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INSTITUTT FOR FORETAKSØKONOMI

DEPARTMENT OF BUSINESS AND MANAGEMENT SCIENCE

FOR 16 2018

ISSN: 1500-4066

December 2018

Discussion paper

CO_2 intensity and GDP per capita

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Abstract

The relationship between CO_2 intensity and GDP per capita is studied. Most rich countries show falling CO_2 intensity over time and a negative correlation with GDP per capita. Many poor and medium rich countries show the opposite, a positive time trend and a positive correlation with GDP per capita. For the majority of countries with a negative correlation between CO_2 intensity and GDP per capita a non-linear function fits the data better than a linear one, implying that CO_2 intensity falls at a diminishing rate as countries get richer. Hence, economic growth will not by itself go very far in reconciling economic growth and reductions in CO_2 emissions. There are indications that poor and medium rich countries experience a boost in CO_2 intensity as they embark on industrialization. This will also make it harder to reconcile economic growth and cuts in CO_2 emissions.

Keywords: carbon dioxide, economic growth, CO_2 intensity

JEL classification: O44, Q43, Q54

August 2018

Introduction

Is economic growth compatible with reduction in carbon dioxide emissions? If so, carbon dioxide emissions per unit of GDP (hereafter CO_2 intensity) will have to fall. New technologies for energy production on a grand scale are likely to be necessary for this, but it would also help if there are structural trends accompanying economic growth that would bring the CO_2 intensity down. This is not unlikely, as economic growth is accompanied by disproportionate growth of services, which are less energy intensive than material production (Medlock and Soligo, 2001).

What is the historical record? As part of its battery of world economic indicators, the World Bank publishes carbon dioxide content per unit of GDP at fixed prices for most countries in the world. In this paper we use this data to investigate the historical record across countries and, in particular, how CO_2 intensity is related to GDP per capita. We get mixed results, but yet a tendency that the CO_2 intensity falls as countries get richer.

According to the BP Statistical Review of World Energy, more than 80 percent of primary commercial energy still comes from fossil fuels. Since most CO_2 emissions are caused by burning fossil fuels, what has happened to CO_2 intensity is in large measure a reflection of what has happened to energy intensity. Many papers on that subject have been published, and most indicate that energy intensity falls as GDP per capita increases, or that the relationship has an inverted U-shape. Csereklyei, Rubio-Varas and Stern (2016) find, for a sample of 99 countries, that energy intensity falls as countries grow richer, but point out that energy intensity may increase in countries experiencing no growth. They also point out that the increasing energy intensity often observed for poor countries could be due to a transition from non-commercial biomass energy to commercial energy. They include non-commercial energy in their data, but recognize the unreliability of such data. Most other studies use only commercial energy. Medlock and Soligo (2001) find the inverted U-shape for intensity of commercial energy, for a panel of 28 countries.

In a recent paper, Semieniuk (2018) investigates the "green growth hypothesis", that is, whether a faster development in productivity will reduce the energy intensity of the economy. Using a large but unbalanced panel—180 countries 1950-2014—he finds that faster growth is not greener; a higher rate of labor productivity growth is typically associated with a higher rate of growth of energy input per unit of labor, canceling the effect on energy intensity. Hence, faster productivity growth will not contribute to reconciling economic growth and reduction in CO_2 emissions.

Two papers study the relationship between CO_2 emissions and GDP. Bella, Massidda and Mattana (2014) study the relationship between total CO_2 emissions and total GDP for a panel of 22 OECD-countries. They find an inverted U-shape for most countries, which most likely implies a similar shape as well for CO_2 intensity and GDP per capita, as for most countries GDP and GDP per capita have moved in the same direction. Jakob et al. (2012) study the growth of CO_2 emissions and GDP for a sample of 51 countries. They break their sample into developing and industrialized countries and find that both grew at a rate higher than average in developing countries while there is no significant relationship between the growth rates of GDP and the use of energy for developed countries. These results are not directly comparable to ours, but neither do they contradict them.

