ENERGY CONTENT OF WORLD TRADE

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This paper constructs a comprehensive dataset of oil and total energy embedded in world trade of manufacturing goods for 73 countries from 1978 to 2000. Applying the data to debates on the dependency on foreign energy sources makes clear that achieving complete energy independence in the foreseeable future is unlikely to be feasible and may not be desirable. Applying it to the discussion of environmental Kuznets curves (EKCs) highlights an important distinction between production and consumption of energy. Richer countries use relatively less energy in their industrial production yet still consume relatively large amounts of energy indirectly. A further investigation largely excludes structural shifts of production in and out of the manufacturing sector as an explanation for the downward-sloping portion of the EKC. Country-level analyses add caveats but show tentative support for the cross-country conclusions.

Keywords: trade, energy dependency, energy intensity, environmental Kuznets curve, energy Kuznets curve

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1. Introduction

The United States imports around 10 million barrels of oil per day.[i] This number is widely known. It is also of much concern in the policy community. “Energy independence” has been buzzword in Washington since the 1970s. The Council on Foreign Relations’ (CFR) Independent Task Force Report on the “National Security Consequences of U.S. Oil Dependency” identified it as one of the main myths. In the foreseeable future, the United States will depend on imported oil, “barring draconian measures” (CFR 2007) that, in any case, would be ill advised. More importantly, even if the United States becomes “energy independent” in the sense conveyed in the report and in much of the policy discussion, it would still depend on imported oil through its trade in manufacturing goods.

In 2000, the United States imported 0.8 million barrels of oil per day embedded in imported manufacturing goods. The number increases to 2.4 million barrels of oil-equivalent energy when accounting for all energy sources (compared to 13.2 million barrels of oil-equivalent energy imported directly).[ii] These embedded energy numbers are not officially calculated and do not register in the policy discussion on energy dependency. Part 2 of this paper focuses on this dataset, which accounts for how much oil and energy are embedded in world trade and lays out possible policy implications.

Using detailed data on the energy content of world trade and given a high correlation between energy use and CO_2-emissions, we can reexamine a well-known and much-discussed relationship between growth and the environment in part 3. The environmental Kuznets curve

(EKC) postulates an inverse-U relationship between pollution and per-capita income. At low levels of development, pollution increases with income at an ever-decreasing rate until the relationship reverses at high levels of development. Pollution now decreases with income. (Figure 1) Described in theory and supported by anecdotal evidence, broad cross-country empirical studies provide a mixed picture.

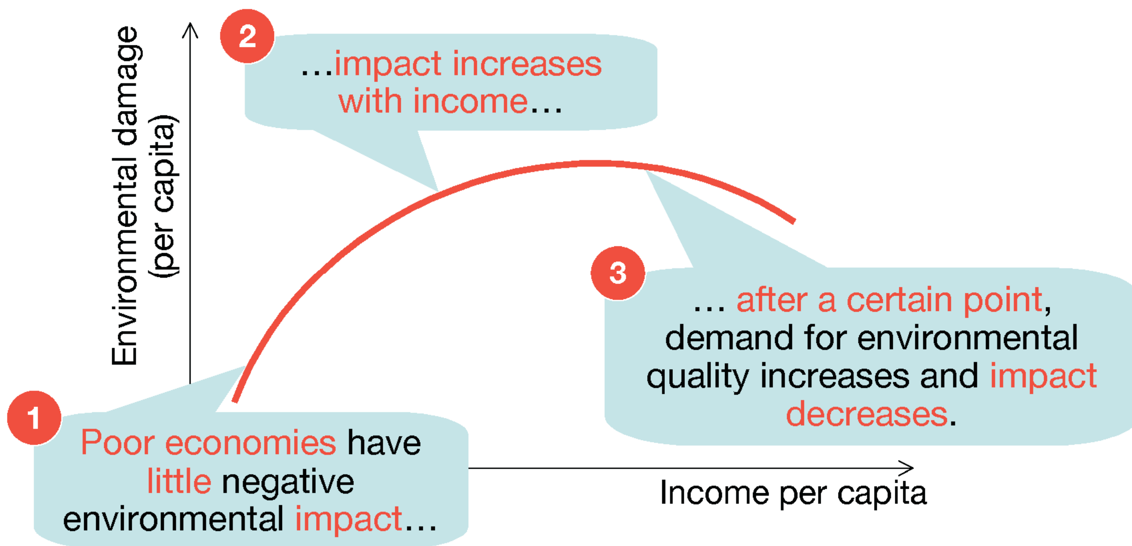

Figure 1 Common theoretical explanation of observed environmental Kuznets curve (EKC) patterns.

Grossman and Krueger (1995) and Selden and Song (1994) were the first to find cross-country EKCs, but subsequent studies have cast doubts on the general conclusions. Harbaugh, Levinson and Wilson (2002) reexamine the evidence and find that the results are highly sensitive to covariates and sample size and ultimately conclude, “that there is little empirical supported for an inverted U-shaped relationship between several important air pollutants and national income.” Dijkgraaf and Vollebergh (2005) also challenge the existence of an EKC for CO_2 emissions, which had previously been shown by Schmalensee, Stoker and Judson (1998). Cole (2003) provides a notable recent exception. He finds support for robust cross-country EKCs for several common pollutants. Brock and Taylor (2004) provide a well-grounded theoretical explanation for the EKC and successfully test the predicted convergence in pollution across OECD countries. Panayotou (2000) and Smulders (2000) offer surveys of the theoretical explanations driving the EKC.[iii] Others have looked directly at the energy-income relationship, which ought to be similar to patterns observed for CO_2 (Galli 1999, Suri and Chapman 1998, Medlock and Soligo 2001, Judson, Schmalensee and Stoker 1999, Richmond and Kaufmann 2006).[iv]

Trade complicates the basic EKC-story. It enables countries to produce in different sectors than they consume. Suri and Chapman (1998), for example, find that richer countries are increasingly importing more energy-intensive products. Including trade also enables a separation of production and consumption EKCs. Potentially harmful effects from energy-intensive goods accrue at the point of production. Consuming these goods releases no further significant quantities of pollution (Figure 2). We may, therefore, expect to find EKCs for production of energy, but perhaps none for consumption.

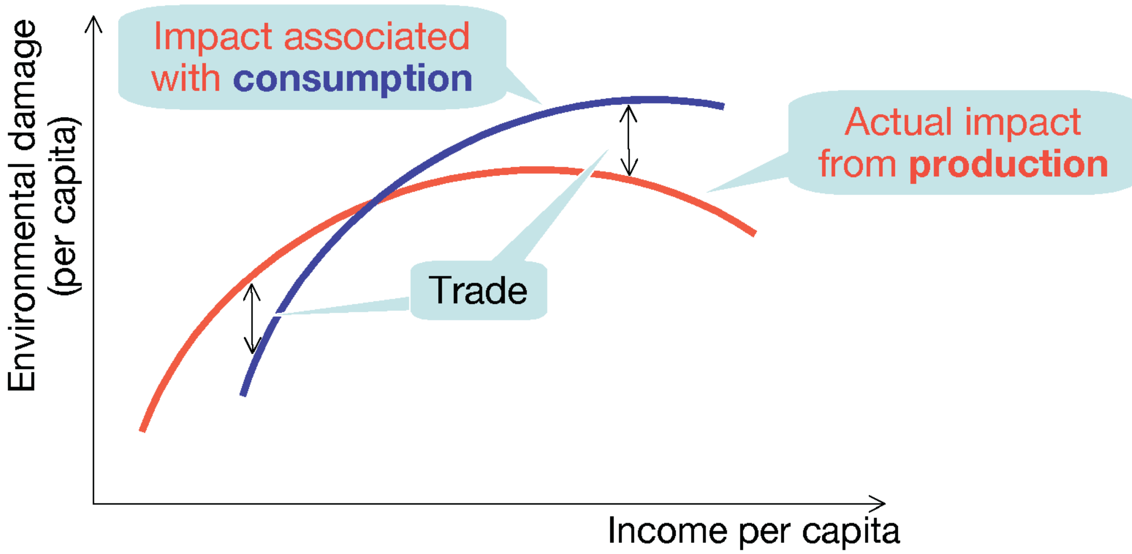

Figure 2 Trade allows a discrepancy between environmental Kuznets curve (EKC) associated with consumption and the actual environmental impact from production.

We will differentiate between production and consumption EKCs in section 3. Following Aldy (2005, 2007), who focuses on CO_2-emissions in the United States and inter-state electricity trade, we calculate consumption of oil and total energy in manufacturing using net factor trades combined with readily available production figures. Subsequently, we will focus on structural shifts in and out of the manufacturing sector and largely exclude them as potential drivers of the EKC. Lastly, we will analyze the EKC more closely using country-level time series econometric techniques. But first, a closer look at the dataset of factor trades in oil and energy.

2. Direct and embedded energy imports

The market for oil – and energy in general – is globally integrated along two dimensions. Two-thirds of the world's oil extracted each day crosses an international border before it is consumed as a primary energy source. Supplies of oil are concentrated in relatively few countries. Five countries hold more than 60 percent of the world's proven oil reserves; the top twenty hold 95 percent.[v] This enormous supply concentration is the root of most national security concerns in the context of energy markets.

Second, oil crosses borders embedded in manufacturing goods. In 2000, global trade in manufacturing goods accounted for 2.9 million barrels of oil per day, compared to 33.2 million barrels of oil per day traded directly. This calculation of oil used in industry includes oil used as a direct input in manufacturing processes. It does not account for indirect oil used, for example by labor. Table I lists oil and energy import figures for the United States. The table includes direct imports and contrasts them with oil and energy embedded in manufacturing imports. It also presents net import figures. The United States is a large net importer, yet some oil and other energy is also re-exported. This holds particularly true for oil and energy embedded in exports. On net, the United States imports 0.4 million barrels of oil embedded in trade per day, while the total figure for embedded imports amounts to 0.8 million barrels in 2000. This last figure is the salient number for energy security considerations, where the entire dependence on foreign oil is more relevant than "net dependence," imports minus exports.

