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Determinants Of Energy Efficiency Across Countries

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ABSTRACT

Yao, Guolin. M.S., Purdue University, May 2014. Determinants of Energy Efficiency across Countries. Major Professor: Wallace E. Tyner.

With economic development, environmental concerns become more important. Economies cannot be developed without energy consumption, which is the major source of greenhouse gas emissions. Higher energy efficiency is one means of reducing emissions, but what determines energy efficiency?

In this research we attempt to find answers to this question by using cross-sectional country data; that is, we examine a wide range of possible determinants of energy efficiency at the country level in an attempt to find the most important causal factors. All countries are divided into three income groups: high-income countries, middle-income countries, and low-income countries. Energy intensity is used as a measurement of energy efficiency. All independent variables belong to two categories: quantitative and qualitative. Quantitative variables are measures of the economic conditions, development indicators and energy usage situations. Qualitative variables mainly measure political, societal and economic strengths of a country.

The three income groups have different economic and energy attributes. Each group has different sets of variables to explain energy efficiency. Energy prices and winter temperature are both important in high-income and middle-income countries.

No qualitative variables appear in the model of high-income countries. Basic economic factors, such as institutions, political stability, urbanization level, population density, are important in low-income countries. Besides similar variables, such as macroeconomic stability and index of rule of law, the hydroelectricity share in total electric generation is also a driver of energy efficiency in middle-income countries. These variables have different policy implications for each group of countries.

CHAPTER 1. INTRODUCTION

1.1 Global Characterization of Energy Efficiency

Energy is a building block of modern civilization. Economies cannot develop without energy consumption. Due to rapid economic development, energy consumption is rising drastically, especially in developing countries. From 1990 to 2008, developing countries experienced a total annual energy consumption growth rate of 2.3%, which is 2.5 times larger than the growth rate of developed countries (Yumkella, 2012). A growing industrial sector in developing countries leads to higher energy consumption. (Yumkella, 2012). Also, the IEA (International Energy Agency) data from 1990 to 2008 indicates that there is a 10% average increase in the rate of energy use per person, while the average increase in world population is 27% over the same period (Wikipedia, 2013f). Thus the rate of increase in energy use is much higher than the population growth rate. IEA states that 40% of the world's electricity needs are from coal; it is the leading source of electricity generation; and coal has been the growing faster than other sources since early in the 21st century (International Energy Agency, 2013a). High dependence on coal suggests paying attention to energy efficiency, since coal always has lower heat efficiency than other types of fossil fuels. Economic growth is associated with higher energy consumption. Accompanied by the continuous growth of GDP, the level of energy consumption and energy sustainability become increasingly important. In addition energy supply growth has not kept up with economic growth in some areas. In late 2005 and early 2008, China experienced severe energy shortages. Due to the diesel fuel and coal shortages during the energy crisis of 2008, China's power generating system has been severely stressed. In 2011, China faced a second quarter electrical power deficit of 44.85-49.85GW (Wikipedia, 2012). Undoubtedly, the insufficient electricity supply will hurt economic growth.

Even though the increase of the energy usage is greater than the population growth rate, energy intensity, which is energy consumption per dollar of GDP, is decreasing for most countries. Figure 1.1 shows the energy intensities in tons of oil equivalent per thousand 2010 dollars of United Kingdom, United States, Japan and Russia. Figure 1.2 displays energy intensity over time between different income levels. Both figures demonstrate a declining trend of energy intensity in recent decades, which is a good indicator of energy efficiency improvement. However, Figure 1.2 tells us the poor countries tend to have higher energy consumption for each dollar of GDP generated. It indicates that the energy efficiency issue is more problematic in poor countries than in rich countries around world, but it becomes less severe as time goes by.

