Undergraduate Economic Review

Volume 16 | Issue 1

Article 5

2019

Is Our Coal-Onial Era Ending Anytime Soon?

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Abstract

In this paper, I estimate the long-run co-integrated relationship between energy demand and economic growth for 20 countries from the year 2000 to 2016. I use panel unit-root and heterogeneous panel co-integration tests to test for non-stationarity of the panels and to determine whether there is a long-run link between energy consumption and GDP per capita. The estimated model uses a first-difference OLS model to estimate income elasticity of energy demand; the empirical results of this model show that there is a long-run relationship between energy consumption per capita and GDP per capita. In the long-term, on average, with 1% increase in GDP per capita, energy consumption per capita on average increases by 0.327%. Moreover, our model provides evidence for an “inverted-U” relationship, thus supporting the theory that post-industrialization, we could expect income elasticity of energy demand to be negative because we have more efficient production technology, which allows us to produce the same output with less energy. However, since many countries like India and China are still developing and industrializing, there will be an ever-greater demand for energy. We need to research policies that will help provide for this increasing energy demand, but at the same time will reduce greenhouse gas emissions.

Keywords

energy consumption, GDP, long-run co-integrated relationship, climate change

Cover Page Footnote

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In this paper, I estimate the long-run co-integrated relationship between energy demand and economic growth for 20 countries from the year 2000 to 2016. I use panel unit-root and heterogeneous panel co-integration tests to test for non-stationarity of the panels and to determine whether there is a long-run link between energy consumption and GDP per capita. The estimated model uses first-difference OLS model to estimate income elasticity of energy demand; the empirical results of this model show that there is a long-run relationship between energy consumption per capita and GDP per capita. In the long-term, on average, with 1% increase in GDP per capita, energy consumption per capita on average increases by 0.327%. Moreover, our model provides evidence for an "inverted-U" relationship, thus supporting the theory that post-industrialization, we could expect income elasticity of energy demand to be negative because we have more efficient production technology, which allows us to produce the same output with less energy. However, since many countries like India and China are still developing and industrializing, there will be an ever-greater demand for energy. We need to research policies that will help provide for this increasing energy demand, but at the same time will reduce greenhouse gas emissions.

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1. Introduction

Countries' fossil fuel use today has become "the symbol of modern industrial civilization" (Li et al. 2011 pp. 568). The global reliance on fossil fuels to provide for our energy demand is greater than ever. As more and more developing countries are industrializing, there is an ever-increasing demand for more energy resources. Fossil fuels are finite, and due to overuse we have an increasingly serious energy security problem. With both an exponentially growing energy demand and a soaring use of fossil fuels to provide for it, greenhouse gas emissions, which can distort our environment and ecosystems, have been consistently high. Greenhouse gas emissions, which are some of the key causes of climate change and global warming, have dire consequences for our sustainable growth and existence.

How regions develop has significant implications for global energy markets because with more development there is a greater demand from production of goods and services. China, India and Africa will be key drivers of energy demand and greenhouse gas emissions in the near future. US Energy Information Administration (EIA) has estimated that between years 2015-2040, China's economy is expected to grow consistently at about 5.7%, India's at 7.1% and Africa's at 5%. Such large scale development foreshadows immense increases in energy use and demand. EIA estimates show that from 1971 to 2016, the global total primary energy supply increased by 25 times. Not only that, but the last IPCC Assessment Report (IPPC AR5, 2015) estimated that our ocean and surface temperatures are the warmest that they have ever been, and our CO_2 emissions contribute to about 78% of our total GHG emissions. Most of these changes have been driven primarily because of rapid global economic and population growth.

Energy consumption is highly correlated with production, income and quality of life. Many economists and policymakers agree that understanding the long-run relationship between energy demand and economic growth and development is incredibly important for achieving greater energy security and improving environmental policies (Medlock & Soligo 2001; Ang; 2005; Li et. Al 2011; Judson et al. 1999). Since the late 1900s, there have been increasing concerns about global warming as a result of extensive fossil fuel use. Measuring energy efficiency by evaluating the relationship between energy consumption and economic growth have become commonly adopted policies. Countries have used improvements in energy efficiency as measures of the reduction of their GHG emissions. For example, International Energy Agency (IEA) started developing energy efficiency indicators like income elasticity or energy intensity in 1995; the US Department of Energy started measuring energy intensity in 1992, and European SAVE project to improve energy efficiency measurement also started the same year (Ang 2005). Similarly, many Asian developing countries have started using energy intensity or elasticities to understand whether their economic development is energy efficient or not.

