WP/18/56

IMF Working Paper

The Long-Run Decoupling of Emissions and Output: Evidence from the Largest Emitters

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INTERNATIONAL MONETARY FUND

 WP/18/56

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Research Department

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Authorized for distribution by Chris Papageorgiou

March 2018

Abstract

For the world's 20 largest emitters, we use a simple trend/cycle decomposition to provide evidence of decoupling between greenhouse gas emissions and output in richer nations, particularly in European countries, but not yet in emerging markets. If consumption-based emissions—measures that account for countries' net emissions embodied in cross-border trade—are used, the evidence for decoupling in the richer economies gets weaker. Countries with underlying policy frameworks more supportive of renewable energy and climate change mitigation efforts tend to show greater decoupling between trend emissions and trend GDP, and for both production- and consumption-based emissions. The relationship between trend emissions and trend GDP has also become much weaker in the last two decades than in preceding decades.

JEL Classification Numbers: O44, Q43, Q54, Q56, E32

Keywords: Emissions, Environmental Okun's Law, Environmental Kuznets Curve

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*We are also grateful to Ottmar Edenhofer, Michael Jefferson, Marina Mendes Tavares, Adele Morris, Ian Parry, Willi Semmler, and participants at the IEW, 5th International Symposium on Environment and Energy Finance Issues (ISEFI), Mercator Research Institute on Global Commons and Climate Change seminar and the IMF’s Development Macroeconomics seminar for their useful comments and advice. Jun Ge provided excellent research assistance. All remaining errors are our own. The views expressed in the paper are those of the authors and do not necessarily represent those of the authors’ professional affiliations.

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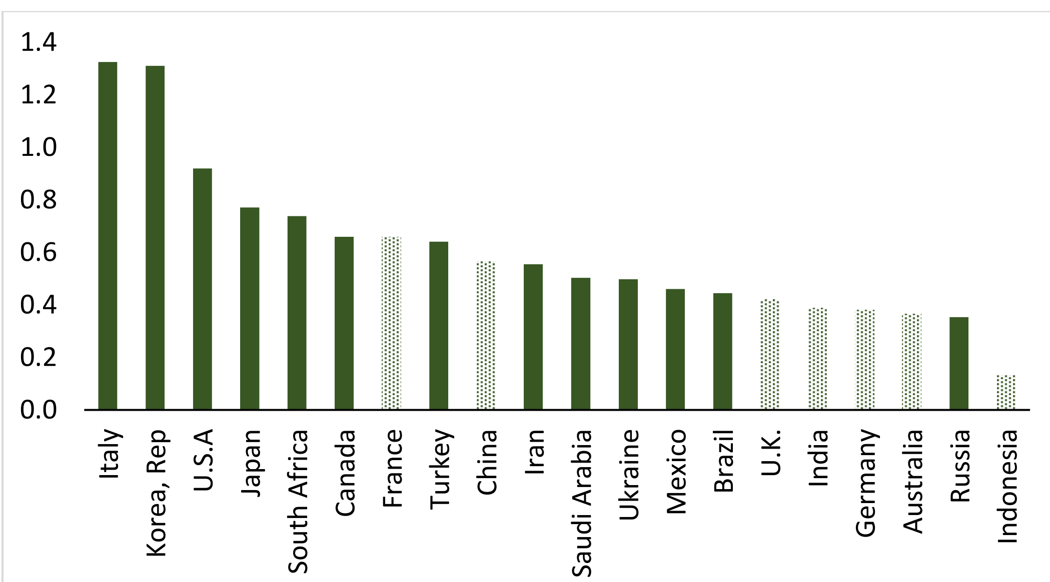
1. Introduction

The Paris climate accord in 2015 – the so-called COP21 – was a landmark effort on the part of countries to set and monitor commitments to mitigate global warming. The COP23 in 2017 in Bonn "sought to maintain the global momentum to decouple output from greenhouse gas emissions" (Gough, 2017). However, the extent to which decoupling is taking place remains a matter of dispute. Drops in emissions often provoke claims from climate sceptics that worries over global warming are exaggerated, while increases in emissions lead to concerns among environmental groups that not enough is being done to address the issue. For instance, a rise in German emissions in 2016 led to alarm in some circles that the country had "further dented" its chances of reaching its 2020 climate targets (Wettengel, 2016).

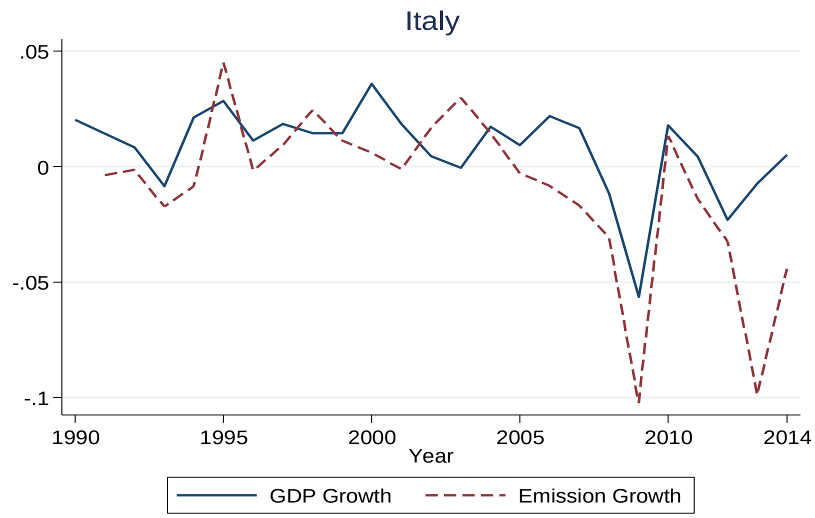
A first crack at the data on emissions and real GDP yields little evidence of decoupling. Figure 1 (a) presents the results of regressions, estimated over the period 1990 to 2014, of growth in greenhouse gas (GHG) emissions on the growth of real GDP for the 20 largest emitters. The bars in the figure show the estimated emissions-output elasticity, the percent change in emissions for a 1 percent change in output, for each of the 20 countries.

Figure 1.a: Response of emissions growth to output growth, top 20 emitters



Note: Each bar denotes the response of emissions growth to output growth. Dark shaded green denote statistically significant coefficient estimates at the 10 percent level or better, while light shaded green bars denote statistically insignificant coefficient estimates.

Figure 1.b: Italy's case: time profile of real GDP growth and emissions growth, 1990-2014



The elasticity is positive for all countries, with an average of 0.6. Figure 1 (b) illustrates the case of Italy, which has the highest elasticity in Figure 1 (a). As shown, between 1990 and 2014, growth in output and emissions are clearly very highly correlated.

This paper revisits the issue of the extent of decoupling between emissions and economic activity and shows why this first crack at the data can be misleading. By decomposing growth in emissions and real GDP into their trend and cyclical components, we show that the trend components reveal clearer evidence of decoupling in richer nations, particularly in European countries, but not yet in emerging markets. The trend elasticities range in value from -0.6 to 1.2. For six countries, including Italy, the elasticities are either essentially zero or negative, suggesting that the trend component of emissions has decoupled from the trend component in output.

We then apply the framework to consider the effects of international trade on the emissions-output elasticities. International trade "gives a mechanism for consumers to shift environmental pollution to distant lands" (Peters and Hertwich, 2008). In particular, as Jaunky (2011) notes, it is possible that although developed economies "may have experienced a change in their production structure, their consumption structure remains unchanged"; hence, the decoupling may arise simply be because "dirty industries in developed countries tend to migrate" to developing economies. To account for these effects, we make a distinction between production-based and consumption-based emissions, where the latter add in the emissions embodies in the net exports of countries. This does make some difference to our results and in the expected direction. The evidence for decoupling for the richer nations gets weaker, including for many European countries (France, Germany, Italy and the UK). For instance, Germany's trend elasticity based on consumption-based emissions is -0.4, compared to -0.8 for production-based emissions.