Table I Oil and total energy imports into the United States (million barrels of oil and oil-equivalent per day).

Year	Oil Imports		Net Oil Imports		Energy Imports		Net Energy Imports	
	direct	embedded	direct	embedded	direct	embedded	direct	embedded
1978	6.75	0.34	6.67	0.21	8.81	0.54	8.05	0.23
1979	6.82	0.32	6.75	0.11	8.88	0.55	7.78	0.05
1980	5.51	0.28	5.43	0.05	7.17	0.53	5.76	-0.04
1981	4.61	0.28	4.57	0.08	6.26	0.54	4.59	0.00
1982	3.75	0.30	3.71	0.13	5.47	0.60	3.63	0.15
1983	3.57	0.34	3.55	0.19	5.42	0.72	3.94	0.32
1984	3.68	0.39	3.67	0.23	5.75	0.83	4.24	0.39
1985	3.42	0.40	3.40	0.24	5.46	0.89	3.78	0.44
1986	4.39	0.41	4.38	0.24	6.46	0.93	4.81	0.48
1987	4.86	0.43	4.84	0.25	7.02	0.96	5.44	0.48
1988	5.17	0.43	5.15	0.22	7.79	0.96	5.98	0.37
1989	5.94	0.46	5.93	0.26	8.42	1.00	6.46	0.45
1990	6.04	0.47	6.03	0.27	8.48	1.09	6.44	0.54
1991	5.88	0.45	5.87	0.23	8.26	1.08	6.07	0.48
1992	6.26	0.46	6.25	0.24	8.83	1.16	6.71	0.56
1993	6.91	0.52	6.91	0.27	9.66	1.33	7.87	0.62
1994	7.26	0.56	7.25	0.30	10.15	1.56	8.45	0.81
1995	7.36	0.61	7.36	0.35	10.05	1.70	8.17	0.94
1996	7.78	0.63	7.73	.	10.76	1.78	8.79	.
1997	8.49	0.71	8.40	0.43	11.50	1.93	9.52	1.15
1998	8.91	0.75	8.81	0.46	12.07	2.15	10.19	1.36
1999	8.92	0.74	8.81	0.45	12.38	2.23	10.76	1.39
2000	9.30	0.80	9.25	0.42	13.15	2.44	11.40	1.32

Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

Appendix A describes the data sources. We employ oil, coal and gas consumption data for industry and the total economy as well as their exports and imports and make two assumptions about crude oil use.

First, we assume that the ratio of crude use to total energy use in manufacturing for country c and time t, $[oil/e]_{ct}$, is the same as in the overall economy, indicated by T for total, $\left[oil^T/e^T\right]_{ct}$. This assumption enables us to calculate total oil use in the manufacturing sector:

$$oil_{ct} = \frac{oil_{ct}^T}{e_{ct}^T} \cdot e_{ct},$$

subsequently presented in units of barrels per capita per day and referred to as oil_{ct}^{prod}, used in parallel with e_{ct}^{prod}. For later use, we can split up oil_{ct}^{prod} and e_{ct}^{prod} into intensities per unit of manufacturing output and manufacturing output, y_{ct}, in million 2000 US dollars:

$$oil_{ct}^{prod} = \left[\frac{oil^{prod}}{y}\right]_{ct} \cdot y_{ct}, \quad e_{ct}^{prod} = \left[\frac{e^{prod}}{y}\right]_{ct} \cdot y_{ct},$$

where y_{ct} figures come directly from UNIDO's Industrial Statistics Database aggregated across industrial sectors. It is unclear which bias this assumption introduces, if any. While it is true that instead of using crude oil directly, industry often relies on other oil products derived from crude, total (direct and indirect) crude use would likely be influenced much less.

Second, we assume that exporting industry sectors are as energy intensive as sectors catering to the domestic market. This assumption allows us to calculate the aggregate amount of oil and overall energy embedded in manufacturing imports, M, and exports, X, from and to all other countries d:

$$oil_{ct}^{M} = \sum_{d}\left(\left[\frac{oil^{prod}}{y}\right]_{dt} \cdot M_{cdt}\right), \quad e_{ct}^{M} = \sum_{d}\left(\left[\frac{e^{prod}}{y}\right]_{dt} \cdot M_{cdt}\right),$$
$$oil_{ct}^{X} = \sum_{d}\left(\left[\frac{oil^{prod}}{y}\right]_{ct} \cdot X_{cdt}\right), \quad e_{ct}^{X} = \sum_{d}\left(\left[\frac{e^{prod}}{y}\right]_{ct} \cdot X_{cdt}\right).$$

Poorer countries are more energy intensive than richer ones. But we may expect exporting sectors in poorer countries to employ production technologies that are more advanced than sectors catering to the domestic market and may, therefore, be more energy efficient. In that case, this assumption may lead to overestimates of the energy content of trade. On the other hand, the pollution haven hypothesis suggests that poorer countries may export particularly energy and pollution-intensive products. Kellogg (2007) confirms this conjecture for coal. If this is the overwhelming effect, the assumption may underestimate the energy content of trade. However, Kellogg also finds that the absolute magnitude of the effect is small.[vi] This is in line with the observation that energy markets are relatively global compared to markets for labor. We would expect that most trade be driven by wage differentials rather than competition based on energy-intensity. In particular, a country like China is not directly competing with the United States for manufacturing jobs. Rather, it is competing with Mexico, Malaysia and other lower-wage producers, which employ similarly high-energy intensive technologies. If this effect dominates, this assumption is unlikely to introduce any significant bias.

Lastly, we calculate oil and energy use in consumption of manufactured goods by subtracting net manufacturing exports from production figures:

$$oil_{ct}^{cons} = oil_{ct}^{prod} - oil_{ct}^{X} + oil_{ct}^{M},$$
$$e_{ct}^{cons} = e_{ct}^{prod} - e_{ct}^{X} + e_{ct}^{M}.$$

Throughout the paper, we frequently refer to both oil_{ct}^{i} and e_{ct}^{i} by the abbreviation E_{ct}^{i}, where $i \in \{cons, prod\}$, and normalize all quantities to units of barrels of oil per capita per day. The complete dataset for all 73 countries in the sample spanning the years 1978 through 2000 is available on http://gwagner.com/research/energy_trade.

Others have worked on similar energy trade datasets, most notably Hertwich and Peters (2009), which focuses on cross-national and cross-sectional data. Wyckoff and Roop (1994) calculate the energy content of imports using a methodology analogous to this analysis, with the goal of imputing carbon contents and the possibility for emissions leakage in a Kyoto-style climate change agreement. Their analysis focuses on one year between 1984 and 1986 for each of six countries: Canada, France, Germany, Japan, the United Kingdom and the United States. See also Machado, Schaeffer and Worrell (2001), who calculate the energy content of trade for Brazil in 1995, and Kellogg (2007), who calculates detailed factor trades in coal for 64 sectors in 17 countries for the years 1985-1997.

Direct and indirect dependency on foreign energy sources

The extent of the present dataset and the inclusion of both direct and embedded energy flows ought to enable a better-informed energy security debate. For one, the focus on embedded energy content highlights the misconception that energy independence is possible or even desirable. Short of cutting off all world trade, the United States will always depend on foreign energy sources through its imports of manufacturing goods, even if it were possible to limit direct energy imports.

Other more intricate implications focus on political realignments of U.S. trading partners and potential leverage of the United States, given its overall trade relationships. CFC (2007) highlights Chinese bilateral oil deals as an illustration of political interventions in oil markets. The present data allow us to quantify the energy link between the United States and China in more detail. In 2000, the United States imported 800 thousand barrels of oil per day embedded in imports of manufacturing goods (Table I). Of those, 100 thousand came from China (Table II). Similarly, 0.6 of 2.4 million of oil-equivalent barrels of energy embedded in U.S. imports per day came from China. Table II presents these numbers for the years 1978 to 2000, with a clearly visible positive time trend primarily driven by increased overall imports of manufacturing goods from China to the United States.

Table II Oil and energy imports from China to the United States (million barrels of oil and oil-equivalent per day) and oil and energy import intensities for imports from China and all imports (barrels of oil and oil-equivalent per million dollars of imports in 2000 dollars).