Looking at the relationship between CO_2 intensity, or energy intensity, and GDP per capita implies that a structural change in GDP as countries grow richer is seen as a driver of changes in CO_2 emissions or energy use. A rationale has already been advanced; as countries get richer, more and more of presumably less energy intensive services is produced and CO_2 intensity falls, while in countries just beginning their industrialization the opposite might happen. But things are more complicated than that. Energy or CO_2 intensity might fall with no change in GDP per capita because of technological progress leading to increased energy efficiency across economic sectors or a transition from fossil fuels to other energy sources, or even between different fossil fuels (such as less reliance on coal and greater use of natural gas). Two studies of the US economy try to tease out how much of energy savings is due to increased energy efficiency (better technology) and how much is due to structural changes following changes in GDP per capita. Metcalf (2008) found that most of the reduction in energy intensity is due to improvements in energy efficiency while Huntington (2010) came to the opposite result. As pointed out by Huntington, the difference could be due to the degree of disaggregation in the data. So, to analyze this question, one needs not only country-specific disaggregated data, but the level of aggregation could have a critical bearing on the answer.

There are more devils in the details. In a recent paper, Croner and Francovic (2018) study structural versus efficiency factors behind changes in energy intensity, using detailed input-output coefficients for a number of countries. They point out that production-based data give more importance to structural factors than consumption-based data would do, because rich countries have to a large extent outsourced the production of CO_2-intensive goods to developing countries, a point also made by Dieter Helm (2012) with the British economy as an example. This present study uses GDP data at a country level and makes no pretense at distinguishing between structural and technological factors behind changes in CO_2 intensity. That said, looking at the relationship between CO_2 intensity and GDP per capita at the country level is interesting in its own right and a first approximation to what is going on.

The time trend

Figure 1 shows the development of the CO_2 intensity world wide, for real GDP measured in 2010 US dollars. The CO_2 intensity fell steadily from 1960 to 2000 and stagnated after that. This is curious, as efforts to develop green energy and otherwise reduce carbon dioxide emissions have been particularly strong after 2000. When China is removed from the sample of nations the stagnation disappears. Nevertheless, the CO_2 intensity has fallen more slowly for the world excluding China in this century than it did before, so we still face the paradox why efforts at decarbonization have achieved so little since they appeared on the world agenda.

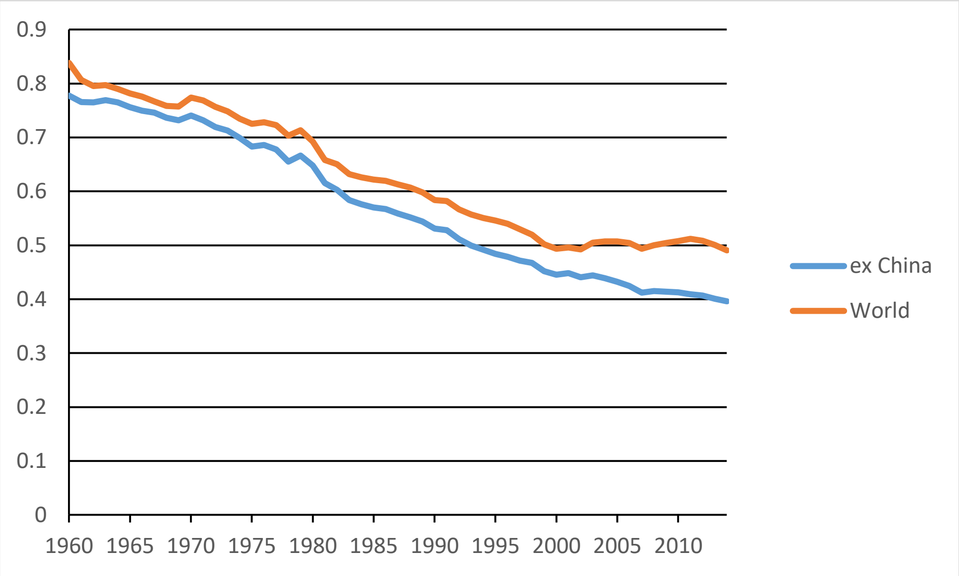


Figure 1: World CO_2 emissions (kg per 2010 US$ of GDP) 1960-2014 with and without China. Data from the World Bank.

What is the time trend across countries? Table A1 in the Appendix shows which countries had a significant (at the 5% level) time trend for CO_2 intensity 1960-2014 (not all countries are represented for the entire period). Most countries with a GDP per capita of more than 23,000 dollars, and there are 36 of them, have a negative time trend, but for five the trend coefficient is insignificant. Below 23,000 dollars of GDP per capita a significantly positive time trend begins to show up, and then we are down to what may be termed medium rich countries; the richest ones of those with a positive time trend are

Greece, Portugal and Saudi Arabia. For the remaining 154 countries, which may be characterized as medium rich or poor, we get a significantly positive time trend for about a half (69), while for 58 we get a significantly negative time trend, and for 28 we get no significant trend at all. The CO_2 intensity has thus tended to rise rather than fall for medium rich and poor countries, contrary to what has happened in rich countries.