To document progress on decoupling over time, the main sample is supplemented with longer time series for CO_2 emissions. For 16 of our 20 countries we have data from 1946 onwards. We find that the trend elasticities have declined over the second sub-period (post-1983) compared to the first (1946 to 1982). The average elasticity has declined to 0.7 from 1.1. For 13 countries, we have even longer time-series, sometime extending as far back as 1850. In each case, we find that the trend elasticity computed over the post-1990 period is much smaller than the elasticity over the full sample period; in the case of Germany for instance, the two estimates are -0.6 and 0.9, respectively.

We also provide evidence on some of the factors that may explain the cross-country variation in trend elasticities, such as per capita GDP, environmental and energy policies, and sectoral structure. We find some evidence that trend elasticities are lower for richer countries, measured either by their per capita GDP or sectoral structure (high share of services in value added relative to that of industry or agriculture). There is also evidence that policy actions to encourage use of renewables foster decoupling of emissions and output.

In addition to these findings about trend elasticities, we find that there is a strong cyclical relationship between emissions and output. The cyclical elasticity is positive for all countries and averages 0.5. For Germany, for instance, the cyclical elasticity is nearly 0.2, which can account for some the increase in emissions observed in 2016 as the economy boomed. In general, cyclical developments can often obscure the trend relationship. Moreover, unlike the trend elasticities, the cyclical elasticities have not declined much between the recent decades and the earlier ones.

The contribution of this paper is therefore threefold. First, it provides an account of how the link between emissions and output has evolved across the largest world GHG emitters, distinguishing trends from cyclical fluctuations. Using long-period as well data for the more recent period, we show that trend elasticities have declined over time (i.e. there is a movement towards decoupling). Second, we show that accounting for international trade linkages does not greatly affect estimates of trend elasticities in most cases. Third, we relate differences across countries in trend elasticities to country characteristics and policies. While there is a large literature on the emissions-output nexus, few studies have addressed all these issues for a large group of top emitters in one simple but comprehensive framework, which is the gap this paper seeks to fill.

The remainder of the paper is organized as follows. Section 2 relates our work to the previous literature on decoupling of emissions and output. Section 3 describes our data and empirical approach. Section 4 presents our estimates of trend and cyclical elasticities and explores the determinants of cross-country differences in trend elasticities.

2. Literature Review

We situate our paper within the vast literature on decoupling by discussing four themes: (i) long-run emissions-output elasticities; (ii) changes in elasticities over time; (iii) consumption-based emissions; and (iv) cyclical relationships.

Long-run emissions-output elasticities: The thrust of our analysis is to measure decoupling using the long-run movements in emissions and output. While we use the standard trend/cycle decomposition used in many other fields of economics, other authors have implemented related ideas using other techniques. Narayan and Narayan (2010) use a panel cointegration model to estimate short-run and long-run elasticities—similar in spirit to our cyclical and trend elasticities—of emissions with respect to output; in addition to the difference in technique from our paper, their paper is concerned with developing economies only. Pao and Tsai (2010) also estimate long-run elasticities but only for the BRICs (Brazil, China, India and Russia). Stern, Gerlagh and Burke (2017) adapt a standard growth model to study the relationship between long-run growth rates in emissions and output.

Changes in elasticities over time: An important focus of our work is on whether the extent of decoupling has changed over time. This focus is shared by Ajmi et al. (2015), who investigate how relationships among emissions, energy consumption and output have changed since 1960 for G-7 countries using a sophisticated time-varying vector autoregressive model. Kristrom and Lundgren (2005) study CO_2 emissions in Sweden since 1900; they single out the use of long time series as the "key contribution" of their paper and discuss the advantages of studying emissions "through several phases of development" instead of relying solely on "short panel data sets". They estimate the trend in emissions over long windows (1900-99) and shorter ones (1970-99) to see how the trend behavior has changed over time. We follow a similar method for a much larger group of countries and relate changes in emissions to changes in output (whereas they model emissions only as a function of time).

Consumption-based elasticities: The introduction already referenced a couple of papers that have stressed the importance of analyzing the emissions embodied in international trade. In a similar vein, Davis and Caldeira (2010) find that, in 2004, nearly a quarter of global CO2 emissions were embodied in exports from China and other emerging markets to more advanced economies, while Peters et al. (2011) document that net emissions from trade from developing to developed countries increased fourfold between 2000 and 2008. Over a more recent period since the global financial crisis, Jiang and Guan (2017) use a structural decomposition analysis to suggest that during 2008 to 2011, OECD economies reduced both their production-based and consumption-based emissions. Given the deep recessions in many of these economies over part of this period, in our framework this reduction would be picked up in the cyclical component and may not have much effect on the trend elasticities.

Determinants of decoupling: There is a large literature on the Environmental Kuznets Curve (EKC) and many good surveys of the literature—see, for instance, Stern (2004) and Kaika and Zervas (2013). Many of the papers test for an inverse U-shaped relationship between per capita income and either the level of emissions or some measure of the elasticity of emissions with respect to output. Levinson (2000) states that attempts to test for this nonlinearity have generated "a thicket of mathematics and econometrics." He posits a weaker version of EKC, namely, testing that environmental quality does not steadily deteriorate with economic growth. To test this, "all one needs to do is show that there are some countries and some pollutants for which a time series of pollution plotted against GDP per capita shows a downward trend." We provide some evidence on both this weaker form of the EKC as well as look for the inverse U-shaped relationship. Brown and McDonough (2016) argue persuasively that, regardless of the precise relationship, such "reduced form models may not be particularly informative for policy making because any number of unspecified and untested levers may link per capita GDP to emissions." Motivated by this observation, we go beyond per capita GDP to look at how trend elasticities are related to summary measures of policy actions.

Cyclical relationships: Some papers delve into the cyclical relationships between emissions and output as we do in our paper. Doda (2014) analyzes the heterogeneity in cyclical properties of

CO_2 emissions for a panel of countries and provides evidence of the higher volatility of cyclical emissions relative to GDP.[1]

3. Data and Framework

3.1 Data

Time period and country coverage: Our main sample covers data from 1990 through 2014.[2] The countries included are twenty largest GHG emitters, which account for 74 percent to the world total level of emissions, 63 percent of the world population, and 77 percent of global GDP. China, the U.S., India, Russia, and Japan are the largest GHG emitters. The major source of emissions is the energy sector, followed by agriculture. The twenty largest consumption-based GHG emitters is quite similar to the production-based group.[3] Advanced economies have much lower production-based than consumption-based emissions, while the opposite is true for some emerging markets.

Emissions data: We use a broad measure of emissions that includes, in addition to CO_2, methane (CH4), nitrous oxide (N2O), and fluorinated gases. The various sources are aggregated by the World Resources Institute (WRI), with weights based on their 100-year Global Warming Potential (GWP-100) according to the IPCC's 2nd Assessment Report. We use this broader measure since about 25 percent of emissions do not derive from CO2; these other sources, particularly methane, are important in major agricultural producers (such as Australia, Brazil, Indonesia and Mexico). The longer time series data are from the Carbon Dioxide Information Analysis Center (CDIAC) on CO2 emissions from fossil fuel combustion. For consumption-based emissions data we use the Eora multi-region input-output (MRIO) database, which provides data on both production and consumption emissions.[4]

Environmental policies: To capture cross-country differences in climate change policies, we used two indices: (i) the Germanwatch's Climate Change Performance Index (CCPI); (ii) EY's

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[1] Heutel (2012) discusses the higher volatility and pro-cyclicality of emissions for the United States. York (2012) demonstrates that the response of emissions to an increase in income is greater during economic expansions than during contractions.

[2] Although more recent data on CO2 emissions is available until more recently, the aggregated from the WRI that we use is only available at present through 2014.

[3] Two countries (South Africa and Ukraine) dropped below the top 20 but remained among the largest 23 world emitters.

[4] Additional details can be found in Lenzen et al. (2012, 2013). Consumption-based emissions measures are not without some weaknesses. They may fail to account for different degrees of trade specialization as Jakob et al. (2013) point out. Kander et al. (2015) propose an improvement to consumption-based emissions that account for technology differences in export sectors.

