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THE DETERMINANTS OF ENERGY INTENSITY

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I. ABSTRACT

The objective of this paper is to answer the question of which country-specific factors have the greatest impact on a country's energy intensity level. The analysis is not built on any known research on this subject, and the data has been taken from eclectic sources and independently brought together for the purposes of this paper. The paper discusses the dependent and independent factors, then provides hypotheses for the expected results of each factor backed by economic rationale. The paper then utilizes linear regression techniques with the gathered dependent and independent variables. The results, including hypotheses confirmation, levels of significance, and impact are disseminated and discussed. The paper then concludes with a discussion of research, results, and future prospects for energy intensity.

II. INTRODUCTION

It is impossible to ignore buzzwords such as "energy," "efficiency," and "sustainability" as we enter the 2^{nd} decade of the 21^{st} century, and one of the most important measures of success in this looming energy era is that of "*energy intensity*." In the language of business terminology, business productivity is to business efficiency as energy intensity is to energy efficiency. That is, energy intensity explains how much output a country can create (measured by gross domestic product) for the energy that it puts in (measured by quadrillion BTUs). The ratio is *Total Energy Consumption/GDP in US dollars,* which brings us to a number that describes the amount of energy consumed per US dollar. The measure of energy intensity does not tell the whole efficiency story,but one can certainly assume that a smaller ratio implies that a country is better at translating its energy into production. Thus,intensity becomes a proxy for oft difficult-to-measure efficiency.

An article in Forbes Magazine that assessed the 10 most energy-efficient countries based on a country's specific energy intensity number galvanized interest into this subject. Forbes declared that, "Not surprisingly, the countries with the most energy-efficient economies are those who import their energy supplies," and "[countries] with little domestic energy production are forced to import most of their fuel supply – creating a powerful economic incentive to use those expensive imports efficiently."[1]

However, energy imports alone certainly cannot be the end all be all of energy intensity determinants. So what else causes fluctuations in a country's energy intensity? In this paper many factors are explored whether they be geographical, industrial, demographical or otherwisein order to discover the answer to that question.

III. SAMPLE

This is a cross-sectional study of the year 2006, which is the most recent year for which data are available. The sample includes all countries for which data are available, which amounts to 160 countries. Notable exceptions include Iraq, Afghanistan, Taiwan, Georgia, and Puerto Rico. The special administrative region of Hong Kong was included as a separate entity from China.

IV. DEPENDENT VARIABLE

Energy Intensity

[1] Forbes.com – "The Most Energy-Efficient Countries"

The dependent variable is *energy_intensity*, which is defined as total primary energy consumption per dollar of gross domestic product (GDP). Total primary energy consumption is measured in British Thermal Units (BTUs) and GDP is measured using 2006 market exchange rates with year 2000 level US dollars as an index. A British Thermal Unit is defined as the amount of energy required to heat 1 pound of water 1 °F. Data are taken from the U.S. Energy Information Administration.[2]To avoid confusion in verbiage for the rest of this paper, an increase in energy intensity denotes a decrease in energy efficiency. For example, Denmark's energy intensity is 4,971 BTUs per US dollar of GDP, and Belgium'senergy intensity is 10,563 BTUs per US dollar of GDP, which means that Denmark is more efficient than Belgium.

V. INDEPENDENT VARIABLES

Standard of Living

A high standard of living is indicative of increased education, increased consumption, increased leisure, increased technology, and across the board enhancements in all aspects of life within a country. In economics, a better and more efficient environment can be considered a normal good. Thus, as standard of living increases (and income along with it), the demand for a better environment and a greater efficiency will increase as well. The independent variable *standard_living* in this case is defined asreal GDP per worker (GDP divided by the labor force). Data for the countries are taken from the Penn World Tables for the year 2006.[3]The predicted sign of this measure is negative, where an increase in standard of living will reduce energy intensity.

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[2] U.S. Energy Information Administration: Energy Intensity Data
[3] Penn World Tables

Education

The education level of a country should have a profound effect on the level of energy intensity. With more education comes more environmental, energy, and economic awareness. Thus, citizens of a country with a high level of education should have greater knowledge in all aspects of academia, and perhaps more germane to this study, they should have an enhanced knowledge ofenergy conservation and efficiency efforts.