CO_2 intensity and GDP per capita

One reason why the CO_2 intensity has been falling over time in many countries is that GDP per capita has been increasing. If CO_2 intensity falls as GDP per capita increases, for reasons already mentioned, this will show up as a falling time trend of CO_2 intensity. We now turn to investigating the relationship between CO_2 intensity and GDP per capita. We focus attention on countries with a negative relationship between these two and specify three models, a linear model, a second degree equation, and a power equation, as follows:

$$y = a - bx$$

$$y = a - b_1 x + b_2 x^2$$

$$y = a x^{-b}$$

where *y* is CO_2 intensity and *x* is GDP per capita. The coefficients are estimated with linear regression, with the last equation on logarithmic form. We retain the model with the largest explanatory power (R^2) and significant coefficients.

The results are summarized in Table A1. We get a significantly negative correlation between CO_2 intensity and GDP per capita for 93 countries, slightly more than show a significantly negative time trend (88). The countries with a negative time trend and a negative correlation with GDP per capita are mostly the same. For only 47 do we get a positive correlation between CO_2 intensity and GDP per capita, far fewer than those which show a significantly positive time trend (69), so there are more countries with no significant correlation between CO_2 intensity and GDP per capita (50) than those with an insignificant time trend (33).

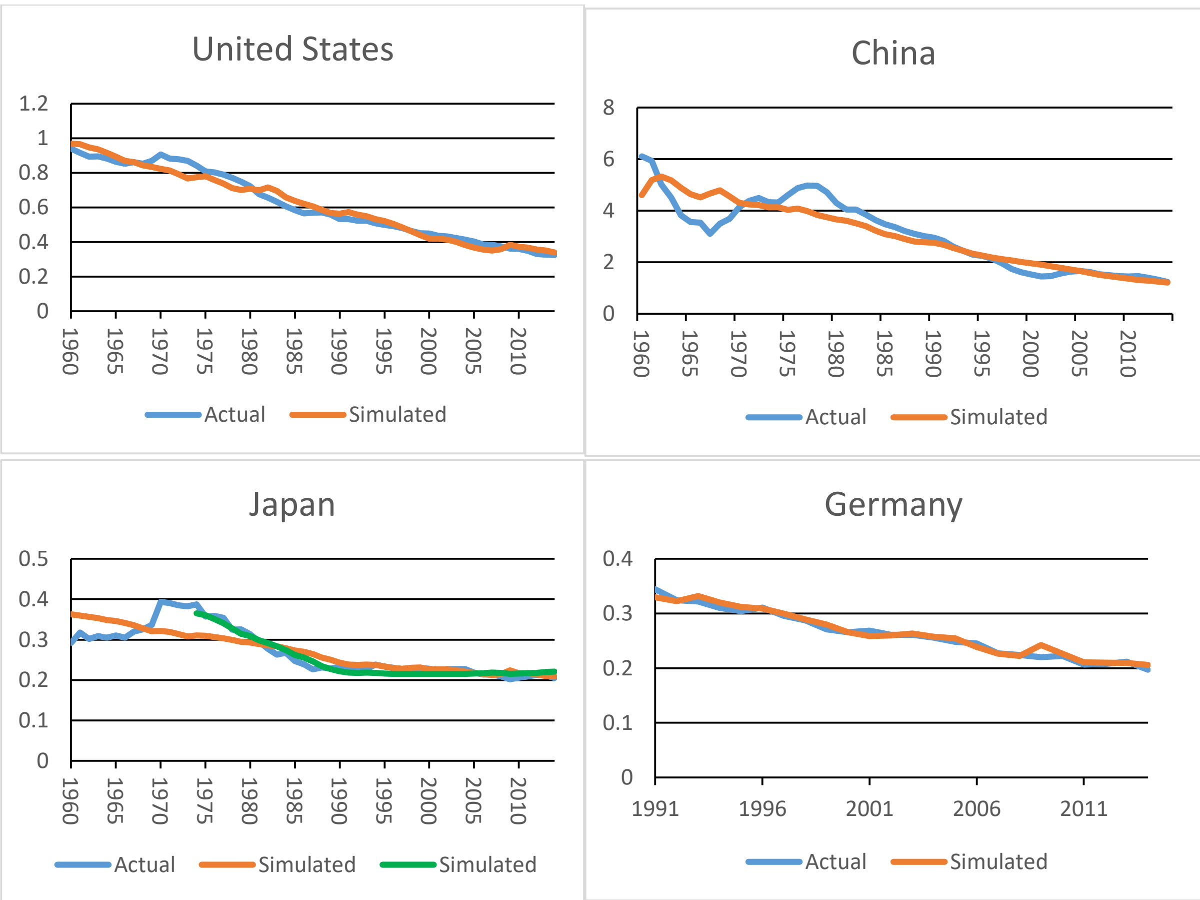
For the majority of countries where CO_2 intensity falls as GDP per capita increases a non-linear relationship is a better description than a linear one (57 of 93), implying less and less decline in CO_2 intensity as GDP per capita increases further (the type of function is reported in Table A1). This is a potential explanation of why the CO_2 intensity has fallen more slowly after 2000; many enough countries may have reached the level of GDP per capita where further gains in declining CO_2 intensity are small. While many countries are still so poor that they are unlikely to have reached that level, what happens in rich countries, which are responsible for most CO_2 emissions, may be decisive.