In this paper, I estimate the income elasticity of energy consumption in order to examine the long-run relationship between energy consumption and economic development. I estimate my results using data from 20 countries[1] from year 2000-2016. The key variables that I use to estimate the elasticities are GDP per capita measured in purchasing power parity, so that exchange rate variations do not distort comparisons, and energy consumption, which is measured in terms of kg of oil equivalent per capita. I find that with 1% increase in GDP per capita, on average the energy consumption increases by 0.327%. This result is highly significant at a 5% significance level with a t-statistic of 3.229. I use a fixed effect OLS model with both country and year fixed effects, as well as first differences of both GDP per capita and energy consumption to deal with issues of confounding and reduce omitted variable biases in my model.

Many of the confounding issues in my model stem from endogeneity problems, which are mostly, associated the lack of unidirectional causality between economic growth and energy consumption. Many economists, particularly Engle and Granger have shown that causal relations could run from either side or both sides at once (Palgrave 2007). That energy consumption leads to economic growth, makes a lot of intuitive sense because there are a lot of positive externalities associated with greater energy use, for example, positive impacts on health services or education or quality of lifestyle. On the other hand, there is a general understanding that greater economic growth and industrialization stimulates a greater demand for energy. The potential for reverse causality between the two variables calls for better understanding of the long-run co-movement of economic growth and energy demand.

The rest of the paper is organized as follows. Section 2 introduces relevant background and reviews literature on the relationship between energy consumption and GDP. Section 3 discusses

[1] See figure 2 for the list of countries, their energy consumption per capita and GDP per capita.

economic theory about how energy demand is expected to change over different stages of economic development. Section 4 presents the data used for analysis, and section 5 describes the methodology, presents results and discusses limitations of the data and the method. Finally, section 6 summarizes results and makes recommendations for further research.

2. Background

In the 1990s, the Kuznets curve was popularized by economists to study inequality and later environmental pollution; its application and logic has been extended to explain the changes in elasticity of energy demand at different stages of economic development (Palgrave 2007). The Kuznets curve argues that income elasticity of energy consumption is positive when countries are industrializing. This could also be understood in terms of rising energy intensity. During the post-industrialization period because of increases in services and efficiency of products and technology, elasticity of energy demand is expected to become negative or in other words, the energy intensity falls below 1. Brookes (1972) explained this change as when GDP per capita increases, the economic efficiency of useful energy demand, which they define as the number of units of output produced per unit of useful energy consumed, declines (Brookes 1972). In a post-industrialization period, where there is greater consumption of energy efficient technology, the same increments of GDP per capita can be produced by using less energy (Brookes 1972). This argument, however, does not imply that more developed countries have a lower energy demand, but only that their energy intensity in declining or that their income elasticities are negative. In other words, they have technology that is more energy efficient and can produce the same output with less energy. These differences in elasticities at various phases of development can lead to an “inverted-U” curve, the turning point of which highlights the maximum energy dependence after which we see negative elasticities.

I plotted the estimates of income elasticities from my model against GDP per cap in PPP. The graph shows of an “inverted-U” curve, thus providing evidence for the Kuznets analysis of the differences in income elasticities between when countries are industrializing and when they are in a post-industrial phase.