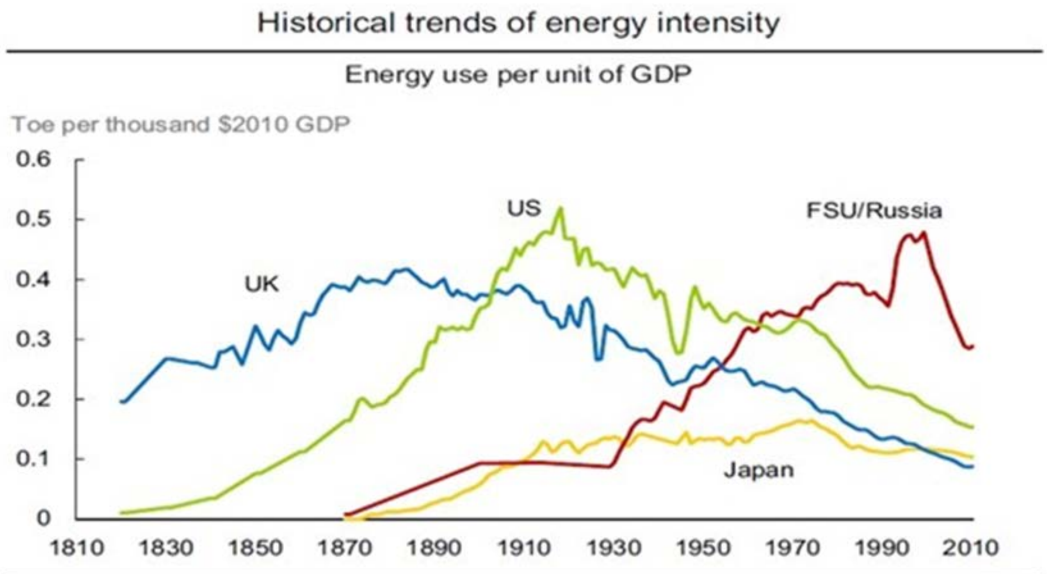

Figure 1.1 Historical Trends of Energy Intensity in UK, US, Japan, FSU/Russia
Source: (Ruhl, C., Appleby, P., Fennema, J., Naumv, A., & Schaffer, M. 2012)

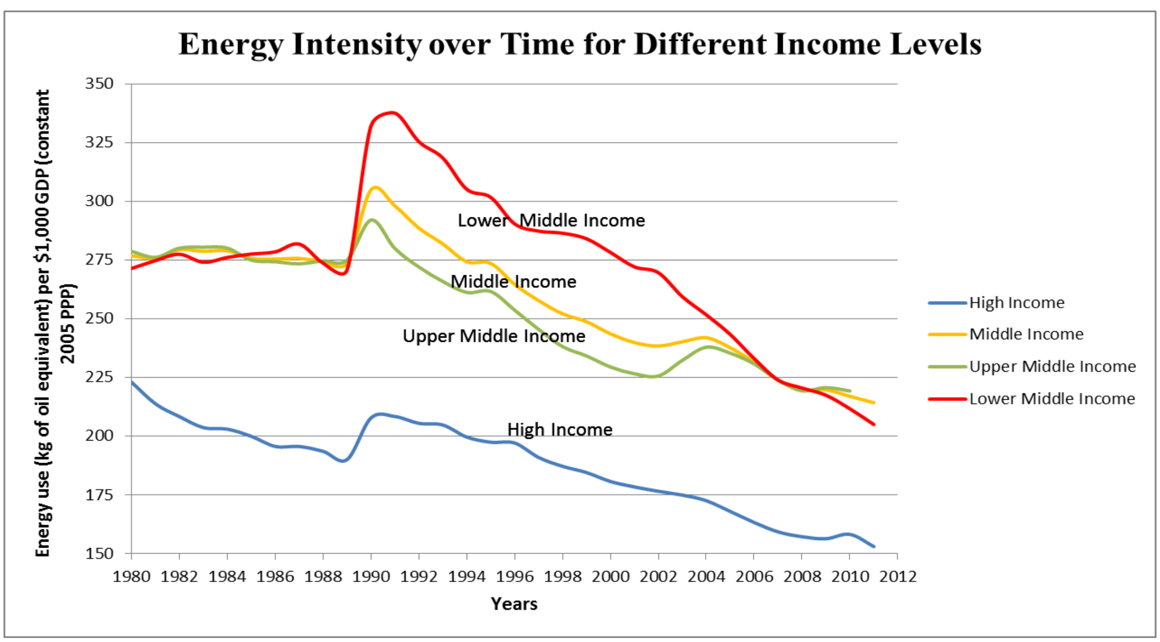

Figure 1.2 Energy Intensity over Time for Different Income Levels
(Source: World Development Indicators 2012)

1.2 Importance of Energy Efficiency

With rapid economic development, people begin to pay attention to their quality of life. Nowadays people around the world are suffering from extreme weather and rising temperature, which is widely believed to be caused by greenhouse gas emissions. Not only are people's lives threatened, but also the agricultural sector faces great potential losses. Most greenhouse gases come from fossil fuel burning. According to the U.S. Environmental Protection Agency, in 2010, fossil fuel burning was responsible for 79% of greenhouse gas emissions in United States (Environmental and Energy Study Institute, 2012). The world's CO_2 emissions have increased rapidly from 18,000 million metric tons in 1980 to around 32,000 million metric tons in 2010. High CO_2 emissions lead to greenhouse effects which cause extreme weather, rising temperature, and agricultural losses. In return, climate change can reduce economic growth.