Renewable Energy Attractiveness Index (RECAI).[5] The CCPI compares the climate protection performance of 58 countries, the largest world emitters, starting in 2006. It is based on an aggregation of fifteen indicators, with policies to foster efficiency, use of renewables and other climate-friendly policies receiving a weight of 40 percent. Since the CCPI also includes the emissions level itself as one of indicators, we use the RECAI measure as well as it is less prone to endogeneity issues. The RECAI measures the attractiveness of 40 advanced and emerging economies for companies interested in investing in renewable energies.

Output: Real GDP growth is taken from the IMFs World Economic Outlook (WEO) database. For the analysis with longer time series, we use output data from the Maddison Project. Sectoral value added are taken from the World Bank World Development Indicators.

Summary statistics on our data are provided in Table 1.

Table 1: Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Total GHG emission excl. land use (Production based)	1348	1912	187	11911
Total GHG emission excl. land use (Consumption based)	1389	1849	113	9337
Co2 emission excl. land use (Production based)	1058	1596	145	10328
Agriculture, value added (percent of GDP)	7	6	0.6	29
Industry, value added (percent of GDP)	34	9	19	67
Services, etc., value added (percent of GDP)	60	12	26	79
RECAI score	57	9	42	75
Climate Change Performance Index score	44	28	-78	116
GDP per capita, PPP (constant 2011 international $)	22356	13686	1554	52067

[5] We also relied on the World Energy Council's Energy Trilemma Index (ETI). The ETI ranks 130 countries since 2011 on their ability to provide sustainable energy using four dimensions: Energy security (with a weight of 30 percent), Energy equity (accessibility and affordability; 30 percent), Environmental sustainability (30 percent), and the Country context (10 percent). Results are qualitatively similar to the use of the other indices but not reported here for reasons of parsimony.

3.2 Econometric framework

The elasticity estimates shown earlier in Figure 1(a) were based on the following specification:

$$\Delta e_t = \alpha + \omega \Delta y_t + u_t \qquad (1)$$

where Δe_t and Δy_t are the growth rates of emissions and real GDP, respectively. As noted, the ω estimates are all positive. To be crystal clear, we reiterate that equation (1) is not our preferred specification for measuring decoupling; we simply use it in the introduction to the paper to show that a preliminary approach that does not distinguish trend movements from cyclical relationships would yield misleading conclusions about the extent of decoupling.

Our preferred approach is to distinguish between trends and cycles in both emissions and output. For this, we estimate equations (2) and (3). For the cyclical relationship we estimate:

$$e^c{}_t = \beta^c y^c{}_t + \varepsilon^c{}_t \qquad (2)$$

where $e^c{}_t$ and $y^c{}_t$ are the cyclical components of the log of emissions and log of real output, respectively, and β^c is the cyclical elasticity.[6] Similarly, we estimate the trend elasticity through the following specification:

$$e^\tau{}_t = \gamma + \beta^\tau y^\tau{}_t + \varepsilon^\tau{}_t \qquad (3)$$

where $e^\tau{}_t$ is the trend of the log of emissions, $y^\tau{}_t$ is the trend of log of real output and β^τ is the trend elasticity. An intercept is included (γ) as countries may start out from relatively different initial conditions and have different historical level of emissions.[7] The estimation of equation (3) represents the thrust of our analysis as it measures the long-run co-movement of emissions and output; the estimates of β^τ are therefore the focus of the paper.

To extract the cyclical and trend components we employ the commonly used Hodrick-Prescott (HP, 1981, 1997) filter. This filter minimizes the following function:

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[6] There is an analogy here with Okun's Law (Ball, Leigh and Loungani, 2017), which relates cyclical movements in labor market indicators, such as employment and unemployment, to cyclical movements in output.

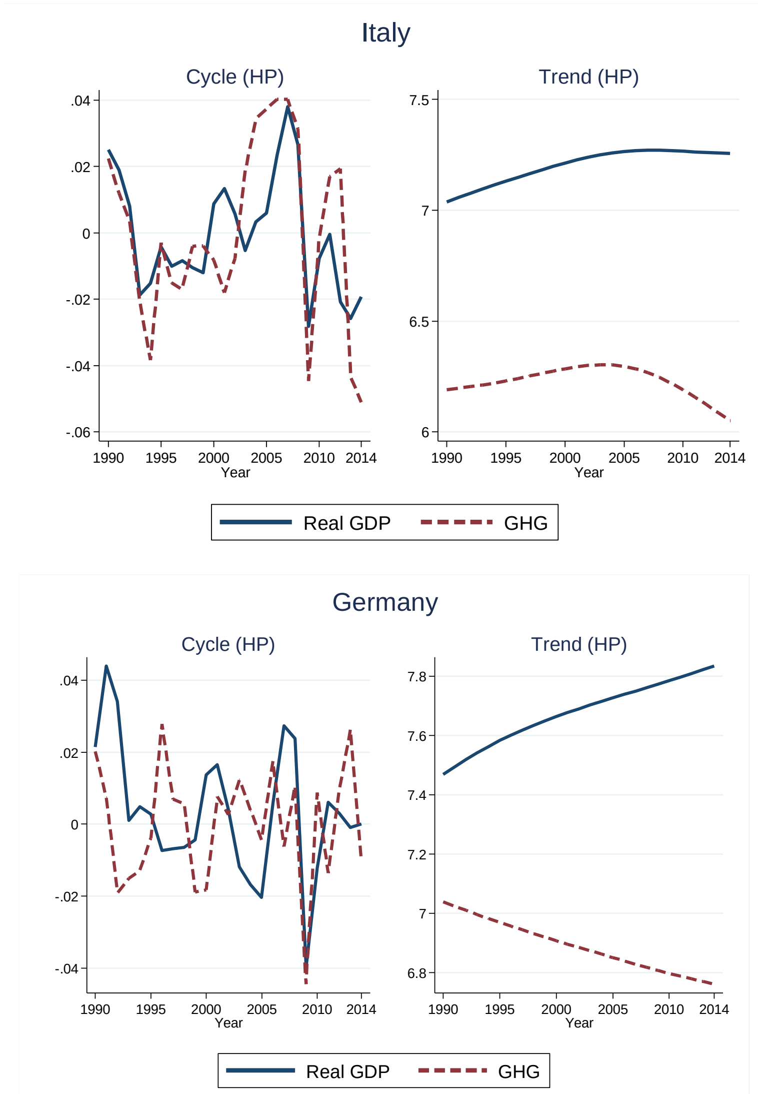
[7] We tested for cointegration between emissions and GDP using three different tests: Augmented Dickey Fuller, the Philipps-Perron and the Kwiatkowski–Phillips–Schmidt–Shin. In the vast majority of cases, the residuals were found to be stationary for the 1990-2014 period; for the longer time series, the early years were characterized by larger residuals. For reasons of parsimony the test results are not reported here.

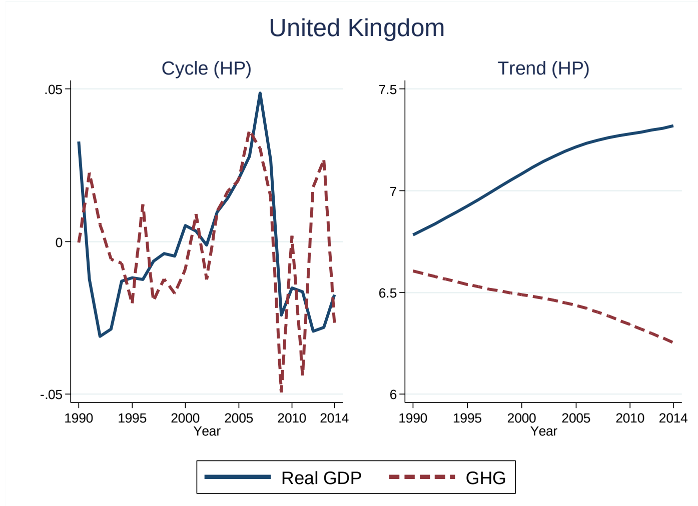
$$\min_{\tau_t}\left\{\sum_{t=1}^{T}(x_t - x^{\tau}{}_t)^2 + \lambda\sum_{t=1}^{T}[(x^{\tau}{}_t - x^{\tau}{}_{t-1}) - (x^{\tau}{}_{t-1} - x^{\tau}{}_{t-2})]^2\right\} \qquad (4)$$