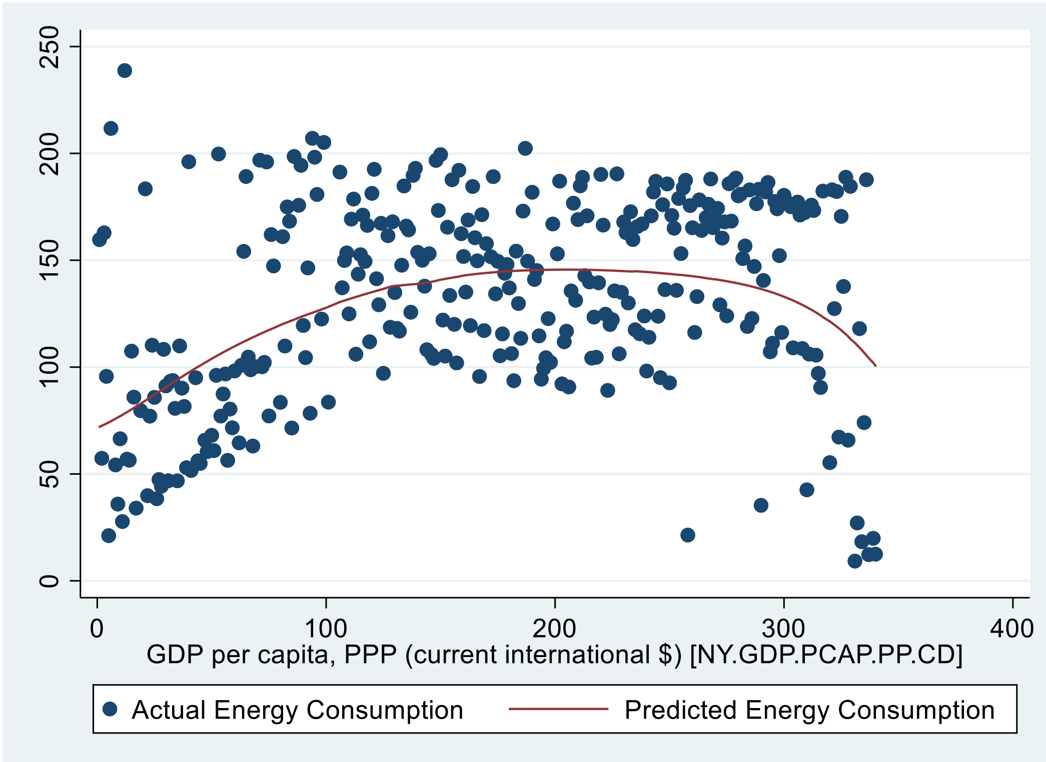

Figure 1. This graph was plotted with elasticities that were predicted from the regression model 6 (discussed later in the paper) against GDP per capita measured in PPP

3. Literature Review

Many economists have previously estimated energy efficiency coefficients to understand the relationship between energy consumption and economic development. Zilberfarb and Adams (1981) estimated the relationship between energy consumption and GDP for developing countries using a pooled cross-sectional dataset. They used a 47 countries dataset from 1970-1976, and estimated an income elasticity of 1.35, which was significantly above 1. Their work is considered a milestone in understanding how the long-run energy consumption and economic growth relationship is critical to forecasting future energy demand and emissions statistics. Moreover, Judson et al. (1999) use aggregate national-level panel data from 1950-1990 to estimate the reduced form of Engle curves for per-capita GDP and commercial energy consumption in major sectors. They use data from 141 countries, and find an "inverse-U" relationship between energy consumption and economic growth. They observe a lot of negative elasticities, which reflect declines in carbon and energy intensities. Similarly, Medlock and Soligo (2001) use a 28 countries panel data from 1985-1995 to estimate the income elasticities for major sectors to see which sectors contribute most to the increasing energy demand. They too observe an "inverted-U" relationship between energy consumption and GDP, which they discuss as a proof that post-industrial development could lead to significant reduction in income elasticities of energy demand. Li et al. (2011) estimate the long-run co-integrated relationship between real GDP per capita and energy consumption in 30 provinces in China. They look at CO_2

emissions as a proxy for their energy consumption, and estimate that with 1% increase in GDP per capita, the CO_2 emissions increased by 0.48-0.50% on average. I use a panel dataset of 20 countries to estimate elasticities using a model that is fundamentally similar to the model used by Medlock and Soligo (2001), but my estimation technique is most similar to the long-run panel co-integration technique used by Li et al. (2011) in China.

As discussed earlier in the paper, there has historically been doubt about the link between income and energy consumption. The causal relationship can run from energy consumption to economic development or from economic development to energy consumption or they could move together. The non-stationarity of the data over time, and the co-integrating link between energy consumption and economic growth have been the two most complicating problems in the analysis of this relationship. Non-stationarity occurs in a time-series when the random variables are not sampled from the same distribution, thus leading to spurious OLS estimators. Therefore, many studies have found conflicting estimates of the relationship between energy consumption and GDP because the estimates are very sensitive to particular time periods and the nature of other drivers of GDP and energy consumption during that time. If we have non-stationarity in our panel, then we also expect to have a co-integrating relationship between our variables; if we find that there is no co-integration between non-stationary variables, then our regression results could also be spurious and nonsensical (Li et al. 2011). Li et al. (2011) use a panel dataset, which allows for dynamic heterogeneity in across groups to account for both co-integration and non-stationarity in their estimation. They use the Levin-Lin-Chu test, the IPS test, and the Fisher-ADF and Fisher- PP tests to test for unit-roots in their time-series (Li et al. 2011). They do not reject their null of non-stationarity in any of their tests. I only use the Fisher-ADF panel unit-root test for my analysis because it is simpler and uses non-parametric specifications. My results confirm that the panel data is non-stationary, and therefore, both GDP and energy consumption are I(1) processes.