In this study, the independent variable *education* is defined using the 2006 Education Index, which gives a two-thirds weight toadult literacy rates and a one-third weight to the combinedprimary, secondary, and tertiary enrollment rates.[4]The literacy rates denote an adult's ability to read and write, while the enrollment rates give a strong indicator of the average level of educational attainment within a country. These two measures combined give us a good sense of how educated a given country is. The values of the education index range from a low .286 in Niger and Burkina Faso to a high of .993 in Denmark. It is hypothesized that an increase in education level will reduce energy intensity (increase energy efficiency) because the country's inhabitants will have a greater understanding and awareness of energy usage.

Energy Imports

Many countries such as Japan and Italy lack domestic resources like coal and oil required to produce their own energy. Without sufficient energy an economy cannot operate at full potential, so in order to bridge the gap between available domestic resources and full potential requirements, a lack of energy must be compensated for by foreign imports. Importing energy is

[4] Human Development Report: Indicators

more expensivethan producing it domestically, so nations who rely heavily on imports must take special notice of how efficiently they use their energy to avoidbeing struck by high energy costs.

The independent variable *energy_imports* is defined as the natural log of a nation's production of energy in quadrillion BTUs divided by its consumption of energy in quadrillion BTUs or ln(*Production/Consumption)*. Energy Production for this data set is defined as "the production of petroleum, dry natural gas, and coal, and the net generation of hydroelectric, nuclear, geothermal, solar, wind, wood, and waste electric power."[5] Energy Consumption for this data set is defined as"the use of energy as a source of heat or power or as a raw material input to a manufacturing process, sources of which include petroleum, dry natural gas, coal, and net hydroelectric, nuclear, and geothermal, solar, wind, wood, and waste electric power."Information for these measures is obtained from the U.S. Energy Information Administration for the year 2006.[6]

A ratio under 1, such as the United State's .704 (natural log = -.3508), implies that a country must import energy in order to meet demand (in this case, 29.6% of it's energy). These nations must take heed of the efficiency in which they use the imports else they get too costly. A ratio over 1, such as Qatar's 4.798 (natural log = 1.5683), implies that a country can meet its own demand and export the leftovers to foreign nations. These energy-fruitful nations have less incentive to be thrifty with the way they operate with their energy. Therefore, it is predicted that an increase in the *Production/Consumption ratio*will lead to an increase in energy intensity, because as a nation nears its ability to cover its energy needs domestically it has less incentive to be prudent.

[5] For the U.S., energy production also includes biomass and geothermal energy.
[6] U.S. Energy Information Administration: International Energy Data

Extreme Climate

As is common practice, we turn down the dial on the air-conditioning to cool off when it is hot outside, and we blast the heat to warm up when it is cold outside. These heating and cooling processes keep our homes and buildings at a comfortable temperature, but also require extra energy in order to do so. Countries that face consistently hot or cold temperatures should lose out on some efficiency because they are constantly pumping more energy into their buildings and homes (non-production).

The independent variable*extreme_climate* is defined using a tool called "energy degree days," which measures variations from a reference temperature. A heating degree day (HDD) is a measure that occurs when it is cold, and a cooling degree day (CDD) is a measure that occurs when it is warm. An HDD is calculated by taking the average temperature for a day, which is the high plus the low divided by two, and subtracting it from 65 (the reference number). So, for example, if for a given day the average temperature is 35, it would be equal to 30 heating degree days (65 – 35 = 30). A CDD is taken if there is a temperature above the reference of 65, in which case you would subtract 65 from the day's average temperature. So, for example, if for a given day the average temperature is 75, it would be equal to 10 cooling degree days (75 – 65 = 10).

For this study, a years worth of monthly highs and lows were averaged and multiplied by the number of days within that month (31 for January, 29 for February, 31 for March, etc.) to arrive at the CDD and HDD for the specific country over the course of a year. The final HDD numbers are added to CDD numbers to arrive at the number known as "energy degree days." Data for these numbers are taken from climatetemp.info.[7]The hypothesis is that as the amount of energy degree days increase, so will too the energy intensity, denoting a decreased energy efficiency.