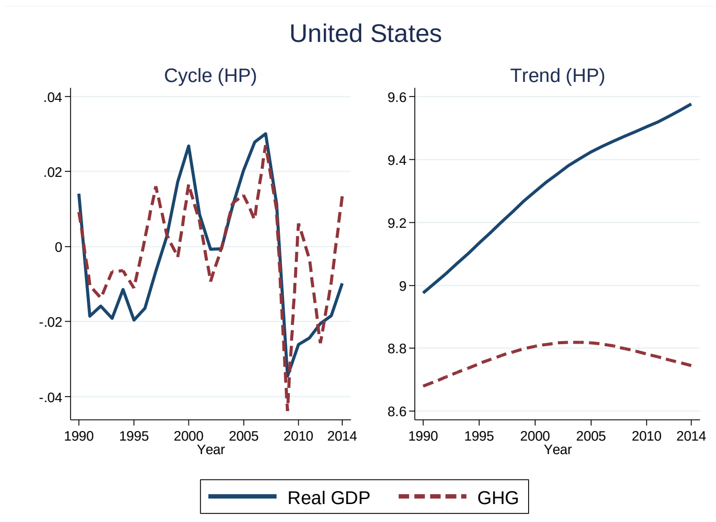
where $x_t = \{y_t, e_t\}$, $x^{\tau}{}_t$ is the trend component and λ is the smoothing parameter (set at 100, which is common practice when employing annual data). The difference between x_t and the trend component is $x^{c}{}_t$, the cyclical component.

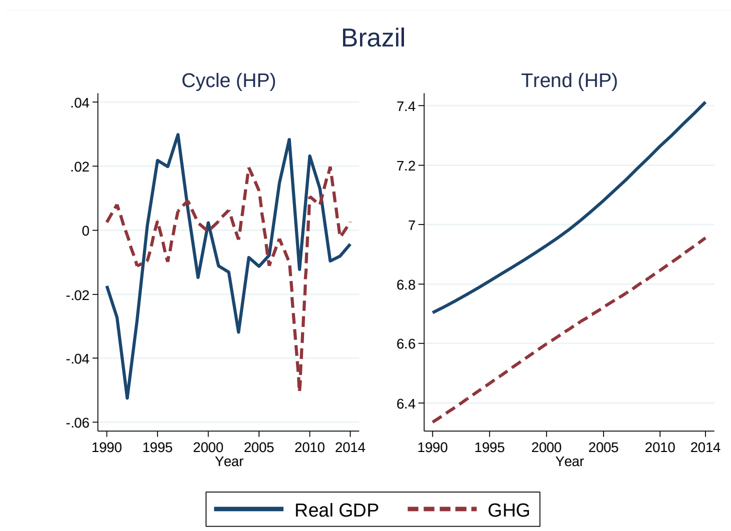
Figure 2 shows the decomposition of emissions and output into cyclical and trend components for four advanced and four emerging market economies.

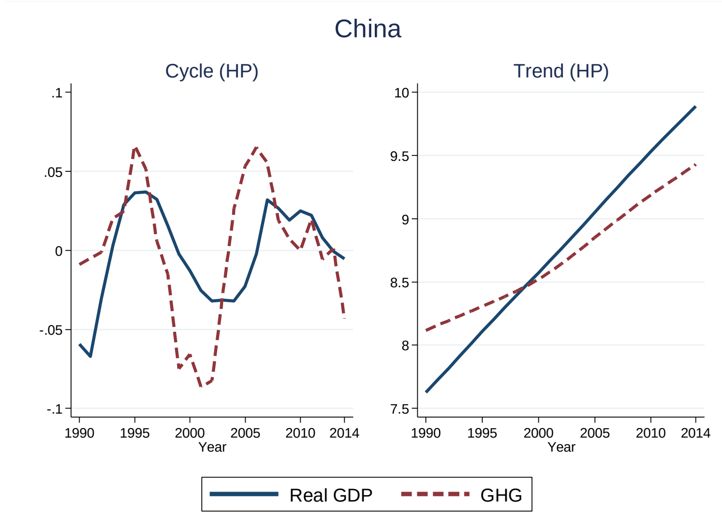
Figure 2: Trends and Cycles in Emissions and Output—Selected Countries, 1990-2014

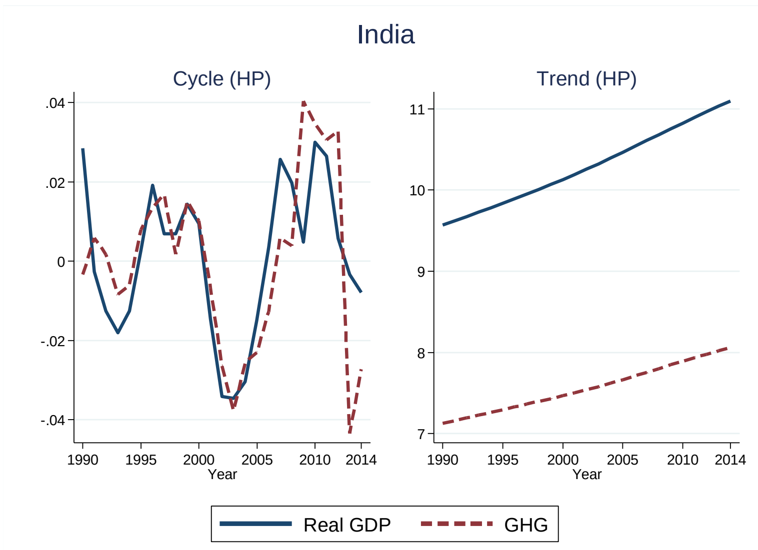



United Kingdom
Cycle (HP)
Trend (HP)
.05
0
-.05
7.5
7
6.5
6
1990 1995 2000 2005 2010 2014
Year
1990 1995 2000 2005 2010 2014
Year
Real GDP
GHG


United States
Cycle (HP)
Trend (HP)
.04
.02
0
-.02
-.04
9.6
9.4
9.2
9
8.8
8.6
1990 1995 2000 2005 2010 2014
Year
1990 1995 2000 2005 2010 2014
Year
Real GDP
GHG


Brazil
Cycle (HP)
Trend (HP)
.04
.02
0
-.02
-.04
-.06
7.4
7.2
7
6.8
6.6
6.4
1990 1995 2000 2005 2010 2014
Year
1990 1995 2000 2005 2010 2014
Year
Real GDP
GHG


China
Cycle (HP)
Trend (HP)
.1
.05
0
-.05
-.1
10
9.5
9
8.5
8
7.5
1990
1995
2000
2005
2010
2014
Year
Real GDP
GHG


India
Cycle (HP)
Trend (HP)
.04
.02
0
-.02
-.04
11
10
9
8
7
1990
1995
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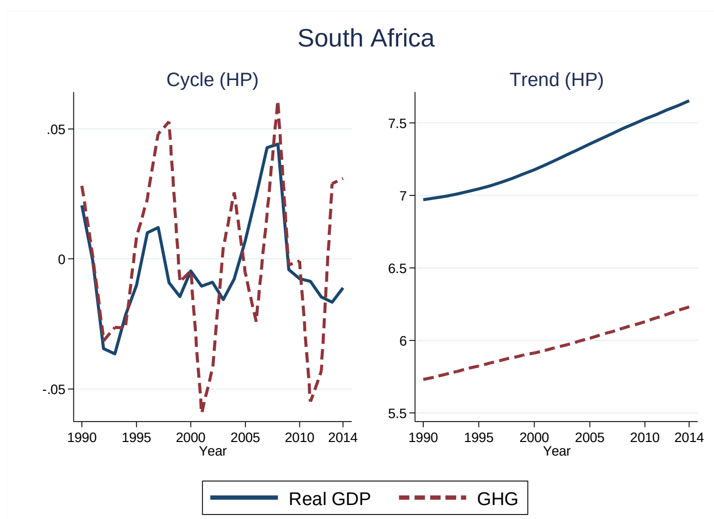
2005
2010
2014
Year
Real GDP
GHG