Therefore, it is urgent for us to understand our current energy usage situation. How efficient is energy use? How do we measure energy efficiency? How does economic development interact with energy efficiency? What determines the level of energy efficiency from country to country? All these questions motivate us to explore variables that influence energy efficiency.

International Energy Agency (2013b) states, "Energy efficiency is a way of managing and restraining the growth in energy consumption." High energy efficiency means that more outputs are produced with same quantity of inputs, or the same amounts of outputs are produced with a lower quantity of inputs. Improving energy efficiency is a good way to achieve sustainable energy future. "Improvements in energy efficiency can reduce the need for investment in energy infrastructure, cut energy bills, improve health, increase competitiveness, and improve consumer welfare. Environmental benefits can also be achieved by the reduction of greenhouse gases emissions and local air pollution." (International Energy Agency, 2013b)

Energy intensity is used to measure energy efficiency in this paper. It is calculated by dividing total energy consumption by a country's gross domestic product (GDP). It means the energy consumption per dollar of GDP. Low energy intensity means higher energy efficiency, because the generation of each dollar of GDP consumes less energy. There are lots of variables, either quantitative or qualitative, that influence energy efficiency: quantitative variables include income per capita, education expenditures, exchange rate-purchasing power parity ratio, capital-labor ratio, labor productivity population density, urbanization level, technology, energy prices, energy reserves, energy composition, net oil exporters, weather, transportation, and even structural transformation, etc. Qualitative variables are based on political, societal and economic dimensions and include political stability, regulatory quality, effectiveness of government, control of corruption, rule of law, quality of health and education, institutions, infrastructures, macroeconomic stability, higher education and training, goods market efficiency, labor market efficiency, financial market sophistication, technological readiness, market size, business sophistication and innovation.

1.3 Objective

The objective of this research is to quantify the importance of various drivers of energy efficiency through examining the relationships among explanatory variables and energy intensity, the indicator of energy efficiency. To do this we will be using cross-sectional data across a selection of countries. The analysis aims to measure the extent to which different variables influence energy efficiency. Understanding the characteristics and determinants of energy efficiency is the first step towards developing better energy policies to improve energy efficiency effectively.

1.4 Organization

Chapter 2 reviews current literature on drivers of energy efficiency, the measurement of energy efficiency, the relationship between energy use and economic growth, the analysis methods and the potential policies for energy efficiency improvement. Chapter 3 presents the definition and the measurement of energy efficiency and the independent variables, the data sources, the data processing methods and the hypotheses in the analysis. Chapter 4 describes the regression approach in this analysis and presents the results of the base case and different scenarios. Chapter 5 concludes this analysis, points out the limitations of this research and proposes topics for future study.

CHAPTER 2. LITERATURE REVIEW

This literature review will include the definition of the measurement of energy efficiency. It will also demonstrate how energy efficiency associates with economic development and explore the various drivers of energy efficiency. The common methodologies used in exploring the relationship between energy efficiency and different drivers will be described as well. This information will serve as foundation for the analysis presented in the following chapters.

2.1 Definition of Energy Efficiency

Energy Efficiency measures how efficient energy use is. It refers to the quantity of output produced from one unit of energy. Energy economists have developed various ways to measure energy efficiency. Hannesson (2009) defines energy efficiency as required unit of energy use per one dollar increase in GDP. Stern (2012) measures energy efficiency by using an energy distance function approach. He introduces a definition of global production frontier which refers to “the country using the least energy per unit output, given its mix of outputs and inputs” (Stern, 2012). Therefore a country’s relative energy efficiency is measured by the distance from the frontier (Stern, 2012).

For the energy distance function approach, it is difficult to determine the country with the minimum energy per unit output. The most widely acceptable measurement of energy efficiency is energy intensity. It refers to the energy consumption per unit of GDP (Rühl et al., 2012). Most of the analyses of energy efficiency use energy intensity.

2.2 Energy Efficiency and Development

There are many papers exploring the relationship between energy efficiency and development. Income and economic structure are two main indicators of development. Developed countries tend to have higher income per capita, and their service and industry sectors are larger, while developing countries tend to have lower income per capita, and their agricultural sectors are larger. Eventually, different countries with different income and economic structure display different energy efficiency.