Manufacturing

As a country increases its output, it needs more energy to support such activities. Countries have very different mixes of industry to reach their GDP levels, whether it isprimarily through manufacturing, construction, mining, services, research & development, etc. The most energy-intensive process of all these industries, however, is manufacturing.[8] Thus, in this study an independent variable for *manufacturing*is included, which is calculated by the GDP due to manufacturing within a country divided by the country's total GDP. Manufacturing industries are classified with an ISIC-D (*International Standard Industrial Classification)* code and data are taken for the year 2006 from the United Nations National Accounts Main Aggregates Database.[9]

It is of note that other industries are also energy-heavy, but for the sake of simplicity and data attainment only manufacturing will be used. It is hypothesized that countries that rely more on the energy-heavy processes of manufacturing for their output will have higher energy intensity, and thus the sign of the coefficient for *manufacturing* will be positive.

Renewable Energy

In an effort to become more sustainable now and for future generations, many countries have turned to adopting renewable energy sources as opposed to exhaustible sources. In this study the independent variable of *renewable_energy* will be defined as the amount of energy a country

[7] www.climatetemp.info: Climate and Temperature
[8] U.S. Department of Energy: Energy Intensive Industries
[9] United Nations Statistics Division

consumes from renewable sources (wind, solar, hydro, geothermal, etc.) divided by the country's total level of energy consumption (*Renewable energy consumption/Total consumption*). Data are taken for each country for the year 2006, and are obtained from the U.S. Energy Information Administration.[10]

In terms of pure economic efficiency and how it factors into energy intensity, these renewable energy sources are currently costly and uneconomical when compared to traditional sources. This effectmeans that as the ratio of renewable consumption to total consumption increases, so should too the level of energy intensity, indicating reduced efficiency.

On the other hand, a high share of renewable energy sources suggests a country's forward thinking and progressive nature. Countries with more renewable energy should also be the ones that pay the most attention to matters such as energy efficiency. This effect works in the opposite direction of the inefficient renewables effect, and it is unclear which effect will dominate more. Therefore, a two-tailed test will be run for this variable.

Fuel Prices

High fuel prices force people to find alternative methods of transportation, whether it is by walking, bicycling, taking public transportation, or in various other manners. These methods of transportation are more energy efficient, as they reduce the amount of energy that goes towards driving, and thus non-production (with the exception of transportation of goods and service-involved transportation as these are energy processes that go towards production).

The independent variable *fuel_price* is defined as the weighted average of gasoline prices and diesel prices in each country, both measured in United States cents. A .60 weight is assigned to

[10] US Energy Information Administration: International Energy Statistics

gasoline prices, and a .40 weight to diesel prices. These weights are based on world consumption numbers, in which roughly 60% of all fuel consumed is gasoline. Data are taken from the German Society for Technical Cooperation (GTZ). [11] The data are from the year 2007, as the GTZ only publishes their study on fuel prices once every two years.

It ishypothesized that a higher gas price will lead to higher energy efficiency, and thus lower energy intensity because countries with high gas prices will be less inclined to use their cars and more disposed to finding alternative methods of transportation.

VI. SUMMARY STATISTICS

Variable	Count	Mean	Std Dev	Minimum	Maximum
energy_intensity	160	21414.709	24769.502	1089.960 (Chad)	190694.109 (Tajikistan)
standard_of_living	160	27007.777	26113.154	996.59 (Congo DR)	126709.09 (Qatar)
education	160	0.794	0.180	0.286 (Niger)	0.993 (Denmark)
energy_imports	160	-1.092	2.163	-11.634 (Hong Kong)	4.536 (Chad)
extreme_climate	160	5113.798	1970.189	1250.5 (Eritrea)	14243.5 (Mongolia)
manufacturing	160	0.131	0.071	0.020 (Ecuador)	0.412 (China)
renewable_energy	160	0.148	0.215	0 (Several countries)	1.243 (Paraguay)
fuel_price	160	93.248	38.147	1.598 (Turkmenistan)	182.757 (Iceland)