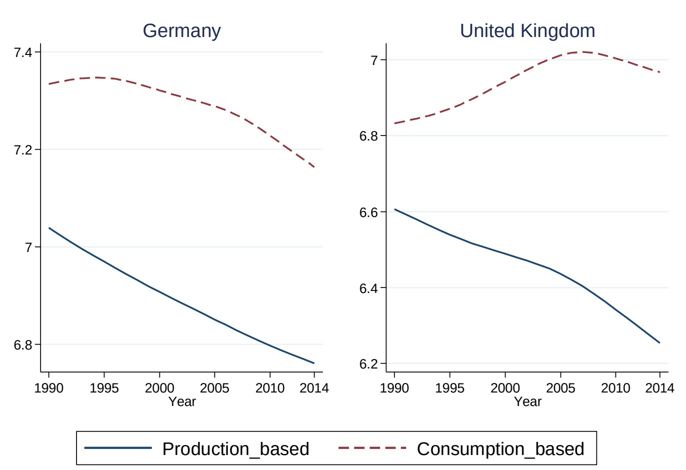

South Africa
Cycle (HP)
Trend (HP)
.05
0
-.05
7.5
7
6.5
6
5.5
1990
1995
2000
2005
2010
2014
Year
Real GDP
GHG

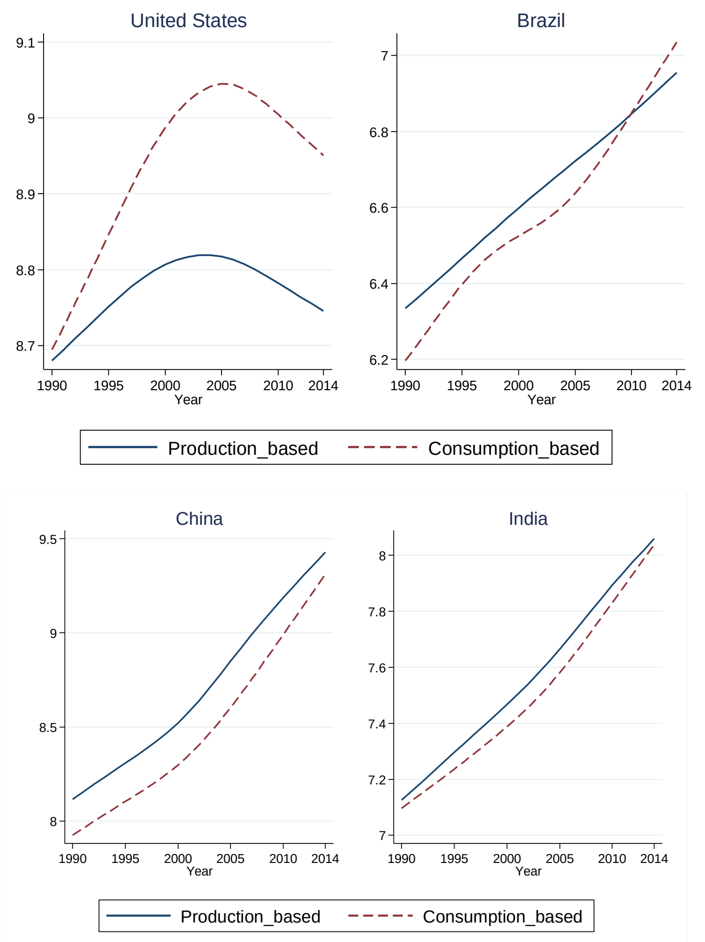
Note: GHG denotes greenhouse gas emissions. "cycle (HP)" denotes the cyclical component of real GDP and GHG emissions and "trend (HP)" denotes the trend component; the components are derived using the Hodrick-Prescott (HP filter).

In each case, the chart of the left shows the cyclical relationship and the chart on the right the trend relationship. In almost all countries, there is a strong cycle in emissions that tracks the cycle in output, with peaks and troughs matching fairly well; the relationship is somewhat weak for Germany and Brazil. The trend behavior differs across advanced and emerging markets. In the former, there is a downward trend in emissions in Germany and the UK over the full period, and a downward trend in emissions in Italy and the US since the mid-2000s. By contrast, in emerging markets there is still a strong upward trend in emissions, matching the upward trend in output.

Figure 3 contrasts the trend components of production-based and consumption-based emissions for six of these countries. In advanced economies, consumption-based emissions are higher than production-based emissions, whereas the opposite is true in emerging markets (Brazil in recent years is a small exception). In Germany, both measures of emissions have trended down over the sample period; in Italy and the US consumption-based emissions have only started to trend down since the mid-2000s. In the emerging markets, differences between the two measures of emissions are small and the trend is upward-sloping for both measures.

Figure 3: Comparison of Trends in Production-Based and Consumption-Based Emissions, 1990-2014





Note: Each chart shows the time path of the trend production-based (solid blue line) and trend consumption-based (dashed red line) versions of emissions.

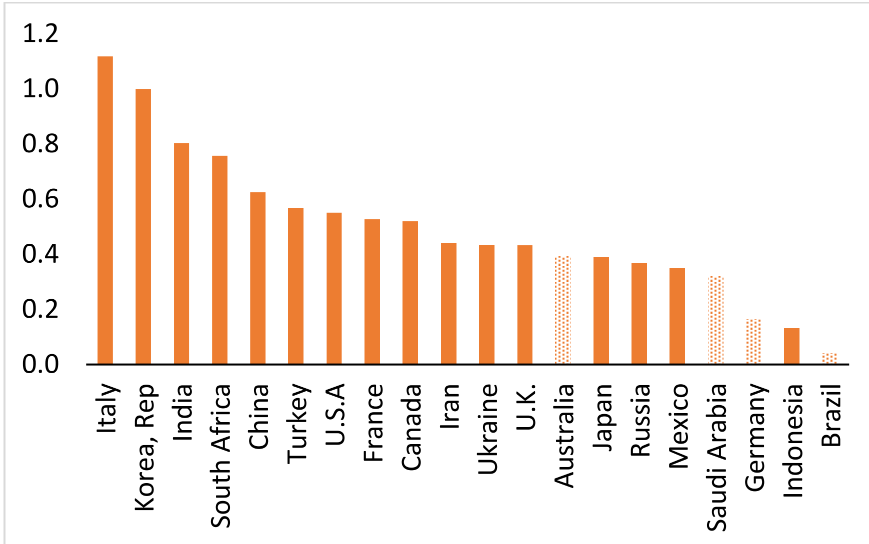
4. Results

4.1 Cyclical and trend elasticities

Figure 4 shows the estimates of β^c using production-based emissions for the 20 countries. In all cases, the estimate is positive: emissions are procyclical. The average elasticity is 0.5 and the estimate is significantly different from zero in all but four cases (Australia, Saudi Arabia, Germany and Brazil). The differences between advanced and emerging markets are not large: the average elasticity is 0.6 for the former and 0.4 for the latter.[8]

[8] We also estimated cyclical elasticities using consumption-based emissions data. These estimates are higher than the production-based cyclical elasticities for most countries. We plan to investigate the possible reasons for this difference in future work.