After testing for panel unit-root, we need to test for a co-integrating relationship between energy consumption and economic growth. The test for measuring co-integration between non-stationary variables in a panel was first developed by Pedroni (Pedroni 1997). This test is based on estimators that simply average the individually estimated coefficients (Li et al. (2011) pp. 570). The goal is to test for co-integration to determine if there is a long-run relationship that we need to control for in the econometric specification. Li et al. (2011) use the Panel-ADF and Kao's co-integration tests in their paper. In this paper, I test for co-integration using Kao test, Pedroni test and Westerlund test. Both Kao's and Pedroni's tests are based on Engle-Granger two-step residual-based co-integration test. Many economists prefer the Westerlund test for panel datasets. Thus, I test for heterogeneous panel co-integration using all three of these tests.

To estimate the OLS estimators after testing for non-stationarity and co-integration, we need to correct for non-stationarity to correct the standard OLS for endogeneity bias and serial correlation of error term. Correct standard errors allow us to test for significance of the relationship between our variables. Both Nachane et al. (1988) and Li et al. (2011) correct for non-stationary after testing for co-integration. I use the first-differences method, which uses lagged variables to reduce the problem of confounding. Li et al. (2011) use the same technique to calculate their dynamic OLS estimators.

Since determining the appropriate number of lags in challenging, I estimated various models with different choices of lag till the final model I based my findings on uses one-time lag in the left-hand variable, energy consumption per capita and the explanatory variable of interest, GDP per capita. Since I am using a panel dataset, it is important to capture the influence of unobserved time-invariant variables like climate, institutions, etc. that effect energy demand without actually observing them. Medlock and Soligo (1981) and Li et al. (2011) both use time and country fixed effects model to avoid potential problems of country-specific heterogeneity, which can otherwise bias our estimators if they are not controlled for in the model. Using a fixed effects model can help reduce endogeneity problems, ignoring which can lead to inconsistent and meaningless estimates of parameters. Judson et al. (1999) also use FE models to eliminate some omitted variable bias, and Zilberfarb and Adams (1981) use dummies to account for heterogeneity among countries. In my model, I use both year and country fixed effects to estimate the relationship between energy consumption and economic growth.

Most papers that have estimated the relationship between energy consumption and GDP have not controlled for many other variables in their models. Judson et al. (1999) recommend controlling for energy prices, but due to lack of data available on actual energy prices, they control for coverage ratio as a proxy. Medlock and Soligo (2001) control for log of prices in their regression model to reduce omitted variable bias because energy prices have been empirically proven to be highly correlated with both income and energy demand, and excluding them from our model will positively bias our estimate of the impact of GDP on energy consumption. Another thing to consider is the specification of our model. I use a double-log model to estimate elasticities and a non-linear quadratic specification like Medlock and Soligo (2001) use for their estimation. A non-linear quadratic specification on the GDP variable makes sense in light of popular economic theory about how elasticities and energy intensities vary during different periods of development. Therefore, if we expect to observe an "inverted-U" like relationship, then using a quadratic specification seems appropriate because it supports the theory that post-industrialization can lead to negative elasticities. Therefore, expect to see a turning point in our elasticities. Lastly, as mentioned earlier the GDP per capita is measured is reported in purchasing power parity, so that the exchange does not distort comparisons across countries.

4. Data

I use three primary sources of data: 1) the World Bank world development indicators data set; 2) Western Texas Intermediate (WTI) average world oil price statistics from the year 2000 to 2016; 3) World Bank GDP per capita in PPP 2000-2018. The World Bank world development indicator dataset is a panel dataset from the year 2000 to 2018 for 20 countries with measures of various development indexes such as electrical use, agriculture, forestry, health, CO_2 emissions, exports, foreign direct investment, contraceptive use, health data, population, external debt, schooling, GNI per capita etc. The dataset also has measures for GDP per capita in current US dollars and energy consumption equivalent to kilogram (kg) oil use per capita. This is calculated using the total primary energy supply (TPES) in kg of oil equivalent units, which is the amount of energy released by burning one kg of oil. Since the data set had GDP measures in US dollars, to standardize comparisons from my estimates of elasticities, I used separate GDP per capita in PPP for all the countries in the world development indicators dataset. To control for prices in my model, I use the WTI average oil prices for the years 2000-2016 for my analysis. These prices work for the purposes of my analysis because WTI oil prices over the last two decades have very closely tracked the world oil prices. For my estimation, I dropped the data for years 2017 and 2018 because there was missing energy consumption data for most countries in the dataset for those years. Below is a table of summary statistics of energy consumption per capita and GDP per capita for the 20 countries in the data over years 2000-2016.