[11] International Fuel Prices 2007 provided by GTZ

VII. REGRESSION RESULTS

One multivariate linear regression was run, taking the form of the equation:

$$energy\_intensity = \beta_0 + \beta_1(standard\_of\_living) + \beta_2(education) + \beta_3(energy\_imports) + \beta_4(extreme\_climate) + \beta_5(manufacturing) + \beta_6(renewable\_energy) + \beta_7(fuel\_price)$$

A discussion of the effect and significance of each independent variable can be found below. The outputtable of the regression may be found on page 13. It is also worth noting that no significant correlation was found amongst variables, avoiding the problem of multicollinearity.

standard_of_living

This independent variable was found to have the predicted negative sign, indicating that an increase in standard of living causes a decrease in energy intensity and thus an increase in energy efficiency. The variable was found to be significant at the 1% level. A one standard deviation increase in the standard of living causes a decrease of 7625.56 in energy intensity, making it the third most impactful variable in this study.One opposing effect not factored in the hypothesis is that of household and commercial appliances. A country with higher standard of living will have more household and commercial appliances such as refrigerators, dishwashers, and washer/dryers, all of which require more energy to operate, increasing the energy intensity of the country and ultimately decreasing the impact of standard of living.

education

Education was the only variable that opposed the hypothesis. The predicted sign was negative, but the regression output resulted in a positive coefficient. The variable was also found to be significant at the 1% level. The impact of this variable is as follows: a one standard deviation increase in education causes a 7279.86 increase in energy intensity. One might suspect a high level of collinearity among *education* and *standard of living.* However, the two variables only have a moderate correlation of .5925.

It is difficult to generate a logical economic rationale behind the coefficient of this variable, and so, the numbers have been examined more in detail. One possible explanation is that many of the low-education countries, such as Burkina Faso (.286), Chad (.334), and Niger (.286) also have extremely low energy intensities that could be due to other independent factors aside from education. One such factor, for example, is that Chad relies on low-technology subsistence farming for much of its output. This specific type of output does not require much advanced knowledge or an intensive amount of energy to produce. Countries such as Chad that rely on low-tech, low-energy, low-intelligence production may have resulted in a noteworthy skewing of the data.

energy_imports

The independent variable for the level of energy imports in a country was found to correspond with the hypothesis with a negative sign, and was also found to be marginally significant at the 10% level. A one standard deviation increase in the variable was found to decrease the dependent variable by 2633.24.

extreme_climate

The regression output for the variable *extreme_climate* was in agreement with the hypothesis that the coefficient would be positive. This variable was found to have the highest level of significance, being considerably below the 1% level. A one standard deviation increase in *extreme_climate* was found to increase energy intensity by 9816.92, which is the highest impact of any variable. The level of climate in a country is the most important variable among the tested variables in determining the energy intensity of a country.

manufacturing

The independent variable *manufacturing* (for the level of manufacturing as a percentage of total GDP) matched with the hypothesis that the effect on the dependent variable would be positive. The variable was found to have just barely missed the 10% cutoff for marginal significance, with a p-value of .10075. The impact of this variable is that a one standard deviation increase will cause an increase of 2229.93 in energy intensity, otherwise stated as a decrease in energy efficiency.

renewable_energy

The hypothesis was one of ambiguity, so a two-tailed test was run for this variable. The result of the regression shows that the coefficient has a positive sign, which can be interpreted with the inefficient renewables effect that was previously discussed in the paper. This variable is significant at the 1% level. The impact of the variable*renewable_energy* isthat a one standard deviation increase will cause an increase of 4499.12 in energy intensity.

fuel_price

The hypothesis for this variable, that as the fuel price increases a country's energy intensity will decrease, was supported by the results of the regression. This variable was found to have a significance that was markedly below the 1% level. The impact of this variable is that one standard deviation increase in *fuel_price* will decrease energy intensity by 8817.05, making it the second most important variable among ones tested.