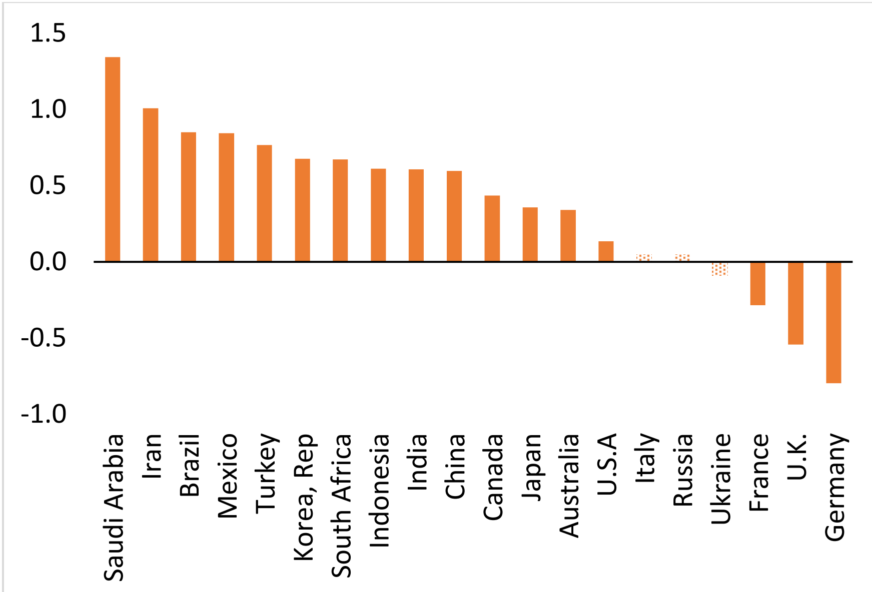
Figure 4: Cyclical Relationship between Production-Based Emissions and Output



Note: Each bar represents the coefficient estimate resulting from country-specific regressions of equation 2. Dark shaded orange bars denote statistically significant coefficient estimates at the 10 percent level or better, while light shaded orange bars denote statistically insignificant coefficient estimates.

Figure 5 presents estimates for β^{τ}, the trend elasticities for all countries. The average elasticity is 0.4 and it is significantly positive for 14 countries. For most of these countries, the elasticity is well below 1; in the terminology of Rodriguez, Pena-Boquete and Pardo-Fernandez (2016), there is thus a relative decoupling between emissions and output. In contrast to cyclical elasticities, differences between the advanced economy group and the emerging market group are now more evident. The average elasticity is close to 0 for the former and nearly 0.7 for the latter. For six countries, the trend elasticities are not significantly different from zero (Italy, Russia, Ukraine) or significantly negative (France, Germany, UK); these countries can be said to have achieved an absolute decoupling, with trend emissions either stable or actually declining and hence no longer correlated with the upward trend in output. These countries are also the ones that are widely regarded as having "taken the lead in implementing national policies" aimed at decarbonizing their economies (Fabra et al. 2015).

Figure 5: Trend Relationship between Production-Based Emissions and Output



Note: Each bar represents the coefficient estimate resulting from country-specific regressions of equation 3. Dark shaded orange bars denote statistically significant coefficient estimates at the 10 percent level or better, while light shaded orange bars denote statistically insignificant coefficient estimates.

To address concerns about the endogeneity of output in the regressions estimated above, we also tried an instrumental variable (IV) approach, where a country's real output is instrumented by the trade-weighted real output of its trading partners (see Burke, Shahiduzzaman and Stern, 2015, for the use of a similar instrument).[9] There are only two cases for which the IV estimates of the trend elasticity differ from that of the OLS estimate, Italy and Ukraine. Overall, the correlation between the IV and OLS estimates is 0.9.[10]

We next look at the role that international trade may have played in helping advanced economies transition to a low-carbon path. Most advanced economies export goods and services that are less pollution-intensive than their imports. Consumption-based trend elasticities can reveal whether countries have maintained consumption patterns that are carbon-intensive despite reducing their (production-based) emissions.

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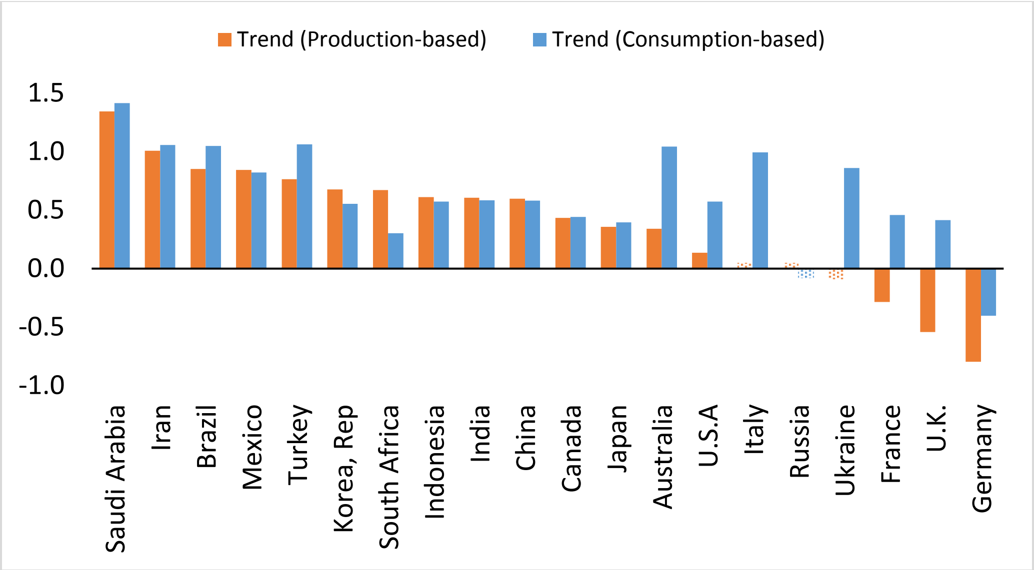
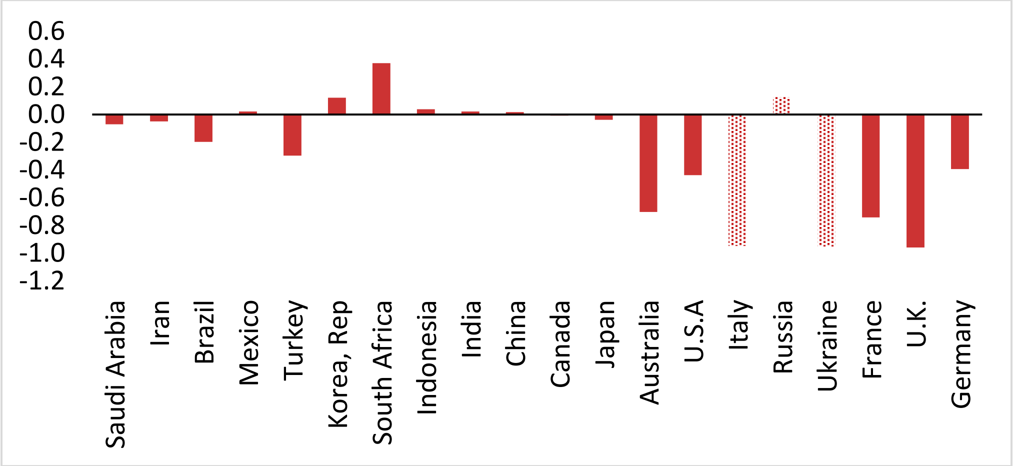
[9] As in other studies which use such an instrument, the real output growth of main trading partners variable is constructed from bilateral trade data from UN COMTRADE database and it is defined as the average growth rate of country i's top 20 trading partners weighted by country j's export share in country i. Moreover, the first stage regression confirmed the suitability and validity of the instrument used: the F-statistic (or robust Kleinberger-Papp rk Wald statistic) for weak identification exceeds all thresholds proposed by Stock and Yogo (2005).
[10] We also estimated a bivariate VAR model to allow for a more dynamic relationship between emissions and output. In general, we found greater evidence for causality from output to emissions than in the other direction.

Figure 6.a: Comparison of Production-Based and Consumption-Based Trend Elasticities



Note: Each bar represents the coefficient estimate resulting from country-specific regressions of equation 3 using either production-based (orange) or consumption-based (blue) emissions as the dependent variable. Dark shaded colors denote statistically significant coefficient estimates at the 10 percent level or better, while light shaded colors denote statistically insignificant coefficient estimates.