Summary statistics:
Country Name:

	N	mean	sd	min	max
Argentina	17	53.118	21.699	1	71
Energy use (kg of ..USE.PCAP.K~]					
GDP per capita, PP..GDP.PCAP.P~]	17	47.059	23.894	2	73
Australia					
Energy use (kg of ..USE.PCAP.K~]	17	245.235	63.256	1	270
GDP per capita, PP..GDP.PCAP.P~]	17	197.882	61.765	102	274
Brazil					
Energy use (kg of ..USE.PCAP.K~]	17	13.118	9.955	1	31
GDP per capita, PP..GDP.PCAP.P~]	17	103.529	132.703	5	340
China					
Energy use (kg of ..USE.PCAP.K~]	17	92	108.635	1	314
GDP per capita, PP..GDP.PCAP.P~]	17	177.176	130.29	4	335
France					
Energy use (kg of ..USE.PCAP.K~]	17	162.353	46.117	1	199
GDP per capita, PP..GDP.PCAP.P~]	17	173.353	50.35	97	245
Germany					
Energy use (kg of ..USE.PCAP.K~]	17	156.647	42.11	1	187
GDP per capita, PP..GDP.PCAP.P~]	17	199.118	62.143	105	286
India					
Energy use (kg of ..USE.PCAP.K~]	17	202.294	82.637	1	276
GDP per capita, PP..GDP.PCAP.P~]	17	201.588	90.189	79	318
Indonesia					
Energy use (kg of ..USE.PCAP.K~]	17	266	100.013	1	311
GDP per capita, PP..GDP.PCAP.P~]	17	238.824	132.642	1	336
Italy					
Energy use (kg of ..USE.PCAP.K~]	17	90.176	25.837	1	115
GDP per capita, PP..GDP.PCAP.P~]	17	164.412	37.432	104	223
Japan					
Energy use (kg of ..USE.PCAP.K~]	17	143.529	40.62	1	173
GDP per capita, PP..GDP.PCAP.P~]	17	170.706	45.453	103	241

Table 1. N represents the number of years in the panel dataset. (Table continued on the next page)

	N	mean	sd	min	max
Korea, Rep.					
Energy use (kg of ..USE.PCAP.K~]	17	201.471	58.763	1	250
GDP per capita, PP..GDP.PCAP.P~]	17	119.588	43.858	61	208
Mexico					
Energy use (kg of ..USE.PCAP.K~]	17	39.824	12.871	1	56
GDP per capita, PP..GDP.PCAP.P~]	17	34.706	19.176	7	62
Netherlands					
Energy use (kg of ..USE.PCAP.K~]	17	209	55.129	1	241
GDP per capita, PP..GDP.PCAP.P~]	17	234.353	51.233	141	291
Russian Federation					
Energy use (kg of ..USE.PCAP.K~]	17	191.118	73.255	1	244
GDP per capita, PP..GDP.PCAP.P~]	17	128.059	115.644	3	333
Saudi Arabia					
Energy use (kg of ..USE.PCAP.K~]	17	226.412	87.406	1	283
GDP per capita, PP..GDP.PCAP.P~]	17	243.941	49.892	149	302
Spain					
Energy use (kg of ..USE.PCAP.K~]	17	90.412	26.947	1	118
GDP per capita, PP..GDP.PCAP.P~]	17	135.471	37.261	78	203
Switzerland					
Energy use (kg of ..USE.PCAP.K~]	17	115.471	31.957	1	139
GDP per capita, PP..GDP.PCAP.P~]	17	269.882	45.086	189	316
Turkey					
Energy use (kg of ..USE.PCAP.K~]	17	25.235	16.215	1	55
GDP per capita, PP..GDP.PCAP.P~]	17	123.353	123.925	9	339
United Kingdom					
Energy use (kg of ..USE.PCAP.K~]	17	113.588	36.659	1	148
GDP per capita, PP..GDP.PCAP.P~]	17	180.529	48.272	100	250
United States					
Energy use (kg of ..USE.PCAP.K~]	17	273.647	70.653	1	305
GDP per capita, PP..GDP.PCAP.P~]	17	266.471	34.286	200	309

Table 1. (cont.) N represents the number of years in the panel dataset.