An illustration

It would require too much space to illustrate the modeling results for all countries, but it is of interest to compare our modeling results with the actual development in the largest economies of the world. After all these countries have, by their sheer size, most effect on world GDP and also on world emissions of CO_2, even if the CO_2 intensity of GDP varies considerably between countries (the CO_2 intensity of China's GDP is about four times that of the United States). Figure 2 shows the development of the CO_2 intensity for the eight countries with the highest total GDP in 2014 and compares it with our modeling results. The model reproduces the actual development in the United States, Germany, France and the United Kingdom quite well (note that we only have data from Germany after 1991). For three of these our best model is non-linear, while for France it is linear. The result is less good for China; in that country the CO_2 intensity shows a rickety ride, with a rapid fall in the 1960s, then a rise, and a fall again from the late 1970s. Our best model, which is non-linear, makes a certain sense from that time on. Likewise the results for Japan are mixed. The CO_2 intensity of the Japanese GDP increased to the mid-1970s and has fallen thereafter. If we estimate our model with data from 1974 on the model captures the actual development quite well. That 1974 is a watershed is probably not a coincidence; this was the time of the first energy crisis. It may also be explained by Japan emerging from a period of rapid economic growth and industrialization implying possibly a rising CO_2 intensity of GDP. An argument against this being valid in general is the fall in the Chinese CO_2 intensity after the late 1970s, which coincided with rapid economic growth and industrialization.

Lastly there are Brazil and India. In Brazil the CO_2 intensity has fluctuated without trend, and in India it rose until the early 1990s, but has fallen since. The model simulations shown in the diagrams for these countries explain very little or nothing of what has happened.

The results for Japan, Brazil and India suggest that there may be a phase in the development of poor and medium rich countries where the CO_2 intensity of GDP increases with GDP per capita, in order to fuel rapid industrialization. Figure 3 shows the CO_2 intensity and the GDP per capita in two countries, Singapore and Thailand, that have experienced rapid economic growth. Singapore appears to have had a phase of increasing and then high CO_2 intensity during its first phase of rapid development up until about 1980. After that the CO_2 intensity has fallen rather evenly, but seems recently to have reached a plateau. In Thailand the CO_2 intensity grew with GDP per capita until 1997, but has since been fairly steady.