Year	Embedded oil imports from China	Embedded energy imports from China	Oil intensity		Energy intensity	
			Imports from China	All imports	Imports from China	All imports
1978	.	.	.	458.7	.	726.8
1979	.	.	.	409.7	.	711.9
1980	0.002	0.014	469.4	355.2	2,992.4	670.3
1981	0.004	0.024	505.0	346.7	3,367.4	676.6
1982	0.005	0.032	546.1	392.1	3,761.7	790.4
1983	0.005	0.034	558.5	408.1	3,836.1	864.4
1984	0.007	0.049	603.6	362.1	4,348.3	778.5
1985	0.007	0.052	584.5	349.8	4,236.4	778.7
1986	0.010	0.073	653.1	328.1	4,578.1	749.1
1987	0.014	0.100	641.3	323.8	4,504.8	730.7
1988	0.013	0.089	540.0	301.8	3,829.5	679.3
1989	0.015	0.104	487.2	323.3	3,400.2	700.9
1990	0.022	0.165	568.4	335.4	4,345.3	771.8
1991	0.030	0.213	631.9	330.5	4,461.9	798.5
1992	0.035	0.239	573.6	312.8	3,941.4	795.7
1993	0.033	0.225	451.4	330.6	3,084.0	846.9
1994	0.050	0.360	551.0	311.3	3,931.2	869.0
1995	0.059	0.426	534.9	309.4	3,856.4	865.7
1996	0.064	0.448	519.4	311.4	3,630.6	879.6
1997	0.072	0.460	482.7	324.1	3,080.1	882.1
1998	0.086	0.556	499.9	322.2	3,223.3	930.0
1999	0.092	0.542	458.3	291.3	2,699.6	880.9
2000	0.105	0.559	432.7	279.2	2,308.0	850.8

Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

The table highlights another stark fact concerning energy intensities. U.S. imports from China in 2000 contained 433 barrels of oil per million dollars of imports. This was more than 50 percent above the average of 279 for all U.S. imports. The difference for all energy sources was even larger. U.S. imports from China in 2000 contained 2,308 barrels of oil-equivalent energy per million dollars of imports, more than 2.5 times the average import-intensity of 851 barrels per million dollars. One immediate implication of this discrepancy in energy intensities is that some of the U.S. dependency on foreign oil and energy embodied in world trade may be reduced at the source through measures of increasing energy efficiency. The next section will take a closer look at other implications arising from different energy intensities across countries.

3. Energy, growth, and trade

The extent of the present dataset allows a reexamination of the energy and income relationship. Environmental Kuznets Curve (EKC) analyses commonly argue that *aggregate* pollution first increases with rising per capita income and then falls, tracing out an inverse U-relationship. Following Selden and Song (1994), Cole (2000) and Richmond and Kaufmann (2006) among others, this present analysis focuses on *per capita* figures. This disentangles the effects of energy use per capita and population growth. The EKC story, however, is still the same. Poor countries use little energy per capita. As the economy gets richer, each person's energy use increases and may ultimately peak before falling for high levels of per capita income.[vii] The underlying cause for EKCs can be twofold: structural shifts and technological changes. Structure, in turn, can imply shifts from agriculture to manufacturing and services as well as shifts within manufacturing from clean to dirty sectors, and vice versa. The following analysis conflates both structural shifts and technological changes. We will address this issue in section 4. First, we focus on overall per capita EKCs.

Aldy (2005, 2007) explores EKCs for CO_2 emissions across the continental United States. He groups his analysis by looking at production and consumption EKCs independently. Since U.S. interstate trade data are not available, Aldy focuses on trade in electricity among states. The production of electricity causes CO_2 emissions, while its consumption is relatively clean. Aldy hypothesizes that richer states still consume high levels of electricity but purchase it increasingly from relatively poorer states. CO_2 emissions associated with production across U.S. states show the typical inverse U-shape; CO_2 emissions associated with consumption rise initially but then flatten out and do not decrease for wealthy states.

We adapt Aldy's methodology to the cross-country energy dataset. Comprehensive production data for oil, oil_{ct}^{prod} and energy, e_{ct}^{prod}, in the manufacturing sector are readily available and have been well studied in an EKC-context.[viii] The dataset of oil and energy embedded in bilateral trade for manufacturing goods allows us to calculate the consumption of oil, oil_{ct}^{cons}, and energy, e_{ct}^{cons}, associated with the industrial sector.[ix] We denote oil use in barrels of oil per capita per day and energy use in barrel-equivalent per capita per day. Subsequently, we will depict both oil_{ct}^{i} and e_{ct}^{i} by E_{ct}^{i}, where $i \in \{cons, prod\}$.

We employ a standard EKC framework. We estimate oil and energy use in manufacturing, E_{ct}^{i}, as a function of overall GDP per capita, Y_{ct}, for countries *c* and years *t* with estimation parameters β_k, where E_{ct}^{i} and Y_{ct} enter the equation in form of their natural logarithms:

(1) $$\ln\left(E_{ct}^{i}\right) = \beta_0^i + \beta_k^i F\left[\ln\left(Y_{ct}\right)\right] + \upsilon_c^i + \tau_t^i + \varepsilon_{ct}^i$$

for oil and energy associated with both consumption and production. The terms υ_c^i and τ_t^i are country and year fixed effects, respectively, and ε_{ct}^i is the exogenous error term. The first set of regressions employs quadratic and cubic functional forms, where *F* represents either a quadratic or cubic function in $\ln(Y_{ct})$. The subscript *k* in equation (1) takes on values from 1 to 2 for quadratic and 1 to 3 for cubic specifications.

Table III shows results for quadratic and cubic regressions with oil use as the dependent variable. Table IV repeats the same for total energy use. While quadratic OLS specifications for oil are generally not significant, FGLS specifications in (5)–(6) are highly significant at the one percent significance level and show the expected EKC shape of an inverted-U. Cubic specifications are significant throughout and provide better fits for the data than quadratic functions. Graphical analyses show that they, too, follow inverted-U shapes. Regression results for total energy use are similar, except that in the quadratic FGLS specification, only the slopes are significant. All cubic specifications are once again significant.

Table III Regression results for oil use in barrels per capita per day associated with both consumption and production.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS		OLS		FGLS		FGLS	
	$\ln(oil_{ct}^{cons})$	$\ln(oil_{ct}^{prod})$	$\ln(oil_{ct}^{cons})$	$\ln(oil_{ct}^{prod})$	$\ln(oil_{ct}^{cons})$	$\ln(oil_{ct}^{prod})$	$\ln(oil_{ct}^{cons})$	$\ln(oil_{ct}^{prod})$
$\ln(Y_{ct})$	1.27	0.91	-14.15	-24.17	4.51	6.53	-11.73	-14.82
	(0.57)**	(0.58)	(4.44)***	(6.70)***	(0.39)***	(0.41)***	(3.66)***	(4.60)***
	[1.27]	[1.51]	[7.27]*	[14.19]*				
$\ln(Y_{ct})^2$	-0.02	-0.02	1.78	2.93	-0.19	-0.30	1.76	2.23
	(0.03)	(0.03)	(0.51)***	(0.78)***	(0.02)***	(0.02)***	(0.43)***	(0.53)***
	[0.07]	[0.08]	[0.83]**	[1.64]*				
$\ln(Y_{ct})^3$			-0.07	-0.11			-0.08	-0.10
			(0.02)***	(0.03)***			(0.02)***	(0.02)***
			[0.03]**	[0.06]*				
Predicted Peak	.	.	45,686	22,440	184,276	59,696	30,854	24,014
			(11,263)***	(3,230)***	(70,595)***	(10,873)***	(3,387)***	(1,771)***
			(19,259)**	[7,580]***				
N	1365	1607	1365	1607	1365	1607	1365	1607
Countries	73	73	73	73	73	73	73	73
R^2	0.97	0.95	0.97	0.95	.	.	.	.

Ordinary least squares (OLS) and feasible generalized least squares (FGLS) regressions. OLS specifications present robust standard errors (in parentheses) and robust standard errors clustered by country [in brackets]. FGLS regressions correct for both heteroskedasticity and first-order serial autocorrelation. All regressions include constant terms as well as country and year fixed effects. Three stars (***) indicate significance at the 1% level, two stars (**) at the 5% level, and one star (*) at the 10% level.

Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

Table IV Regression results for energy use in barrels-equivalent per capita per day associated with both consumption and production.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS		OLS		FGLS		FGLS	
	$\ln(e_{ct}^{cons})$	$\ln(e_{ct}^{prod})$	$\ln(e_{ct}^{cons})$	$\ln(e_{ct}^{prod})$	$\ln(e_{ct}^{cons})$	$\ln(e_{ct}^{prod})$	$\ln(e_{ct}^{cons})$	$\ln(e_{ct}^{prod})$
$\ln(Y_{ct})$	-0.98	0.42	-30.03	-35.62	1.10	1.14	-16.62	-19.34
	(0.61)	(0.52)	(5.18)***	(6.06)***	(0.40)***	(0.39)***	(4.01)***	(3.66)***
	[1.40]	[1.48]	[10.10]***	[13.01]***				
$\ln(Y_{ct})^2$	0.09	-0.00	3.50	4.24	0.00	-0.00	2.10	2.45
	(0.03)***	(0.03)	(0.60)***	(0.70)***	(0.02)	(0.02)	(0.46)***	(0.42)***
	[0.08]	[0.08]	[1.15]***	[1.50]***				
$\ln(Y_{ct})^3$			-0.13	-0.16			-0.08	-0.10
			(0.02)***	(0.03)***			(0.02)***	(0.02)***
			[0.04]***	[0.06]***				
Predicted Peak	.	.	33,421	18,987	.	.	54,251	39,655
			(4,986)***	(1,380)***			(11,234)***	(4,951)***
			(10,494)***	[4,218]***				
N	1374	1626	1374	1626	1374	1626	1374	1626
Countries	73	73	73	73	73	73	73	73
R^2	0.96	0.96	0.97	0.97	.	.	.	.

Ordinary least squares (OLS) and feasible generalized least squares (FGLS) regressions. OLS specifications present robust standard errors (in parentheses) and robust standard errors clustered by country [in brackets]. FGLS regressions correct for both heteroskedasticity and first-order serial autocorrelation. All regressions include constant terms as well as country and year fixed effects. Three stars (***) indicate significance at the 1% level, two stars (**) at the 5% level, and one star (*) at the 10% level.