There are a few problems with the data that make it challenging to estimate the model on a large scale. Firstly, the dataset is not large enough with enough variation of countries to understand the pattern of changes in global energy demand. The use of limited number of countries stems primarily from the lack of data on energy consumption in many countries. A solution to this problem could be to use a proxy for energy consumption like CO_2 emissions. Another problem with the variable energy consumption in the dataset is that it only measures commercial use of energy. Therefore, for developing countries like China, India, Indonesia, Mexico, where there is still a great reliance on non-commercial sources for energy demand, we do not have exact measures of energy consumption, which is linked to economic output.

5. Methodology

In this section, I will discuss the estimations of my unit-root test for stationarity, my panel heterogeneous co-integration test, and estimations of my OLS regression model. Then I will explain my results, and discuss certain limitations of my model.

As discussed earlier in the paper, we use a unit-root test to detect any non-stationarity in a time-series data because if we have non-stationary variables, our OLS estimators can be spurious and give us nonsensical relationships. Therefore, we need to control for non-stationarity to correct standard OLS for endogeneity bias and serial correlation of error term. This correction will also give us correct standard errors, which allow us to do significance tests on our parameters for inference. If we have evidence for non-stationarity, we also test for co-integration to determine if there is a long-run relationship between our variables. We almost always expect there to be a co-integrating relationship whenever our variables are non-stationary; otherwise, we have a problem because our OLS parameters will not make much sense. I use Fisher-ADF unit-root test, which is based on an augmented Dickey-Fuller test. In my unit-root test for both energy consumption per capita and GDP per capita, I fail to reject the null hypothesis that all the panels contain a unit-root; I observe strong evidence of evidence of non-stationarity in both our variables in our time-series data. We observe very high p-values for all chi-squared, inverse normal, inverse logit and modified inverse chi-squared statistics, such that we cannot even reject our null at a 10% significance level. These statistics are shown in the table below:

Fisher-ADF Unit-Root Tests		Energy Consumption per Capita (statistic)	GDP per Capita in PPP (statistic)
Inverse chi-squared (40)	P	12.3924 (1.0000)	30.7840 (0.8522)
Inverse normal	Z	4.6664 (1.0000)	0.9262 (0.8228)
Inverse Logit [t(89), t(104)]	L*	4.9693 (1.0000)	0.8790 (0.8093)
Modified inv. Chi-squared	Pm	-3.0866 (0.9990)	-1.0304 (0.8486)

Table 2. The Fisher-type unit-root test is based on an augmented Dickey-Fuller test. The null hypothesis, H_0 of this test is that all panels contain a unit root; the alternative, H_A in a Fisher-type unit-root test is that at least one panel is stationary. We fail to reject the null of non-stationarity for both Energy Consumption per Capita and GDP per Capita. Probabilities for a Fisher-type test are calculated using an asymptotic chi-squared distribution. The test assumes asymptotic normality. P-values are in parentheses.

Since we have non-stationary variables in our panel, we need to test for co-integration between the variables. I use three different tests, namely, Pedroni test, Kao test and Westerlund test to test for a long-run relationship between energy demand and economic development. The null hypothesis for all three tests is that there is no evidence of co-integration. The alternative to the null for Kao test and Pedroni test is that there is co-integration in the panel. The alternative in the Westerlund model is slightly different in that some, but not necessarily all the panels are co-integrated. Many economists prefer the Westerlund test for panel data to determine if there is a co-integrating relationship because this test is very sensitive to any co-integration present in the data. We see in the Kao test, only the modified-DF statistic and DF statistics reject the null of no co-integration at a 5% and a 10% confidence level respectively. The Pedroni test strongly rejects the null of no co-integration for two of the three estimated statistics, and the Westerlund variance ratio statistic also strongly rejects the null of no co-integration with a p-value of zero. We see from these tests that there exists a long-run relationship between energy consumption per capita and GDP per capita that we need to control for in our econometric specification.

Panel Co-integration Tests

Co-integration Test	**Kao Test**	**Pedroni Test**	**Westerlund Test**
Modified Dickey-Fuller t	-1.9819 (0.0237)**		
Dickey-Fuller t	1.4030 (0.0803)*		
Augmented Dickey-Fuller t	-0.3098 (0.3784)	2.3586 (0.0092)***	
Modified Phillips-Perron t		0.0351 (0.4860)	
Phillips-Perron t		2.7827 (0.0027)***	
Variance ratio			-3.1523 (0.0000)***

Table 3. The null H_0 for all these co-integration test is "no co-integration"; the alternative, H_A is that there is co-integration, except the alternative hypothesis is slightly different for the Westerlund test, namely, that some (not necessarily all) of the panels are co-integrated. I reject the null at ***, ** and * (1%, 5% and 10% respectively). Most of the results reject the null of no co-integration. The Pedroni and the Westerlund tests show most evidence for co-integration between Energy Consumption and GDP per capita.