VII. REGRESSION OUTPUT

*It should be noted that all regressions were run using a two-tailed test by default. For all variables aside from *renewable_energy*, the reported p-value should be divided by two in order to get the actual p-value.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.59978572
R Square	0.359742909
Adjusted R Square	0.330257386
Standard Error	20270.8165
Observations	160

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	35093276518	5013325217	12.20066194	2.53086E-12
Residual	152	62457712257	410906001.7		
Total	159	97550988775			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-15269.05456	9353.69041	-1.632409658	0.104663155	-33749.08359	3210.97447
extreme_climate	4.982733212	0.856293414	5.818955429	3.38948E-08	3.290959542	6.674506882
education	40443.66364	11927.59413	3.390764575	0.000888292	16878.38875	64008.93853
manufacturing	31407.52074	24482.95513	1.2828321	0.201503589	-16963.30421	79778.34569
standard_of_living	-0.292015972	0.079477676	-3.674188633	0.000330113	-0.44903953	-0.134992414
fuel_price	-231.1336466	47.50584639	-4.865372669	2.82972E-06	-324.9906573	-137.276636
log of energy imports	-1217.402736	872.694282	-1.394993368	0.165052903	-2941.5795	506.7740285
renewable_energy	20926.13218	8344.687376	2.507719132	0.013201701	4439.584288	37412.68008

VIII. DISCUSSION AND CONCLUSION

Getting back to what sparked interest into this paper, analysis of the data indicates that, while the level of a country's energy imports does play a role in it's energy efficiency, it is not nearly the most important variable. In fact, the most important variable, extreme climate, is the only variable studied that is beyond the control of a country's reigning regime. The other factors may be indeed difficult to change, but they are not immutable.

A couple caveats due to the climate variable. One, heating and cooling technologies differ. Heating requires more energy than does cooling, which, if weighted properly, would ultimately change the final numbers for that variable. However, an ample weighting mechanism was not discovered despite contact with a few experts. This will be something improved upon in future editions of this paper. Two, the climate variable does not take into account the amount of construction that requires heating or cooling within each country. For example, Mongolia may have the highest *extreme_climate* number, but it's overall population of 2,670,966 suggests that it does not have nearly the amount of buildings to heat as Russia with it's population of 141,850,000. This will also be addressed in future editions of the paper.

Also, a quick note regarding the renewable energy variable. Lately, so much attention has been put towards developing efficient renewable energy technologies. As the necessity for renewable energy (or some alternative form) becomes more apparent, there could be a day somewhere in the near future where the "inefficient renewables effect" described in this paper becomes moot.

Another interesting point discussed in an article in The Economist[12] is that over a period of years, energy intensity usually peaks when the activity level of heavy, energy-intensive "smokestack" industries within a country is at its highest. For the United States, this peak came around the 1920's, and for China it came around the 1960's. As countries move towards more modern "lighter" industry and service-driven economies, that peak has fallen, and it is predicted that it will continue to fall. The idea that energy intensity is at its highest when energy-intensive industry is also at its highest may seem paradoxical to the results of this paper in which the *manufacturing* variable just missed the cutoff of marginal significance, however that result may be due to the fact that this paper is a cross-sectional of the year 2006. If the same paper were to be researched in 1920, the results may have been vastly different.

So what should be taken away from this paper? Well, for one, that climate, fuel price, and standard of living are by far the most impactful and significant factors to look at when dissecting the energy efficiency of a country. Unfortunately this brings me to another conclusion: That the future prospects are bleak for an underdeveloped, extreme weather nation to improve on its energy efficiency due to the intractability of the standard of living and climate variables. These countries were likely put in low standard of living situations in the first place because they lacked the required resources to develop into global forces.

Sometimes, it comes down to the luck of the draw. The United States has been blessed with tremendous amounts of resources since its nascent stages, which has ultimately led to a high standard of living and our assertion as a dominant power. We also have relatively tepid temperatures overall. Hopefully, we can continually improve in other areas so that we may one

[12] http://www.economist.com/blogs/dailychart/2011/01/energy_use

day be a global leader in energy efficiency, a hot-button issue bound to be inextricably linked to all nationsas we head into the unforeseeable future.