Figure 6.b: Difference between Production-Based and Consumption-Based Trend Elasticities



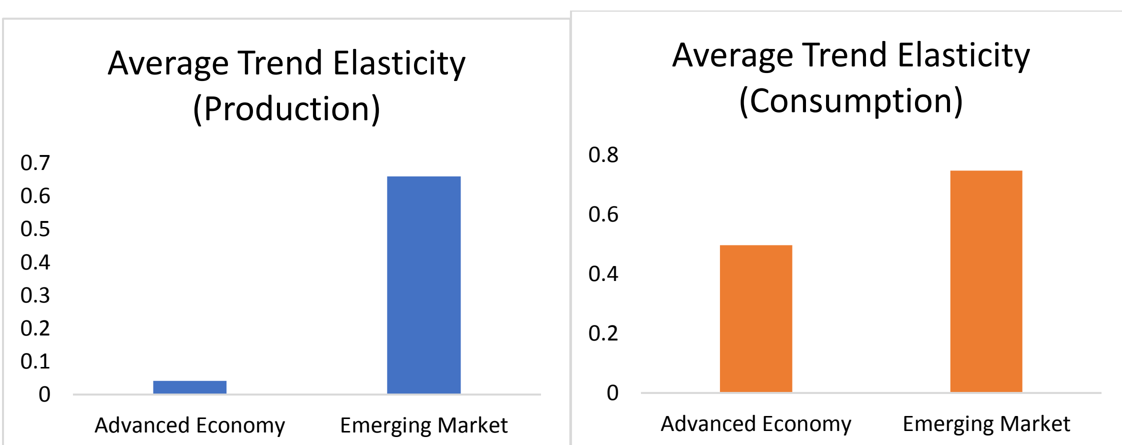
Note: Each bar corresponds to the difference between the corresponding blue and orange bars in figure 6.a. The lighter colors are used to indicate that the production-based elasticity is not statistically significant in figure 6.a.

To this end, Figure 6a presents estimates the consumption-based trend elasticities for the 20 countries, while Figure 6b shows the difference between the production-based and the consumption-based elasticities to make it easier to see where the two differ substantially. The average consumption-based trend elasticity is 0.6, higher than the 0.4 average with production-based emissions. The average elasticity for advanced economies increases to 0.5 from zero, while the average elasticity for emerging markets remains essentially unchanged at about 0.7. The biggest differences occur largely in cases where the production-based trend elasticities were very low. For Germany, for instance, the consumption-based elasticity is -0.4, compared with -0.8 with production-based emissions. For France and Italy, the consumption-based elasticity is positive, while the production-based elasticity is negative. For the emerging markets, the differences are smaller, with Ukraine being an exception.

4.2 Determinants of Cross-Country Differences

Our results support Levinson's view that "pollution does not necessarily increase" as countries get richer. The evidence is summarized in Figure 7 by showing the average trend elasticities for production-based and consumption-based emissions for the advanced country group and emerging markets group. It is evident that, if anything, trend elasticities decline with per capita incomes, though the decline is starker with production-based estimates.

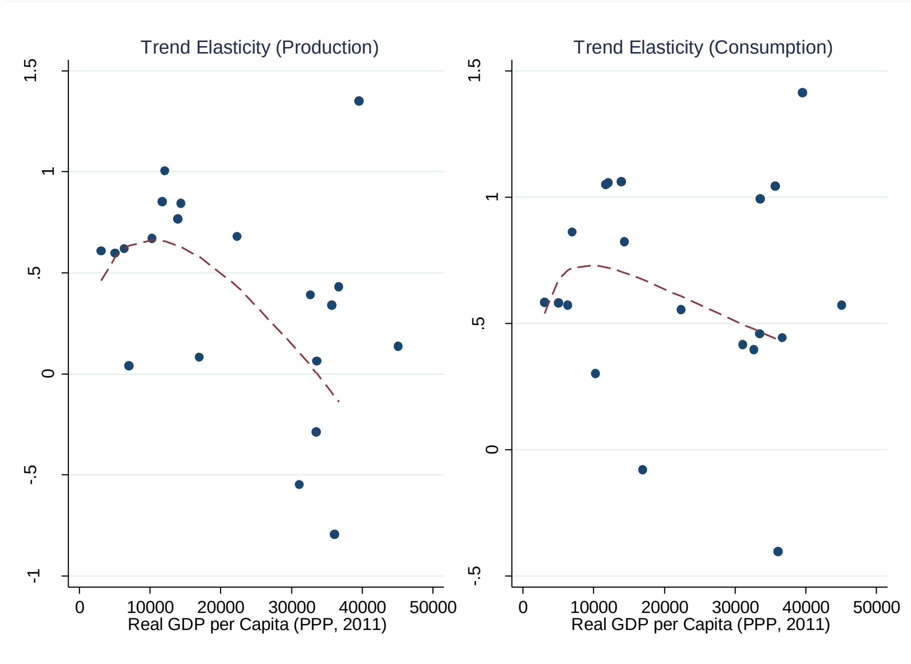
Figure 7: Average Trend Elasticities for Advanced Economies and Emerging Markets, Production vs Consumption-based emissions



Note: Each bar averages the estimates obtained by each country group according to the type of dependent variable used in the underlying estimation (production or consumption-based emissions).

Exploring further and plotting the elasticities against per capita income, there is some support for an inverted-U shape, as shown in Figure 8.

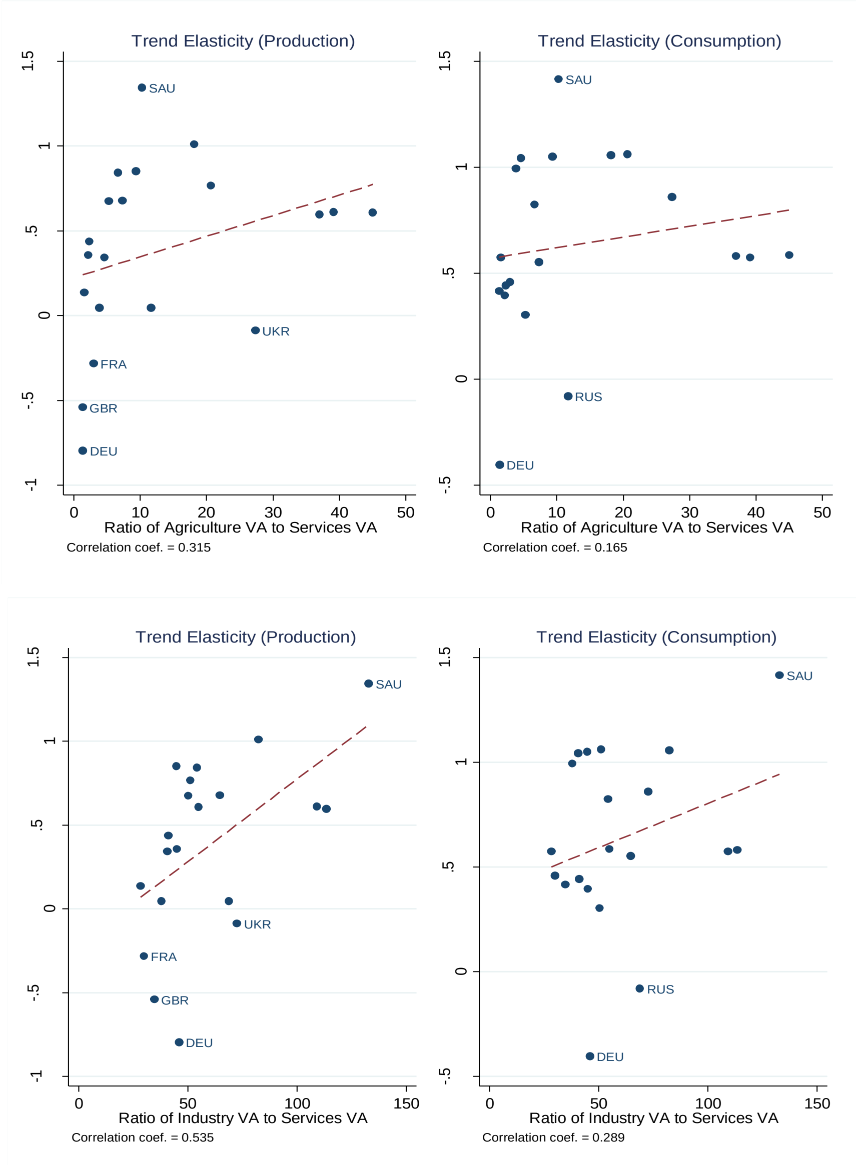
Figure 8: Trend Elasticities and Per Capita GDP



Note: Real GDP per capita is an average over the 1990-2014 period. Data for all countries are measured in PPP-based constant (2011) US dollars.

