ambitious environmental targets initiated by China in 2011 in its Twelfth Five-Year plan, which was followed by a reduction in carbon intensity by 15 percent to 20 percent over the subsequent few years, and by double-digit increases in the share of non-fossil-fuel energy over a similar timeframe. In California, Bill 32, passed in 2016, established the nation's first binding greenhouse-gas reduction programme, while the US Environmental Protection Agency issued more stringent national ambient air quality standards.

[12] Results available on request.

These changes were followed by very clear and large reductions in carbon emissions *per capita*. Similar patterns were observed in South Africa, following its strengthening of environmental standards in 2009, France following the strengthening of its standards in 2004, and Switzerland following the strengthening of its standards in 2008.

Finally, we estimate Equation (2) at the regional level. As the indicator of the degree of stringency of CCPs, we use the country-level average value of the combination of carbon taxes and ETS from Dolphin (2022), and we include country and year fixed effects. Results confirm that a high stringency of CCPs (at the 75^{th} percentile of the distribution in our sample) makes the EKC lower and flatter, to the extent that the income-emissions relationship is not statistically significant for any given level of income. These results suggest that strict CCPs contribute to a more pronounced decoupling of emissions and economic development.

Figure 8: The mediating role of CCPs (regional-level analysis)



Source: authors' calculations. Note: chart reports the effect of the (log of) GDP *per capita* on the (log of) emissions, for different levels of the (log of) GDP *per capita*, interacted with a (country-level average) climate change policy (CCP), drawn from Dolphin (2022), including carbon tax and emissions trading systems. Red-line reports coefficient of the non-interacted model; green-line reports coefficient of interacted model, with CCP at 25^{th} percentile of its distribution (only considering positive values of CCP); red-line reports coefficient of interacted model, with CCP at 75^{th} percentile of its distribution (only considering positive values of CCP). Shaded areas represent 90 percent confidence band. Estimate is based on a sample of 140 regions in 4 countries, over the period 1995-2018. OLS model with country and year fixed effects. Heteroskedasticity robust standard errors.

5 Conclusions

The trade-off between economic development and environment quality is subject to an ongoing debate. In recent years, global uncertainty has undermined economic growth, while climate change is at the forefront of modern challenges. The validation of the EKC hypothesis may identify economic development as a pathway for environmental improvements.

Using a large sample of 191 advanced and emerging countries for a period of over 30 years, as well as regional-level data for four major countries, we confirm the validity of the EKC hypothesis. Emissions increase with income up to a threshold of economic development, corresponding to *per-capita* income of approximately $25,000 on average in our sample. Afterwards, emissions *per capita* decline at higher levels of income *per capita*, as suggested by the EKC. Results are robust to several sensitivity checks. Moreover, we show that the EKC has a better-defined shape in relation to emerging countries, and from 2005 onwards.

More importantly, we shed light on the role of CCPs in the EKC. As we expect theoretically, CCPs make the EKC lower and flatter for any given level of income. Among CCPs, the impact is more pronounced in the case of market-based CCPs, such as emissions trading systems and (particularly) carbon taxes.

These results have significant policy implications. They indicate that pursuing economic development and environmental quality are not necessarily at odds, as high income may allow economies to adopt virtuous green practices and reduce emissions. However, in the path towards decoupling emissions and economic activity, the role of governments is crucial, through the implementation of strict (market-based) CCPs.

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Bruegel, Rue de la Charité 33, B-1210 Brussels
(+32) 2 227 4210
info@bruegel.org
www.bruegel.org