I estimate the OLS regression model using first-differences, fixed effects and a double-log model that will allow for measuring income elasticities of energy demand.

In my model, I use log of energy consumption per capita as my dependent variable and log of GDP per capita as my variable of interest. I also include a quadratic specification of log of GDP per capita to account for the non-linear relationship that we expect to see between energy consumption and GDP. We expect the coefficient on log of GDP per capita to be positive because with economic growth, we would expect greater energy demand, which would increase our energy consumption; we expect the coefficient on the quadratic term to be negative, which would provide evidence for the "inverted-U" curve, with positive elasticities when GDP is lower, and negative elasticities when GDP is higher.

I also control for prices to reduce omitted variable bias because prices have shown to be very strongly correlated with both our left hand and explanatory variable of interest. Therefore, excluding them from the model can lead to biases in our OLS estimators. I use log of prices in my model; this allows for the distinction between the income effect of GDP, and the impact of changes in prices of oil (Medlock and Soligo 2001). In other words, we can measure price elasticity and income elasticity of fossil fuel energy demand separately. The coefficient on log GDP per capita estimates the income elasticity of energy demand whereas the coefficient of prices estimates the price elasticity of energy demand, thus including prices separates the two.

I use both country and year time effects for a fixed effects model. This allows us to control for unobserved time-constant heterogeneity between different countries in the dataset, thus helping with endogeneity problems by reducing some omitted variable bias. If we do not control for fixed effects, our model will imply that there is non-heterogeneity in energy demand for all countries, and that the elasticities are the same for all for countries in our sample. This result is not really useful because this non-heterogeneity assumption if we do not use a fixed effects model is very doubtful when we have countries like, US and Mexico, both in the dataset. We have no reason to believe that the income elasticities work the same way for these two countries, and that both these countries have similar unobserved time-invariant factors that affect energy demand. Therefore, we use a fixed effects model to account for unobserved differences. We can also estimate the model using random effects, but it is not preferred since random effects models make a lot of very strong assumptions, such as individual effects are independently and identically distributed. In fixed effects estimations, on the other hand, individual effects are assumed to be fixed, and the OLS estimators are always BLUE (Best Linear Unbiased Estimator) (Palgrave 2007).

Although the null of no co-integration was rejected by both Pedroni and Westerlund tests, that evidence is not enough to ensure that the relationship between energy consumption and GDP can be meaningfully estimated because most estimators require the whole panel to be co-integrated (Westerlund, Thuraisamy, Sharma, 2015). Therefore, I use first-differences with lags on variables on each side of the model to account for non-stationarity of our variables energy consumption and GDP. Since it is often fairly tricky to predict how many lags will be necessary to estimate the appropriate relationship, I estimated seven different models as shown in figure 5, and finally used model (6) with one time lag on both energy consumption per capita and GDP per capita. The model I used for the purposes of my analysis is as follows:

$$ln(C_{it}) = \alpha_i + \beta_1 ln\,(Y_{it}) + \beta_2 (ln(Y_{it}))^2 + \beta_3\, ln(P_{it}) + \varepsilon_{it}$$
$$C_{it} = Energy\ Consumption\ per\ capita$$
$$Y_{it} = GDP\ per\ capita$$
$$P_{it} = Oil\ Prices$$
$$\alpha_i = Country\ and\ year\ fixed\ effects$$

The equation above can be viewed as a long-run relationship between energy demand and GDP. The equation yields a long-run elasticity of:

$$\beta_1 + 2\beta_2\, ln(Y_{it})$$

We would expect the coefficient on β_1 to be positive while we would expect the coefficient on β_2 to be negative, which would imply that there is an “inverted-U” relationship between energy consumption and income. We would also expect to see a turning point, where the income elasticity of energy demand is zero. After the turning point, which represents maximum energy dependence, energy demand will start to decline as GDP per capita increases.