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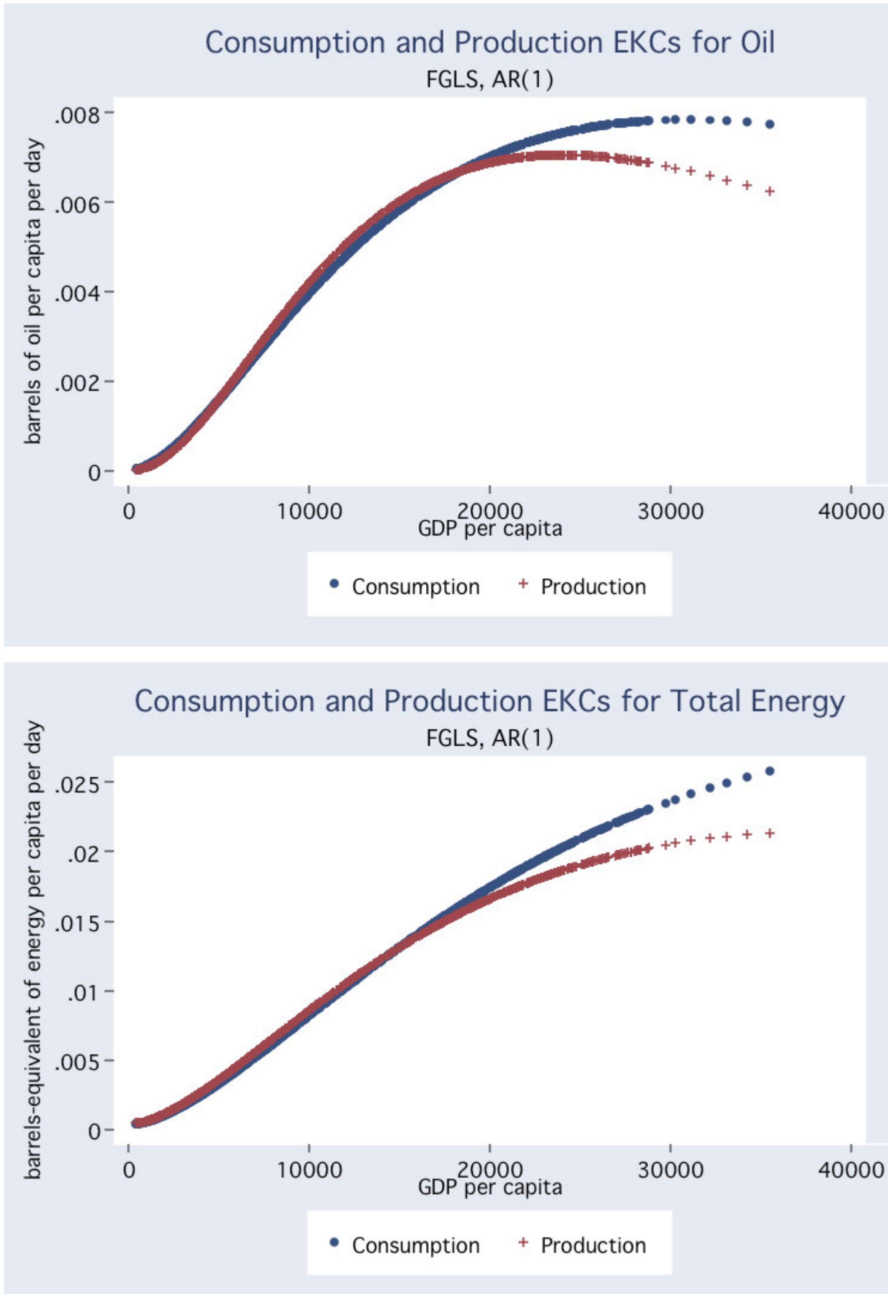


Figure 3 Oil and energy use associated with consumption and production from cubic regression.

Predicted values come from cubic feasible least squares (FGLS) regression with corrections for heteroskedasticity and serial correlation as presented in columns (7)-(8) of Table III (for oil) and Table IV (for energy).

Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

Figure 3 demonstrates a striking relationship prevalent in all specifications. Regressions with production as the dependent variable show more prominently curved U-shape patterns. This relationship holds for both oil and energy. All other specifications follow the same pattern: richer economies produce less oil and energy than they consume embedded in manufacturing goods. Poorer economies produce more than they consume.

The difference between consumption and production of oil is statistically significant. At first glance, we see that predicted consumption peaks are much higher than production peaks. FGLS specifications for oil predict a peak of oil use in consumption at a per capita income of \$30,854, with a standard error of \$3,387. The peak for production occurs at \$24,014, with an error of \$1,771 (Table III, columns (7)-(8)). The corresponding peaks for total energy are \$54,251 for consumption and \$39,655 for production, with errors of \$11,234 and \$4,951, respectively. To test the significance of these differences, mirroring Aldy (2005), we create robust simultaneous variance-covariance matrices following Zellner's seemingly unrelated regression framework, which allows for correlation in the error terms across the consumption and production regressions:

(2)
$$\begin{aligned}\ln\left(E_{ct}^{cons}\right) &= \beta_0^{cons} + \beta_k^{cons} F\left[\ln\left(Y_{ct}\right)\right] + \upsilon_c^{cons} + \tau_t^{cons} + \varepsilon_{ct}^{cons} \\ \ln\left(E_{ct}^{prod}\right) &= \beta_0^{prod} + \beta_k^{prod} F\left[\ln\left(Y_{ct}\right)\right] + \upsilon_c^{prod} + \tau_t^{prod} + \varepsilon_{ct}^{prod},\end{aligned}$$

where F represents either a quadratic or cubic function in $\ln\left(Y_{ct}\right)$ and all regressions include country and year fixed effects. We perform two tests to see whether predicted consumption and production EKCs are equal. First, we test whether their slopes are distinguishable from one another. To that effect, we test the null hypotheses that β_k^i parameters are equal for consumption and production measures. We perform this test both with the constant terms,

$$H^1_{0,quadratic}: \hat{\beta}_k^{cons} = \hat{\beta}_k^{prod} \ \ for \ \ k = 0,1,2$$
$$H^1_{0,cubic}: \hat{\beta}_k^{cons} = \hat{\beta}_k^{prod} \ \ for \ \ k = 0,1,2,3,$$

and without,

$$H^2_{0,quadratic}: \hat{\beta}_k^{cons} = \hat{\beta}_k^{prod} \ \ for \ \ k = 1,2$$
$$H^2_{0,cubic}: \hat{\beta}_k^{cons} = \hat{\beta}_k^{prod} \ \ for \ \ k = 1,2,3.$$

We also test the equality of income levels of the estimated peaks for quadratic specifications,

$$H^3_{0,quadratic}: \exp\left[-\frac{\hat{\beta}_1^{cons}}{2\hat{\beta}_2^{cons}}\right] = \exp\left[-\frac{\hat{\beta}_1^{prod}}{2\hat{\beta}_2^{prod}}\right],$$

and for cubic specifications:[x]

$$H^3_{0,cubic}: \exp\left[\frac{-2\hat{\beta}_2^{cons} - \sqrt{4\left(\hat{\beta}_2^{cons}\right)^2 - 12\hat{\beta}_1^{cons}\hat{\beta}_3^{cons}}}{6\hat{\beta}_3^{cons}}\right]$$
$$= \exp\left[\frac{-2\hat{\beta}_2^{prod} - \sqrt{4\left(\hat{\beta}_2^{prod}\right)^2 - 12\hat{\beta}_1^{prod}\hat{\beta}_3^{prod}}}{6\hat{\beta}_3^{prod}}\right].$$

Table V shows test results for consumption and production-based EKCs for oil and total energy with quadratic and cubic specifications. The χ^2 statistics for H_0^1 and H_0^2 for oil range from 35 to 42, which strongly favor rejecting the null hypotheses of equal slopes at the 1% significance level. Test statistics for total energy range from 49 to 59, with the same clear conclusion. We repeat the tests with robust errors clustered by country. Test statistics now range from 9 to 41 for oil and 11 to 30 for energy. All tests lose significance, but still point to rejecting the null at least at the 5% significance level for oil and the 1% significance level for energy.

Tests of H_0^3, which hypothesize equal peaks for consumption and production, point in the same direction. Quadratic specifications do not have peaks; we therefore focus on cubic specifications. We reject the null hypothesis of equal peaks at the 5% significance level for oil and the 1% significance level for energy. Once we resort to using robust errors clustered by country, the difference for oil disappears with a p-value of 0.16 but remains for energy at the 10% significance level. However, all χ^2 statistics in Table V are based on two-sided tests. If we were to perform one-sided tests of whether consumption-based EKCs have larger peaks than their production-based counterparts, we would be able to reject all tests at least at the 10% significance level.

Table V Test results comparing slope coefficients and peaks of consumption and production-based environmental Kuznets curves (EKCs) for oil and total energy with quadratic and cubic specifications.

	(1)	(2)	(3)	(4)
	Oil		Energy	
	Quadratic	Cubic	Quadratic	Cubic
χ^2 statistic H_0^1	38.58***	42.34***	49.26***	58.51***
	[29.88]***	[41.25]***	[25.97]***	[29.71]***
χ^2 statistic H_0^2	35.44***	38.40***	48.61***	57.72***
	[8.88]**	[9.36]**	[11.34]***	[12.51]***
χ^2 statistic H_0^3	.	5.22**	.	10.72***
		[1.96]		[3.21]*

Ordinary least squares (OLS) regressions for consumption and production-based estimations with country and year fixed effects. All test statistics are based on robust simultaneous variance-covariance matrices. [Square brackets] present test statistics for robust errors clustered by country. Three stars (***) indicate significance at the 1% level, two stars (**) at the 5% level, and one star (*) at the 10% level.
Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

Sensitivity tests confirm these conclusions. The right-most tail of the income distribution in Figure 3 represents the United States. Recent developments, particular in the United States, may account for some of the consumption and production disparities observed here. Manufacturing imports account for a large portion of the steadily increasing recent trade deficit of the United States with China. We repeat the preceding analyses with datasets excluding the United States as well as excluding the last five years after 1995.[xi]

We also repeat the graphical analysis by employing a cubic spline function of income, $F\left[\ln\left(Y_{ct}\right)\right]$. This more flexible functional form better approximates the data by not constraining the overall model to a quadratic or cubic forms. We employ spline functions divided into 2 to 12 knots for production and consumption of both oil and energy measures. The resulting figures are sensitive to including the United States, particularly as more knots are added. Figure 4 presents predicted oil use associated with consumption and production with and without the United States. Graphs for energy follow very similar patterns. Unlike the previous quadratic and cubic analyses, the right-most part of the production-EKC with the United States included slopes upwards. Once we exclude the United States, the graph regains its original shape with production trending downward. But in either case production clearly lies below consumption for richer economies. Neither sensitivity tests nor different functional forms alter the main conclusion: richer economies use relatively less oil and energy in their industrial production yet still consume relatively large amounts.