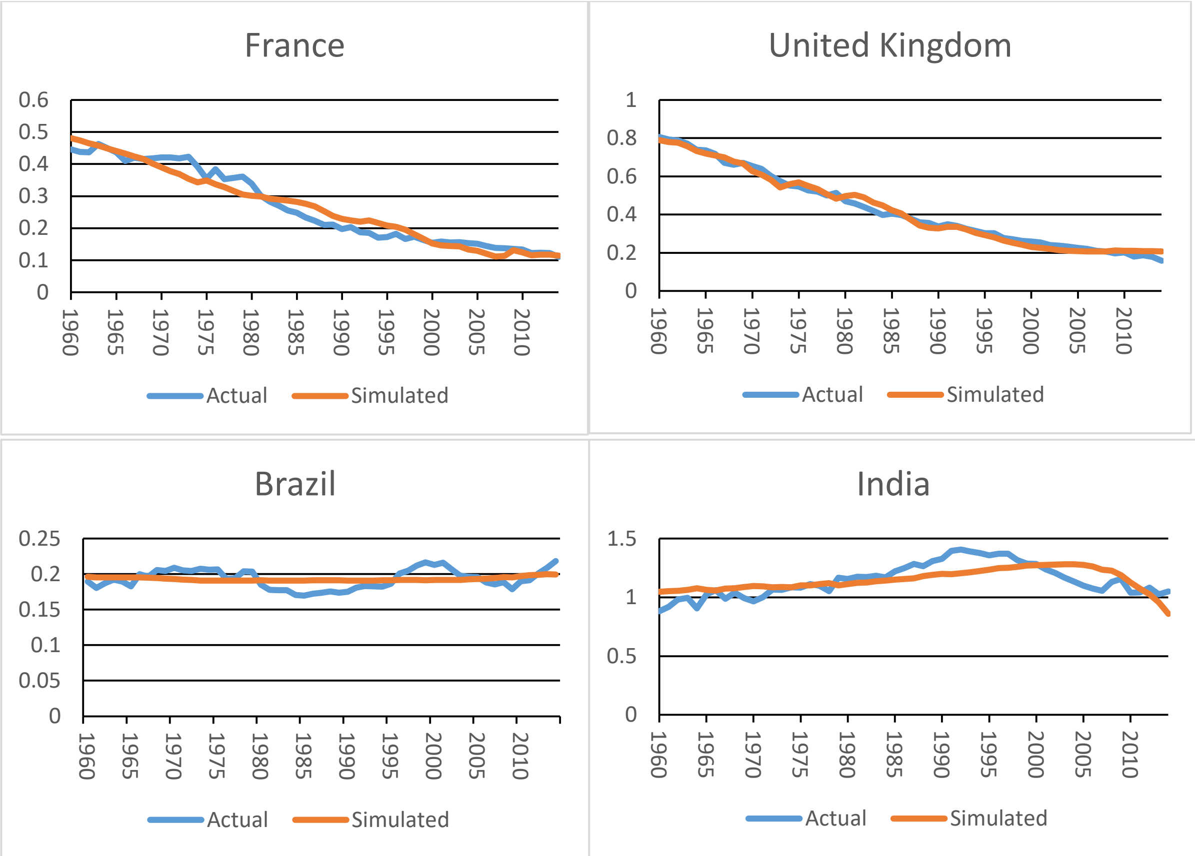


Figure 2: Actual and simulated CO_2 intensity (kg per dollar GDP) in the six largest economies of the world.

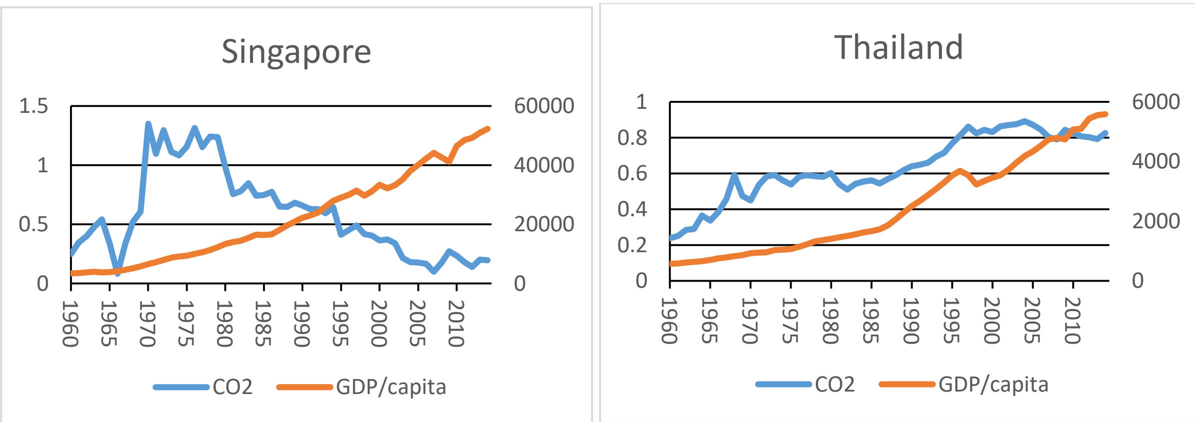


Figure 3: CO_2 intensity (left axis) and GDP per capita (right axis) in Singapore and Thailand.

Does CO2 intensity fall at a diminishing rate?

For the majority of countries, CO_2 intensity appears to fall as they get richer, and for these the relationship is non-linear in the majority of cases, implying that the CO_2 intensity falls at a diminishing rate. This is supported by estimating the second degree equation for the entire panel of data, with country-specific dummy variables. The results are shown in Table 1, with dummies omitted.