The impact occurs in part through the sectoral transformation of production as countries get richer and move into less pollution-intensive services sectors. This is illustrated in Figure 9, which plots trend elasticities against the share of agriculture relative to services in value added (top panel) and the share of industry relative to services in value added (bottom panel). Countries with larger shares of agriculture or industry relative to services have higher trend elasticities, with the relationship holding more strongly for production-based than for consumption-based emissions.

Figure 9: Trend Elasticities and Sectoral Value-Added Composition



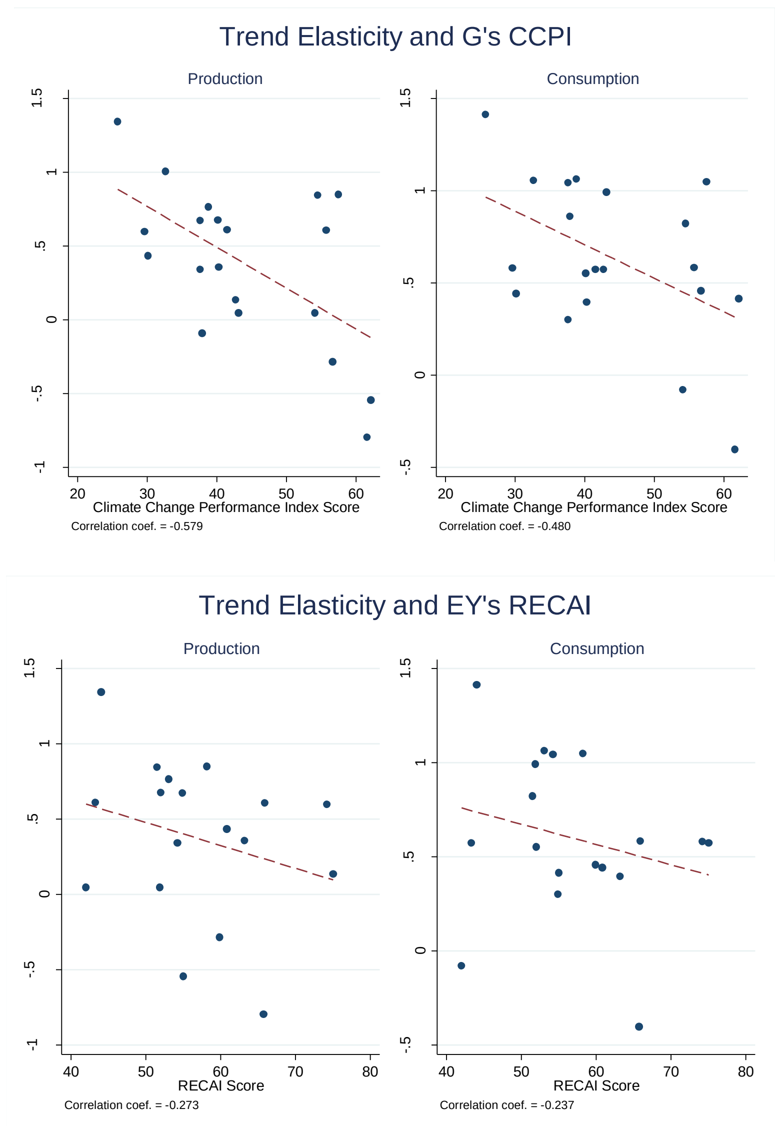
Note: Ratios are measured as an average over the 1990-2014 period; they have been scaled up by 100.

Trend elasticities are also correlated with measures of environmental policy setting capturing the relative attractiveness and quality of climate change policies. For both measures used, greater policy efforts to foster renewables and encourage energy efficiency, reflected in higher values of the indices, is correlated with lower trend elasticities. This is shown in Figure 10 for CCPI index (top panel) and the RECAI index (bottom panel).[11] Simple regressions of trend-based

[11] The relationships are a bit weaker for consumption-based elasticities, perhaps reflecting the fact that the indices rank countries according to their policies on curbing production-based emissions rather than including measures embedding the carbon-intensity of consumption.

production or consumption-based elasticities on measures of environmental policy setting (together with real GDP per capita and sectoral value-added ratios), confirm the negative and statistically significant influence of the former set of policies on long-run emissions. Given the small number of observations, these regressions should be regarded as suggestive, and further work is needed to understand fully these relationships.

Figure 10: Trend Elasticities and Climate-related Policy Indices



Note: Policy indicators are averages over the 2006-14 period.

4.3 Changes in trend elasticities over time

We carry out two exercises to see how the production-based trend elasticities for CO_2 emissions have changed over time. First, for the 20 countries in our sample, we compare elasticities for the post-WWII period (1946-1982) with the period since the Great Moderation (post-1983). Table 2 summarizes the average trend elasticities across the two periods. The post-WWII period brought carbon intensity to a new level. The rapid growth in energy demand, mostly for oil, accounts for the high elasticities during this time. Most of the countries have trend estimates greater than 1 over this period and some (China, India, and Korea) have coefficients greater than 1.5. The trend elasticities have come down significantly over the later period, averaging 0.7. The Kyoto protocol and the slowdown in energy consumption, in particular of coal until 2001, may have played a role. China's trend elasticity more than halved relative to the previous period.

Table 2: Trend and Cyclical Elasticities for CO_2 Emissions

	Post-WWII period (1946-1982)	**Great Moderation (post-1983)**
Trend Elasticity (average, 20 countries)	1.11	0.66
Cyclical Elasticity (average, 20 countries)	0.64	0.65

The second exercise compares elasticities over long periods with those over the post-1990 period for 16 countries where we have historical data on both emissions and output. The estimates in Table 3 show that in all cases but one (Brazil), the elasticity for the later period is much lower than the one for the full sample. The reduction is more striking for the advanced economies (the average is 0.3 in the recent period compared with 1 over the full sample), but emerging markets have made progress as well—the averages are 0.9 and 1.3, respectively.

Table 3: Trend Elasticities for CO_2 Emissions

Advanced	Initial Date	Full Period	Since 1990
Australia	1860	1.4	0.7
Canada	1870	1.0	0.5
France	1850	0.7	0.1
Germany	1850	0.9	-0.6
Italy	1860	1.5	0.6
Japan	1950	0.9	0.7
Korea	1911	1.4	0.7
U.K.	1850	0.4	-0.2
U.S.A	1850	1.0	0.3
Emerging			
Brazil	1901	1.2	1.2
China	1950	1.0	0.6
India	1884	1.8	0.8
Indonesia	1889	1.7	1.2
Mexico	1900	1.1	0.8
South Africa	1950	0.9	0.7
Turkey	1923	1.3	1.0
Average (all countries)		*1.1*	*0.6*
Advanced		*1.0*	*0.3*
Emerging		*1.3*	*0.9*

5. Conclusions

We have proposed a simple but comprehensive framework—the trend/cycle decomposition that is widely used in many other fields in economics—to investigate the decoupling of emissions and growth. For the twenty largest emitters, the average trend elasticity, viz. the response of trend emissions to a 1 percent change in trend GDP, is 0.4. For the advanced economies within this group, the elasticity averages zero; some countries have negative elasticities, suggesting that they had made progress in decoupling their trend emissions from trend GDP. Taking account of consumption-based emissions weakens the case for progress but does not overturn it. Encouragingly, we find suggestive evidence that trend elasticities can be lowered through policy efforts on the part of countries. Moreover, our investigation of the historical relationships between emissions and GDP shows that elasticities in recent decades are considerably lower than in previous decades.

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