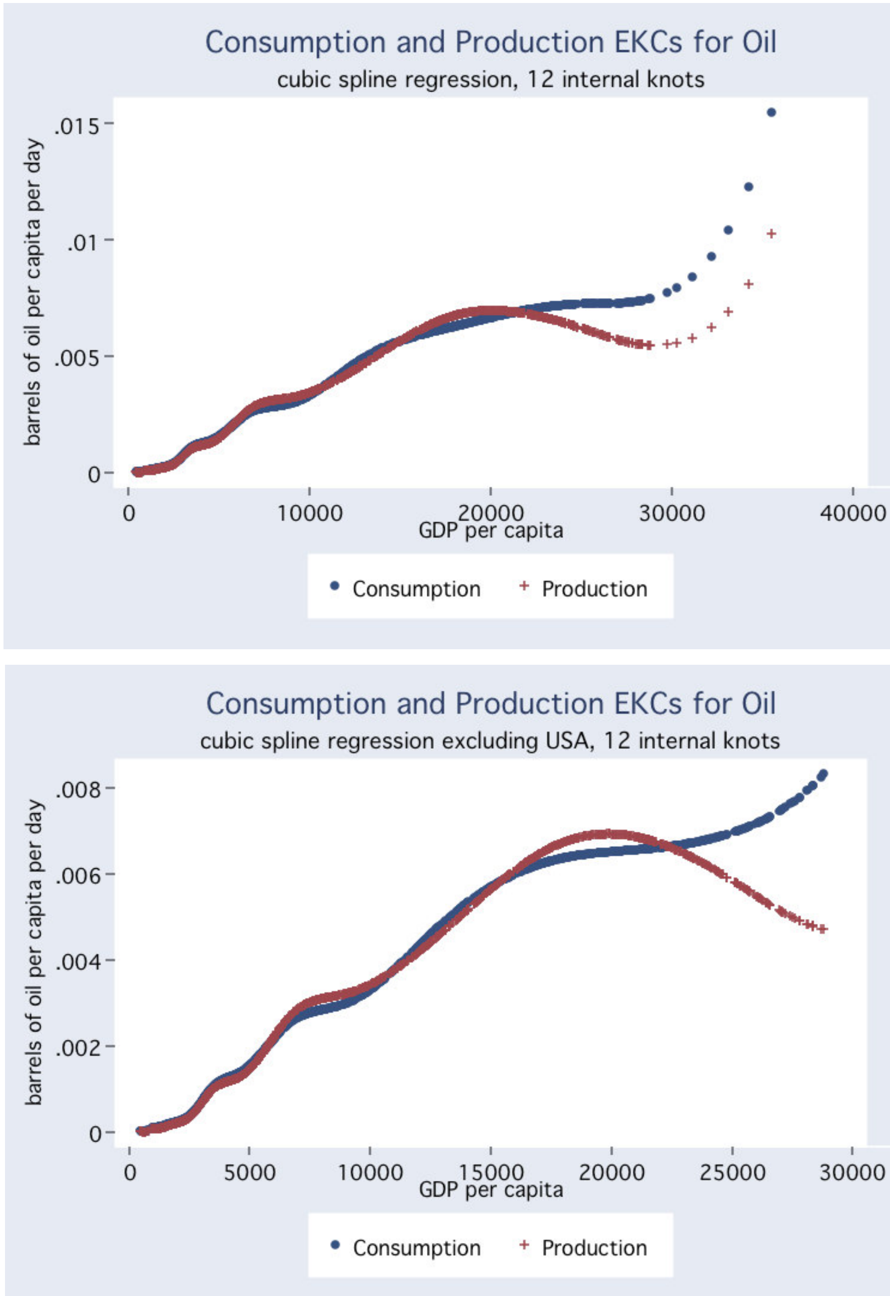


Figure 4 Oil use associated with consumption and production from cubic spline regressions with and without the United States.

Predicted values come from cubic spline OLS regressions with 12 evenly spaced knots.

Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

4. Structure versus Technique

We now turn to the question of whether underlying structural differences across economies account for the observed overall EKC patterns. This line of research follows a long tradition in the environmental trade literature.[xii] Trade influences a country's energy use through three avenues: size of the economy, structural changes and technology. Grossman and Krueger (1993) introduced this classification for identifying the effects of trade on the environment in an EKC framework. Antweiler, Copeland and Taylor (2001) provide the most complete answer to date that trade, perhaps surprisingly, is good for the environment. They note that trade causes some relocation of dirty industries, which increases pollution, but they conclude that this effect is far outweighed by a combination of scale and technique effects. Others have studied structural versus technological changes and their effects on energy intensity. Hogan and Jorgenson (1991) and Sue Wing and Eckaus (2004) focus on energy intensity trends in the U.S. economy.

Structural movements come in two forms: shifts from agriculture to manufacturing to services and shifts within manufacturing from one industrial sector to another. Ideally, we would like to separate technology from structure altogether by separating energy intensities from output per industrial sector within manufacturing. We would decompose energy use E_{cts} in country c, year t, and a particular sector s into energy intensity and output,

(3) $$E_{cts} = \left[\frac{energy}{y}\right]_{cts} \cdot y_{cts} ,$$

where $energy$ stands for total energy use in the particular sector and y_{cts} captures output in that sector. Unfortunately, we only have energy data for the entire manufacturing sector rather than particular industries within manufacturing. The decomposition in this analysis, therefore, focuses on overall manufacturing, aggregating over all individual industrial sectors:

$$E_{ct} = \left[\frac{energy}{y} \right]_{ct} \cdot y_{ct} \,. \tag{4}$$

Differences in energy intensity, $[energy/y]_{ct}$, now reflect both changes in actual intensity across countries and a particular country's manufacturing product mix. Take for example two products, steel S and toys T. S is more energy intensive than T. If China and the United States used the same techniques of production for products S and T but China produced more S than T and the United States produced more T than S, China's aggregate production would appear to be more energy intensive, even though the product mixes account for all of the difference in energy intensity. In reality we would expect Chinese manufacturing to be more energy intensive than U.S. manufacturing. Nevertheless, we cannot ascribe all of the difference in $[energy/y]_{ct}$ to techniques, but ought to account for the product mix as well. What we can do is separate large-scale structural movements in and out of manufacturing from product mix and technique effects.

Both y_{ct} and intensities, $[energy/y]_{ct}$, vary by country and year. Figure 5 depicts oil and energy intensities for China and the United States. China is on average twice as energy-intensive as the United States. The dataset also ascribes it great volatility, while U.S. intensities appear relatively stable. In 1995, the United States used 168 barrels of oil per million U.S. dollars of manufacturing output. This makes it the eleventh lowest of all 73 countries in the sample, but its series is relatively stable compared to most other countries. We can, therefore, focus on one year, for the subsequent analysis: 1995.[xiii]