Table 1

Results from estimating the equation $y = a + b_1 x + b_2 x^2$, with t-values in parentheses.

a	b_1	b_2	R^2
1.028136 (25.07)	-.0000147 (-13.49)	7.23e-11 (6.54)	0.8244

The estimated curve is shown in Figure 4, together with the CO_2 intensity in select countries, adjusted to the level of the United States, which is used as base for the dummies. The data for Thailand, the United States, the United Kingdom and Singapore were shown in Figures 2 and 3 and commented on in the previous section. Thailand and Singapore do not follow this overall tendency at all in their early phase. Data for the three richest countries in the world in 2014, Luxembourg, Norway and Switzerland, are also shown. The CO_2 intensity for the latter two is fairly flat. The CO_2 intensity for Luxembourg falls rapidly in the beginning, but is fairly flat in later years. Luxembourg is an example of a country that has developed rapidly towards a service-based, wealthy economy.

It could be argued that the results in Table 1 are biased because we have an unbalanced panel. For many countries data are not reported for the early years; there is a large influx of countries in the early 1990s, associated with the downfall of the Soviet Union and the disappearance of the iron curtain. Estimating the equation for data from 1992 onwards still gives significant coefficients with the same sign, but their numerical values now produce a U-shaped curve with a minimum at a GDP per capita of about 70,000 dollars. It is unlikely that the CO_2 intensity will begin to increase again at higher GDP levels, so we take this as a further evidence that the CO_2 intensity does indeed fall with GDP per capita, but at a diminishing rate.

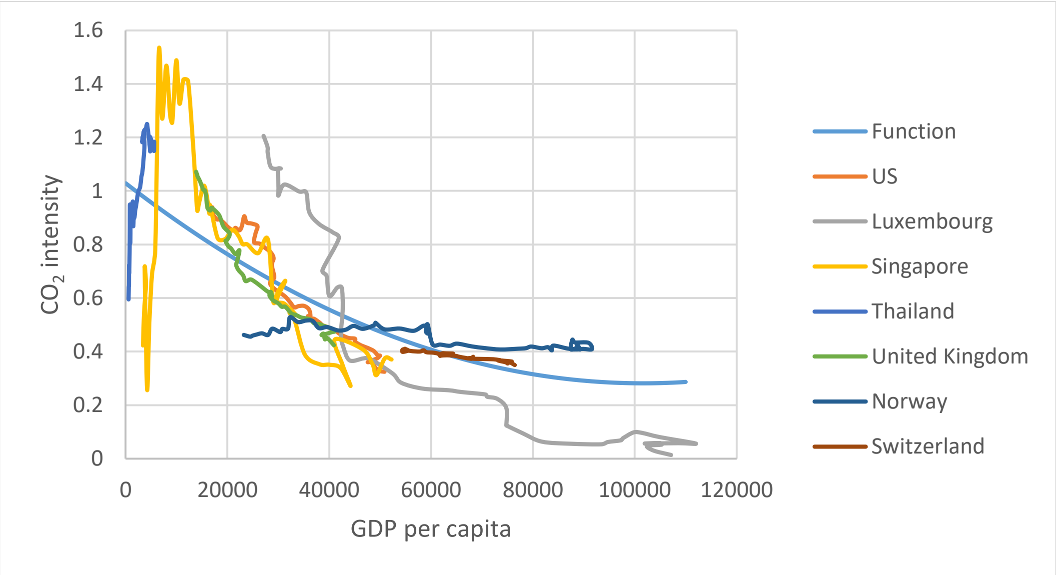


Figure 4: The equation $y = a - b_1 x + b_2 x^2$ (y = CO_2 intensity, x = GDP per capita), as estimated for the entire panel of countries, and the CO_2 intensity of 7 selected countries.

Policy implications

A falling CO_2 intensity as GDP per capita grows would contribute to reconciling economic growth and reduction in CO_2 emissions. But there is considerable evidence that this is primarily the case in rich countries and that the effect becomes smaller and smaller as countries get still richer. This will increase the burden on alternative technologies to deal with emissions. Furthermore, the need for alternative technologies will increase if the poor and medium rich countries of the world must go through a phase of increased energy use as they grow out of poverty. Hence, reconciling economic growth and reduction in CO_2 emissions would seem to depend critically on the development of energy sources other than fossil fuels. Economic growth by itself will not sweep this problem away.