In model (6) in Figure 5, we estimate that with 1% increase in GDP per capita, energy consumption per capita increases by 0.327. Our model explains about 56% of the variation in energy consumption per capita. The coefficient on β_1 is estimated as 0.327, which has both a positive sign as we had expected and is highly statistically significant at 95% confidence level with a t-statistic of

3.229. Our coefficient on β_2 is -0.0517, which also has the sign we had expected it to have, and is statistically significant with a t-stat of -3.425. We see that with 1 unit increase in GDP per capita in PPP, our estimated income elasticity changes by $2\beta_2\ (ln(Y_{it2}) - \ln(Y_{it1}))$; since the coefficient on β_2 is negative, we estimate a declining income elasticity, which we expect to continue to decline till zero after which it will become negative. We observe an "inverted-U" relationship that supports our theory about how energy demand changes at different levels of development. With high levels of GDP per capita, which we would observe in a more developed country, we would expect there to be negative income elasticities. As GDP per capita increases, the energy required to produce additional amount of output decreases because production technology improves and becomes more efficient. On the other hand, when countries are developing and industrializing, elasticity is positive because with increasing GDP per capita, energy demand increases.

Energy Consumption and GDP per Capita Models

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	log Energy Consumption (0,0)	log Energy Consumption (0,0)	log Energy Consumption (0,0)	log Energy Consumption (1,0)	log Energy Consumption (2,0)	log Energy Consumption (1,1)	log Energy Consumption (2,2)
Log GDP per Capita in PPP	-0.108***	-0.108***	0.782***	0.296***	0.293***	0.327***	0.302***
	(-3.961)	(-3.961)	(7.404)	(3.378)	(3.274)	(3.229)	(2.727)
Log Price		0.111	0.400*	0.128	0.0389	0.131	0.0475
		(0.422)	(1.704)	(0.981)	(0.306)	(1.005)	(0.372)
(Log GDP per cap)^2			-0.119***	-0.0461***	-0.0452***	-0.0517***	-0.0476***
			(-8.663)	(-3.887)	(-3.674)	(-3.425)	(-2.849)
Constant	5.221***	4.844***	2.404***	1.231**	1.942***	1.138**	1.952***
	(34.84)	(5.163)	(2.733)	(2.434)	(3.899)	(2.149)	(3.627)
Observations	313	313	313	293	273	293	273
R-squared	0.094	0.094	0.287	0.562	0.492	0.562	0.494
Number of Countries	20	20	20	20	20	20	20
Country FE	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES

Table 4. t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1
GDP per capita is in Purchasing Power Parity. The specifications of model 6 are used to analyze results in this paper.
Model 4 has the left-hand variable, Log Energy Consumption with one lag. Model 5 has two lags on the left-hand variable, Log Energy Consumption. Model 6 has one-lag for both Log energy consumption and Log GDP per cap in PPP. Model 7 has two time lags on both Log energy consumption and Log GDP per cap in PPP. Models 1, 2 and 3 do not have any lagged variables. The coefficients on Log GDP per cap in PPP and Log Price show elasticities with respect to energy consumption. (. , .) in parentheses at the top of each column represents the number of lags on energy consumption per capita and GDP per capita, respectively.

There are, however, few problems in our model. This model does not account for the structural changes in production of outputs or possibilities of substitution in consumption. These structural changes should be reflected in our coefficients for more accurate estimates of how income changes energy demand, and therefore, energy consumption.

6. Conclusion

In this paper, I estimated the long-run co-integrated relationship between energy demand and economic development. The estimated model, which was comprised of data from 20 countries from 2000 to 2016, estimated that with one percent increase in income energy consumption on average increases by 0.327%. I employ panel unit-root test to test for non-stationarity and co-integration tests to determine whether there is a long-run link between energy consumption per capita and GDP per capita. I find evidence for both non-stationarity and co-integration. Then, I estimate a dynamic OLS model with one period time lag in both the left-hand variable and the explanatory variable of interest.

My results are consistent with existing economic theory about the relationship between energy demand and economic growth. This means that when countries are industrializing and developing, our energy demand is expected to increase. We know today that many countries like India and China are expected to experience immense economic growth in the near future, and therefore, we expect their energy demand to be really high as they are developing. This means that the demand for fossil fuels will be rise substantially and with it, our greenhouse gas emissions will continue to rise, and so will our energy shortages. This has serious implications for our sustainable environmental existence and long-term energy security. We need to develop policies that encourage the use of renewable energy sources to provide for the ever-increasing global energy demand. We need to also track our energy efficiency, and work on improving our technological production efficiency, so that we require less amount of energy to produce the same amount of outputs or services.

There can be further research done on estimating income elasticities for a larger sample of countries, and over a larger span of time. More data can help us gain more accurate estimates of how our energy demand changes with GDP per capita, and also how income elasticity of energy demand changes with GDP per capita. Most importantly, we need to do more research on how we can reconcile policies that encourage economic development and growth in developing countries with policies that help mitigate impacts of climate change and global warming, which are direct consequences of greenhouse gas emissions from extensive fossil fuel use.

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