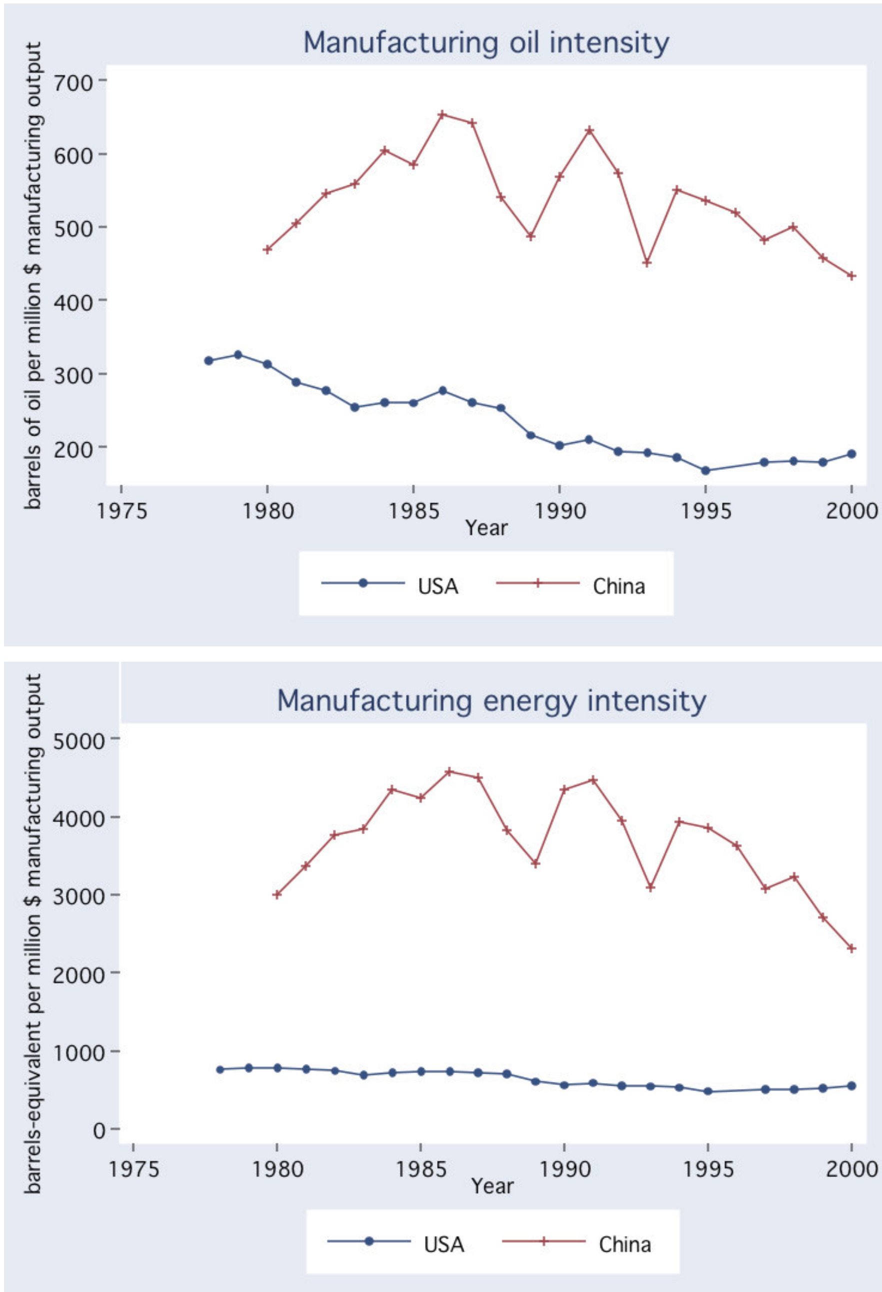


Figure 5 Oil and energy intensities in the United States and China (in barrels of oil and barrels-equivalent energy per million 2000 US dollars of manufacturing output).

Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

To disentangle large-scale structural effects on the one hand from product mix and technological effects on the other, we create a composite indicator using U.S. intensities in 1995 for all countries and years:

(5) $$\bar{E}_{ct} = \left[\frac{energy}{y}\right]_{US,95} \cdot y_{ct} .$$

This indicator removes any volatility in the product mix and technique factor and ascribes all changes in the data to the country-specific output term. It also removes any underlying time trend in the intensities such as continued increases in energy efficiency over time, a process commonly termed "dematerialization," or structural changes within manufacturing.[xiv]

We use $\bar{E}^i_{ct}$ for $i \in \{cons, prod\}$ and repeat the analysis in the preceding section. Disregarding the constant term, $[energy/y]_{US,95}$, the regression for $\bar{E}^i_{ct}$ reduces to:

(6) $$\ln\left(y^i_{ct}\right) = \beta^i_0 + \beta^i F\left[\ln\left(Y_{ct}\right)\right] + \upsilon^i_c + \tau^i_t + \varepsilon^i_{ct} ,$$

where all variation in the dependent variable arises from changes in output across countries and time. In short, we test whether income correlates with any systematic changes in the relative size of the manufacturing sector. An EKC-like result now would suggest that structural movements from agriculture to manufacturing and services drive the results presented in section 3. Differences in technique – oil and energy intensities – and changes in the product mix over time would account for any divergence between the previous results and current ones. Since all variation now arises from output terms common to both oil and total energy, it is no longer necessary to distinguish between the two types of intensities. The only difference will be in the constant term due to different U.S. intensities. We therefore analyze oil alone.

Table VI presents the regression output. The most striking observation is how little resemblance the results bear with standard EKCs. Quadratic regressions are either insignificant or point to increasing U-shaped curves, in contrast to inverse U-shaped EKCs. Moving to cubic functional forms for income improves significance but does not alter the upward-sloping shapes. Only the cubic FGLS specification has peaks of the predicted functional form. Both, however, are around $82,000 and well outside any currently observed income values. Moreover, the two values for consumption and production are practically identical. A graphical analysis confirms these conclusions. Both predicted oil consumption and production curves slope upwards without any sign of turning around (Figure 6).

Table VI Regression results for oil or energy use in barrels per capita per day associated with both consumption and production, using 1995 U.S. energy intensities for all countries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS		OLS		FGLS		FGLS	
	$\ln(\bar{E}_{ct}^{cons})$	$\ln(\bar{E}_{ct}^{prod})$	$\ln(\bar{E}_{ct}^{cons})$	$\ln(\bar{E}_{ct}^{prod})$	$\ln(\bar{E}_{ct}^{cons})$	$\ln(\bar{E}_{ct}^{prod})$	$\ln(\bar{E}_{ct}^{cons})$	$\ln(\bar{E}_{ct}^{prod})$
$\ln(Y_{ct})$	-0.42	1.17	-3.80	-1.57	-0.64	-0.35	-23.36	-23.23
	(0.47)	$(0.50)^{**}$	(4.75)	(5.15)	(0.41)	(0.39)	$(4.17)^{***}$	$(4.18)^{***}$
	[1.05]	[1.25]	[9.29]	[9.54]				
$\ln(Y_{ct})^2$	0.11	0.02	0.50	0.34	0.12	0.11	2.79	2.80
	$(0.03)^{***}$	(0.03)	(0.55)	(0.59)	$(0.02)^{***}$	$(0.02)^{***}$	$(0.49)^{***}$	$(0.49)^{***}$
	$[0.06]^{*}$	[0.07]	[1.07]	[1.10]				
$\ln(Y_{ct})^3$			-0.02	-0.01			-0.10	-0.10
			(0.02)	(0.02)			$(0.02)^{***}$	$(0.02)^{***}$
			[0.04]	[0.04]				
Predicted Peak	.	.	.	.	.	.	82,266	82,097
							$(23,093)^{***}$	$(22,370)^{***}$
N	1374	1374	1374	1374	1374	1374	1374	1374
Countries	73	73	73	73	73	73	73	73
R^2	0.98	0.98	0.98	0.98	.	.	.	.

Ordinary least squares (OLS) and feasible generalized least squares (FGLS) regressions. OLS specifications present robust standard errors (in parentheses) and robust standard errors clustered by country [in brackets]. FGLS regressions (5)-(8) correct for heteroskedasticity and first-order serial autocorrelation. All regressions include constant terms as well as country and year fixed effects. Three stars (***) indicate significance at the 1% level, two stars (**) at the 5% level, and one star (*) at the 10% level.
Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

Based on the regression analysis presented in Table VI and comparisons to standard EKC regressions, we can conclude that systematic trends in the size of the manufacturing sector compared to the overall economy cannot account for the observed EKCs in section 3. Conversely, most of the difference between oil and total energy use in consumption and production must be due to differences in technology and product mix across countries rather than structural changes in and out of the manufacturing sector.

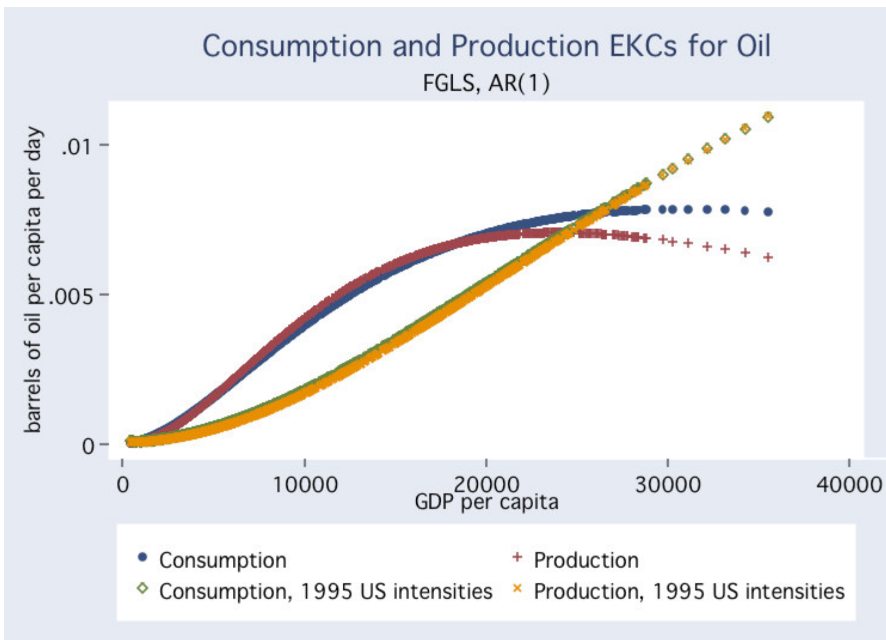


Figure 6 Oil use associated with consumption and production from cubic regression, using actual and 1995 U.S. energy intensities for all countries.

Predicted values come from cubic feasible least squares (FGLS) regression with corrections for heteroskedasticity and serial correlation as presented in columns (11)-(12) of Table III (for original intensities) and Table VI (for 1995 U.S. intensities).

Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

Cole (2000) supports this finding in a similar decomposition analysis by showing that structural changes alone do not account for EKCs. The conclusion may seem to contradict previous findings showing that structural composition of the economy clearly does matter for its fuel mix. Both Judson, Schmalensee and Stoker (1999) and Medlock and Soligo (2001) analyze energy use in industrial, household, transportation and other sectors, and find that energy use shifts between sectors as economies grow. That result still stands. We merely ascribe the particular functional form of the production EKCs primarily to technological and product mix differences across countries and time. Shifts in and out of manufacturing alone do not account for the downward sloping portion of the EKC.