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APPENDIX

Table A1

Countries in the sample, their GDP per capita (2010 us dollars in 2014), whether CO2 intensity has a significant time trend, whether CO_2 intensity is correlated with GDP per capita, and what type of model best fits the relationship between CO_2 intensity and GDP per capita.

		Time trend			Correlation w GDP/cap			
	GDPcap	Pos	Neg	Ins	Pos	Neg	Ins	Model
Luxembourg	107152.9		x			x		Power
Norway	89274.96		x			x		Linear
Bermuda	79251.78		x				x	
Switzerland	76410.86		x			x		Linear
Macao	69749.16		x			x		2nd degree
Qatar	67901.22		x			x		2nd degree
Denmark	59437.93		x			x		Linear
Australia	54546.2		x			x		Linear
Ireland	54052.95		x			x		2nd degree
Sweden	53561.89		x			x		Power
Singapore	52244.44		x			x		Linear
United States	50871.67		x			x		2nd degree
Netherlands	50497.24		x			x		Linear
Canada	50221.84		x			x		Linear
Austria	47922.34		x			x		2nd degree
Japan	46484.16		x			x		Linear
Greenland	46443.76		x			x		2nd degree
Finland	45239.37		x			x		Linear
Germany	45022.57		x			x		2nd degree
Iceland	44775.64		x			x		2nd degree
Belgium	44676.66		x			x		2nd degree
France	41374.76		x			x		Linear
United Kingdom	40908.75		x			x		2nd degree
Andorra	40785.05		x			x		Power
United Arab Emirates	39146.11			x		x		2nd degree
Kuwait	36259.67			x		x		Power
New Zealand	36142.52			x		x		Linear
Hong Kong	35717.68		x			x		Linear
Italy	33615.97		x			x		Linear
Brunei	33313.83			x			x	
Israel	32661.29		x			x		Linear
Spain	29496.38			x			x	
Bahamas	27246.48		x			x		Power
S Korea	24323.57		x			x		Linear
Malta	23676.03		x			x		Power
Slovenia	23224.4		x			x		2nd degree
Greece	22565.68	x			x			

Bahrain	22390.68		x			x		2nd degree
Portugal	21533.49	x			x			
Saudi Arabia	21183.46	x				x		Linear
Czech Republic	20343.68		x			x		2nd degree
Cyprus	20009.06		x			x		2nd degree
Slovak Republic	18003.54		x			x		Power
Estonia	17453.37		x			x		2nd degree
Oman	17167.05	x			x			
Trinidad and Tobago	16641.74	x			x			
Equatorial Guinea	16028.25			x			x	
Barbados	15901.9	x			x			
St. Kitts and Nevis	15029.62	x			x			
Lithuania	14935.54		x			x		Power
Chile	14681.33		x			x		Power
Hungary	14119.07		x			x		2nd degree
Poland	14090.62		x			x		Power
Uruguay	13856.7		x			x		2nd degree
Latvia	13758.96		x			x		Power
Venezuela	13709.04	x				x		2nd degree
Croatia	13651.99		x			x		Linear
Turkey	13312.46	x			x			
Seychelles	12850.49	x			x			
Antigua and Barbuda	12403.53		x			x		2nd degree
Brazil	11870.15			x			x	2nd degree
Russia	11865.03		x			x		Power
Kazakhstan	10646.03		x			x		Power
Malaysia	10398.23	x			x			
Panama	10350.4		x			x		Power
Argentina	10323.21			x		x		Linear
Palau	9692.272			x		x		Power
Mexico	9536.6	x			x			
Gabon	9508.285			x	x			
Romania	9227.437		x			x		Power
Caribbean small states	9169.713	x			x			
Mauritius	9163.633	x			x			
Costa Rica	9065.026	x			x			
Suriname	8942.961		x			x		2nd degree
St. Lucia	8147.524	x			x			
Maldives	8124.708	x			x			
Grenada	7932.668	x			x			
South Africa	7582.553	x					x	
Botswana	7574.282			x			x	
Lebanon	7447.364		x			x		Linear
Bulgaria	7299.549		x			x		Power
Colombia	7291.692		x			x		2nd degree