5. Country-level EKCs

The EKC analysis so far assumed that all countries follow the same path of increased energy use at low levels of development, followed by a flattening and reversal at later stages. Fixed effects allow this relationship to shift across countries and time, but they do not allow for country-specific growth paths. The imposed inverse U-shape is common to all countries. Beginning with List and Gallet (1999), EKC studies have allowed for more flexible specifications across economies. The results have not boded well for simple inverse-U EKC relationships.

List and Gallet (1999) allow for heterogeneous slopes across states in their analysis of SO_2 and NO_X emissions within the United States and reject the standard reduced-form model. Aldy (2005) repeats this state-level analysis for CO_2 emissions and draws similar conclusions. Perman and Stern (2003) and Dijkgraaf and Vollebergh (2005) employ similar techniques in cross-country analyses and reject homogenous relationships even more decisively. Instead of the reduced-form relationship assumed in equation (1), we now allow the constant term and slopes to vary across countries, depicted by the added subscripts c on all β^i coefficients:

$$\ln\left(E_{ct}^i\right) = \beta_{c,0}^i + \beta_c^i F\left[\ln\left(Y_{ct}\right)\right] + \tau_t^i + \varepsilon_{ct}^i \tag{7}$$

Intercept $\beta_{c,0}^i$ subsumes the previous country fixed effects υ_c^i. Otherwise the regression is identical to equation (1) with τ_t^i depicting time fixed effects and ε_{ct}^i the exogenous error term. We estimate this relationship for oil and energy in quadratic and cubic specifications and test whether slopes are equal across countries, a requirement for justifying the reduced-form model in equation (1):

$$H_0^4: \hat{\beta}_{1k}^i = \hat{\beta}_{ck}^i \; for \; k = 0,1,2(,3), \; i = \{cons, prod\}, \; and \; all \; c = 2, ..., 73.$$

Table VII reports χ^2 test statistics, which overwhelmingly support rejecting the null hypothesis that coefficients across countries are equal. Only cubic energy specifications for consumption do not allow us to reject the null unequivocally, but p-values are still very close to the 10% cutoff. Statistics for oil tend to be larger than those for energy, suggesting that industrial oil use may be more country-specific than energy use. In line with List and Gallet (1999) and Aldy (2005) for the United States and Perman and Stern (2003) and Dijkgraaf and Vollebergh (2005) internationally, we can conclude in general that reduced-form EKCs prescribing the same U-shape across economies may misrepresent the actual experience of individual countries.

Table VII Test results comparing slope coefficients of consumption and production-based environmental Kuznets curves (EKCs) for oil and total energy with quadratic and cubic specifications across countries.

	(1)	(2)	(3)	(4)
	Oil		Energy	
χ^2 statistic H_0^4 for	Quadratic	Cubic	Quadratic	Cubic
$\hat{\beta}_0^{cons}$	1.76***	0.94	1.48***	0.90
$\hat{\beta}_1^{cons}$	1.97***	1.66***	1.47***	1.27*
$\hat{\beta}_2^{cons}$	1.98***	1.66***	1.46***	1.22
$\hat{\beta}_3^{cons}$	.	1.64***	.	1.21
$\hat{\beta}_0^{prod}$	2.17***	1.95**	1.40**	1.35
$\hat{\beta}_1^{prod}$	2.16***	2.20***	1.40**	1.41**
$\hat{\beta}_2^{prod}$	2.18***	1.88***	1.42**	1.24*
$\hat{\beta}_3^{prod}$	.	1.90***	.	1.24*

Ordinary least squares (OLS) regressions for consumption and production-based estimations with country and year fixed effects and heterogeneous slopes across countries. All test statistics are based on robust error terms. Three stars (***) indicate significance at the 1% level, two stars (**) at the 5% level, and one star (*) at the 10% level.
Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data.

Instead we will now focus on country-by-country analyses. As Aldy (2005) observes for U.S. states, country-specific regressions allow us to verify whether countries indeed follow the observed EKC pattern. We would expect poorer economies to show increasing per capita oil and energy use and richer economies to show decreasing trends or inverse U-shaped patterns within their observed levels of income. Most importantly, country-level analysis allows us to employ several time series econometric techniques to verify that any observed relationships are not merely artifacts of spurious correlations.

We conduct two country-level tests in various specifications and structural forms for the quadratic oil and energy regressions. First, we test for unit roots using augmented Dickey-Fuller tests in connection with the Akaike Information Criterion. We would like to reject these tests to avoid time series data with unit roots. Unfortunately, albeit unsurprisingly, that is only the case for a small fraction of countries. Assuming a model with intercept and trends, 10 of 73 countries have no unit roots in consumption and 13 in production at the 5% significance level. Data for $\ln(Y_{ct})$ and $\ln(Y_{ct})^2$ have no unit roots in 7 countries each. At the 10% significance level, the numbers are 16, 19, 10, and 9, respectively, barely a quarter of countries in the best scenario.[xv]

Second, we test whether the data used in country-level regressions are cointegrated. The message here is slightly better. Assuming a model with intercept and an underlying trend, 20 of 73 countries allow us to reject the Engle-Granger test for consumption at the 5% significance level; 22 allow us to do so for production. At the 10% significance level, the numbers increase to 24 and 25 for consumption and production, respectively. The numbers improve for a model assuming intercepts but no time trends. Now tests for 23 countries indicate cointegrated data for consumption regressions and 31 for production regressions at the 5% significance level. The numbers increase to 31 and 39 at the 10% significance level, respectively.

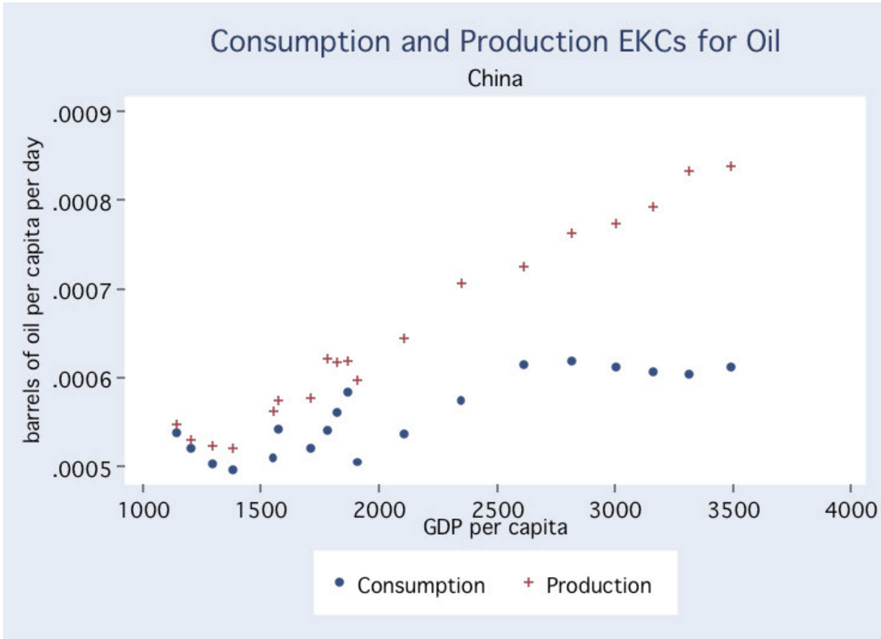
No country allows us to fully reject both tests for no unit roots and no cointegration.[xvi] Two notable countries are China and the United States. China allows us to reject one test for unit roots in consumption. It also exhibits cointegrated data for consumption, but not for production. The United States allows us to reject one test for unit roots in production assuming no time trends at the 10% level. It also shows cointegrated data for both consumption and production assuming intercepts but no time trends.

We proceed by estimating country-by-country dynamic ordinary least squares (DOLS) regressions with Newey-West standard errors to account for heteroskedastic and potentially autocorrelated error terms up to a lag of two years:

(8)
$$\ln\left(E_t^i\right) = \beta_0^i + \beta^i F\left[\ln\left(Y_t\right)\right] + \sum_{s=-2}^{2} \delta^i F\left[\Delta \ln\left(Y_{t-s}\right)\right] + \varepsilon_t^i .$$

The term $F\left[\Delta \ln\left(Y_{t-s}\right)\right]$ represents in changes in $\ln\left(Y_{ct}\right)$ and $\ln\left(Y_{ct}\right)^2$ with two and one-year lags and leads represented by *s* taking on values from –2 to 2. We repeat this analysis for all 73 countries and compare it to DOLS regressions with one-year lags and leads as well as standard country-level OLS regressions. The verdict, while mixed, does show tentative support for previously drawn conclusions.

We would expect a country at the level of development of China to show increasing oil and energy use per capita as its income increases. Similarly, we would expect the United States, a country that has consistently been richer than its trading partners to show decreasing levels of energy use by virtue of being on the downward-sloping portion of any observed EKC. That is, in fact, the case. Figure 7 shows estimation results for equation (8) for China and the United States. The graphs follow expected patterns. Moreover, production lies above consumption in China and below in the United States, again as expected.



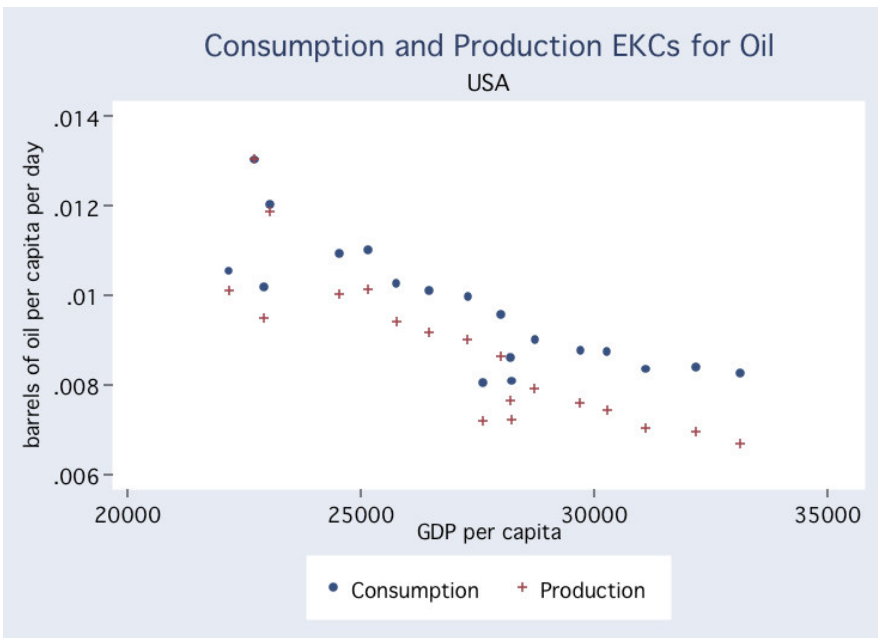


Figure 7 Oil use associated with consumption and production in China and the United States.
Predicted values come from quadratic dynamic ordinary least squares (DOLS) regression with Newey-West standard errors to account for heteroskedastic and potentially autocorrelated error terms up to a lag of two years.
Sources: International Energy Agency's Extended Energy Balances, Feenstra *et al.*'s (2005) world trade flows dataset, and United Nations Industrial Development Organization's Industrial Statistics Database. See Appendix A for a detailed description of the data

6. Conclusion

This article presents a comprehensive dataset of oil and total energy embedded in world trade and analyses its implications for the environmental Kuznets curve (EKC) as well s for energy security and wider policy considerations.

Applying this dataset in the context of environmental or "energy Kuznets curves" allows a separate discussion of energy use in consumption and production. Richer economies use relatively less energy in their industrial production yet still consume relatively large amounts. Trade in energy-intensive goods accounts for the difference. This conclusion points to disconcerting structural shifts as countries develop, which remain hidden in EKC debates that only focus on pollution associated with production. While energy and pollution-intensive production migrates to poorer countries, rich societies do not alter their tastes accordingly. Trade enables richer economies to consume less energy yet still benefit from energy and pollution-intensive production.

Closer examination of structural versus technological shifts paints a slightly more optimistic picture. We can exclude large-scale structural shifts as an explanation for the observed EKC patterns. But given that data for manufacturing are on a country-level rather than further split into particular industries or product categories, we cannot assign the downward-sloping portion of the EKC to technology alone. Structural shifts within manufacturing may account for part of the difference.

Applying this dataset to debates on the dependency on foreign oil shows that the often-cited policy goal of independence from foreign sources of energy is increasingly difficult to achieve, once one considers oil and energy embedded in goods crossing international borders. The flip side of any of these energy security arguments is that indirect dependence on foreign oil through world trade may lessen direct dependency. While ignoring the importance of energy embedded in world trade would be a mistake, equating it with the direct dependency on foreign oil sources would be equally wrong.

Shining a light on embedded energy has much larger policy implications. It is intimately tied to embedded carbon, which raises questions of consumption versus production-based emissions. Currently, responsibility for greenhouse gas emissions more often than not falls on the producer. Most emissions accounting frameworks do not take embedded carbon into account. It is, however, crucial for any discussions of border adjustments and other trade-related implications of domestic climate policy. Embedded carbon and, by extension, embedded energy may well become dimensions through which trade competitiveness gets judged. A key factor is the decoupling of energy and carbon. The energy content of production may increase, while its carbon content will need to fall considerable to avoid the worst consequences of global warming. Countries with abundant, carbon-free energy may experience considerable boosts to energy-intensive exporting sectors.

This dataset and analysis opens avenues for a wealth of future research. First, concerted efforts by researchers or national and international agencies such as the EIA and IEA should provide a reliable stream of annual data on the energy content of trade. Present data limitations force us to assume that exporting industry sectors are as energy intensive as sectors catering to the domestic market. Detailed input/output analyses may account for further indirect oil use, for example by labor employed in the manufacturing sector. This effect will need to be contrasted with direct impacts caused by decreased labor costs in developing countries and the host of implications associated with it. Second, present energy trade data could be expanded to account for the carbon content of trade by using relevant energy-carbon coefficients, with important implications for global climate policy.

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Appendix A: Data Sources

Feenstra *et al*.'s (2005) world trade flows dataset comprises bilateral trade data by value for the years 1962 to 2000 covering more than 180 countries and other trading entities. From 1988 to 2000, we use adjusted trade flows for China and Hong Kong to avoid double-counting of Chinese re-exports through Hong Kong. We have removed all trade between the two former German republics and put outside trade into a single German category. Lastly, we have converted the data to 2000 U.S. dollars using GDP deflators generated by the U.S. Department of Commerce's Bureau of Economic Analysis (BEA).[xvii]

The United Nations Industrial Development Organization's (UNIDO) Industrial Statistics Database supplements the economic data. It provides basic economic figures for 28 industrial sectors across 180 countries from 1963 to 2003. We aggregate across industrial sectors to obtain a panel of industry-wide output data. GDP adjusted by purchasing power parity and population data are taken from the Penn World Table Version 6.1 (Heston *et al*. 2002).

Energy data come from the International Energy Agency's (IEA) World Energy Statistics and Balances available through SourceOECD. The Extended Balances cover supply, trade and use by energy type for total industry and the overall economy in 30 OECD and 105 non-OECD countries. Data for OECD cover 1960 through 2004, those for non-OECD countries cover 1971 though 2003. The most complete energy data cover years from 1978 onwards. Combined with trade and economic data, the resulting dataset spans 73 countries over the time period from 1978 through 2000.

[i] The U.S. Department of Energy's Energy Information Administration (EIA) estimates oil imports for 2004 at 14.2 million barrels per day (EIA 2006). The International Energy Agency's World Energy Statistics and Balances estimate imports for 2004 to be 10.4 million barrels per day. Their figure for 2000, the last year in the present analysis is 9.3 million barrels (Table I, page 8).

[ii] See Table I, page 8.

[iii] EKC hypotheses are often tested for both aggregate and per capita pollution and emissions. Grossman and Krueger (1995), for example, analyze aggregate figures; Selden and Song (1994) focus on per capita values. We will discuss the distinction further in section 3.

[iv] Schmalensee, Stoker and Judson (1998) calculate a correlation of 0.9974 between CO_2-emissions and total energy use for a large panel of 141 countries between 1950 and 1990.

[v] The five countries with the largest reserves are Saudi Arabia, Canada, Iran, Iraq, and Kuwait. They are also the only ones with reserves above 100 billion barrels. (Oil and Gas Journal 2005; also see EIA 2006 and CFR 2007.)

[vi] Copeland and Taylor (2004) provide a comprehensive survey of the Pollution Haven Hypothesis, which also distinguishes it from a Pollution Haven Effect. While several papers demonstrate the Effect, support for the Hypothesis is less clear.

[vii] See Figure 1, page 3.

[viii] See Galli (1998), Medlock and Soligo (2001), and – for the most comprehensive treatment to date – Judson, Schmalensee and Stoker (1999).

[ix] The focus on manufacturing rather than the whole economy is largely driven by the availability of trade data. Feenstra *et al.*'s trade database focuses on bilateral trade of manufacturing goods. See Appendix A.

[x] We use the estimated equations,

$$\ln\left(\hat{E}_{ct}^{i}\right) = \hat{\beta}_0^i + \hat{\beta}_1^i \ln\left(Y_{ct}\right) + \hat{\beta}_2^i \ln\left(Y_{ct}\right)^2 + \hat{\beta}_3^i \ln\left(Y_{ct}\right)^3 \text{ for } i \in \{cons,\ prod\},$$

to calculate the levels of income per capita where their slopes are zero and test their equality. Slopes are zero when,

$$\hat{\beta}_1^i + 2\hat{\beta}_2^i \ln\left(Y_{ct}\right) + 3\hat{\beta}_3^i \ln\left(Y_{ct}\right)^2 = 0\,,$$

which, using the quadratic formula, holds for:

$$\ln\left(Y_{ct}\right) = \frac{-2\hat{\beta}_2^i \pm \sqrt{4\left(\hat{\beta}_2^i\right)^2 - 12\hat{\beta}_1^i\hat{\beta}_3^i}}{6\hat{\beta}_3^i}\,.$$

Given the S-shapes of the observed EKCs, we can focus on one of the two roots and ignore the case where $\sqrt{\cdot}$ is added instead of subtracted in the numerator.

[xi] The year 1995 is a natural break in the dataset. Some countries, including the United States, lack output data for 1996.

[xii] See Copeland and Taylor (2004) for a recent survey of the trade and environment literature.

[xiii] In practice, we could have used any intensity factor for the purpose of the subsequent regression analysis. Since the intensity factor is common to all countries, the results are not sensitive to the intensity used.

[xiv] An alternative indicator would be to use U.S. intensities by year for all countries: $\tilde{E}_{ct} = \left[e/y\right]_{US,t} \cdot y_{ct}$. This measure disentangles cross-sectional structural and intensity effects, but does not accomplish the same along the time dimension. $\tilde{E}_{ct}$ would be the preferred indicator for a cross-sectional analysis focusing on particular years. (Cole 2000)

[xv] Changing the model specifications to one with assumed intercepts but no trends improves the rate of rejection for consumption and production series but worsens those for income and income squared.

[xvi] Full test results are available on http://gwagner.com/research/energy_trade.

[xvii] Bureau of Economic Analysis Table 1.1.4. Price Indexes for Gross Domestic Product.