Montenegro	7045.116			x			x	
Dominica	6951.032	x			x			
Libya	6697.103			x		x		2nd degree
Belarus	6664.097		x			x		Power
St. Vincent and the Grenadines	6467.158	x			x			
Turkmenistan	6399.271		x			x		Power
Dominican Republic	6203.726	x					x	
Cuba	6182.774		x			x		Power
Iran	6161.104	x					x	
Azerbaijan	6122.98		x			x		Power
China	6108.239		x			x		Power
Namibia	5901.243			x			x	
Peru	5825.198			x			x	
Serbia	5593.061		x			x		Linear
Thailand	5591.106	x			x			
Ecuador	5428.714	x			x			
Iraq	5253.627		x			x		2nd degree
Bosnia and Herzegovina	4992.949	x			x			
Macedonia	4920.216		x			x		Linear
Jamaica	4714.861			x			x	
Algeria	4675.885	x			x			
Albania	4413.562		x			x		Linear
Belize	4411.856		x			x		Linear
Tunisia	4271.327			x			x	
Fiji	4084.2		x				x	
Swaziland	3980.774		x				x	2nd degree
Mongolia	3901.867		x				x	
Georgia	3851.723		x				x	
Armenia	3827.343		x			x		Power
Paraguay	3761.912	x			x			
Angola	3746.66	x					x	
Indonesia	3692.943	x			x			
Guyana	3595.925		x			x		Linear
Tonga	3581.837	x			x			
Samoa	3524.596		x			x		2nd degree
Sri Lanka	3506.871		x			x		2nd degree
Cabo Verde	3369.643			x			x	
Jordan	3348.827	x					x	
Marshall Islands	3333.361	x			x			
El Salvador	3272.74	x			x			
Tuvalu	3196.979			x			x	
Morocco	3160.526	x			x			
Pacific island small states	3116.11		x			x		Power
Guatemala	3007.9	x			x			

Ukraine	2967.213		x			x		2nd degree
Congo, Rep.	2922.973			x			x	
Vanuatu	2909.775		x				x	
Micronesia	2716.323	x					x	
Egypt	2608.375			x			x	
Nigeria	2563.092			x			x	
Timor-Leste	2547.159			x		x		Linear
West Bank and Gaza	2529.996	x					x	
Philippines	2505.819			x			x	
Bhutan	2500.26	x					x	
Papua New Guinea	2329.891	x				x		
Bolivia	2317.257	x				x		
Honduras	2059.475	x				x		
Moldova	1986.941		x			x		Power
Sudan	1837.138		x				x	
Nicaragua	1812.995	x				x		2nd degree
Uzbekistan	1744.491		x			x		2nd degree
Ghana	1659.797	x					x	
India	1645.326	x					x	
Zambia	1620.823		x		x			
Kiribati	1565.243	x				x		Power
Vietnam	1565.02	x			x			
Solomon Islands	1475.528			x		x		Power
Laos	1470.5	x			x			
Cameroon	1428.216	x			x			
Cote d'Ivoire	1384.91	x					x	
Mauritania	1326.159	x					x	
Lesotho	1323.238		x			x		2nd degree
Myanmar	1266.124		x			x		Power
Sao Tome and Principe	1241.459			x			x	
Pakistan	1111.196			x			x	
Yemen	1101.117	x			x			
Kenya	1075.659		x			x		2nd degree
Senegal	1018.393	x				x		Linear
Kyrgyzstan	1003.51		x				x	
Cambodia	972.9792			x			x	
Chad	967.1028			x			x	
Zimbabwe	939.7803		x				x	
Bangladesh	922.1611	x			x			
Tajikistan	892.64		x				x	
Benin	833.6409	x			x			
Tanzania	782.6772	x			x			
Comoros	779.8398	x				x		Power
Haiti	728.7803	x				x		Power
Guinea	714.1633			x			x	

Mali	705.7885			x			x	
Nepal	675.7353	x			x			
Rwanda	672.6396	x					x	
Uganda	642.8774	x			x			
Burkina Faso	639.7096	x			x			
Sierra Leone	562.8597		x				x	
Guinea-Bissau	545.8985			x			x	
Togo	531.1561	x					x	
Gambia	530.3189	x			x			
Eritrea	514.1796		x				x	
Mozambique	493.2533		x			x		Power
Malawi	484.3686		x			x		Power
Ethiopia	452.7782			x			x	
Madagascar	408.661	x				x		Power
Congo, Dem. Rep.	397.582		x		x			
Niger	386.7258	x				x		Power
Liberia	376.5889	x				x		2nd degree
Central African Republic	302.5465	x				x		2nd degree
Burundi	243.1019	x			x			
Total		69	88	33	47	93	50	