2.2.1 Energy Efficiency and Income

Metcalf (2008) says that income can predominantly influence energy intensity through changes in energy efficiency. He uses log of income and log squared of income as explanatory variables to explore the relationship between energy intensity and income in the United States. He states that energy intensity has a quadratic response to income. It means that with the increase of income, energy intensity first rises and then falls. Metcalf focuses on the United States where energy intensity falls as income increases (Metcalf, 2008).

Song and Zheng (2012) study China, and they also state that rising income is imperative in reducing energy intensity. Stern (2012) points out that income per capita and energy efficiency have a stronger global relationship. His paper shows that over time energy efficiency improves for most high income countries and many poorer countries.

Energy efficiency in developing countries either remains constant or declines over time. He also concludes that there is a convergence trend of energy efficiency across countries over time except for African countries because of their economic troubles in recent years.

Huang, Hwang, and Yang (2008) divide countries into four groups based on income levels to explore the causal relationship between energy consumption and GDP growth: low income group, lower middle income group, upper middle income group and high income group. Their conclusion is that lower middle income group is the most efficient in energy usage; high income group ranks the second; then upper middle income group; and finally the low income group countries. Hannesson (2009) conducts his research based on the intuition that GDP may become less energy intensive with the growth of a nation's wealth. His result shows that GDP per capita energy use grows faster in poor and medium rich countries than anywhere else.

Liu, Lund, and Mathiesen (2013) explain the relationship between income and energy consumption in terms of transportation. They state that income increase leads to more leisure time which further increases the diversity of activities which boost transportation demand and thus energy consumption. Therefore, high income leads to high energy consumption.

2.2.2 Energy Efficiency and Economic Structure

Economic structure refers to the relative shares of agriculture, service and industry sectors. When a country is at an early development stage, most economic activities concentrate in the agricultural sector, which is less energy intensive. With the development of a country, the economy is industrialized and the energy usage becomes more intensive. When an economy is further developed, some economic activities shift to the service sector which is less energy intensive (Rühl et al., 2012). Therefore, energy intensity displays an inverted-U shape with time or development degree. Ang (2006) also addresses the role that structural change plays in energy intensity by decomposing an economy into transportation, industrial, residential, and commercial sectors.

2.3 Oil Production and Energy Efficiency

Many economists point out the different energy usage situation and policies in oil-exporting countries from other countries. There are three reasons that explain why oil-exporting countries tend to consume more energy per dollar of GDP. First, oil-exporting countries usually have more energy reserves, so they tend to be wasteful in consuming energy. Second, some of the oil-exporters subsidize their domestic use of oil (Hannesson, 2009). Third, oil production itself is energy intensive (Hannesson, 2009). So Hannesson (2009) assumes that oil-exporting countries have higher energy consumption growth rate and less sensitivity to the world market price of oil. His result shows that "the coefficients of oil-exporting countries' oil prices are not significantly different from zero, while non-oil exporting countries are significant and negative. Geller et al. (2006) point out that "eliminating subsidies for fossil fuels can help foster energy efficiency". Stern (2012) drops "all oil producers with a larger share of GDP generated in mining and utilities section than Norway (19%)" in his paper, because the contribution of oil resources to the economy in these countries is much greater than that in the United States. Ramanathan (2006) studies the energy efficiency of 17 oil rich countries in Middle East and North Africa in terms of energy consumption and carbon dioxide emissions. He finds out that

Sudan, Bahrain and Oman are the most energy-efficient countries, and Saudi Arabia is the least efficient in the selected 17 countries. He concludes that most oil rich countries are neither energy efficient nor carbon dioxide friendly. Thus, the literature supports the notion that oil-exporting country behavior can be different from other countries.

2.4 Determinants of Energy Efficiency

2.4.1 Investment

Investment is closely related to the technological change, which is widely believed among energy economists to be one of main drivers of energy efficiency. However, it is hard to measure the level of technological change. The amounts of capital invested on energy efficiency technologies can be used as a measurement of technological change. In some countries and some sectors, there is government-funded Research and Development which contributes to developing and commercializing new energy efficiency technologies (Geller et al., 2006).

When exploring determinants of energy intensity in the United States at the state level, Metcalf (2008) includes log of capital-labor ratio, squared log of capital-labor ratio, and capital stock (turnover of the capital stock) investment capital ratio to measure capital investment. He states that capital and energy are likely substitutes in production. He holds the opinion that faster growing states are more likely to introduce more energy-efficient infrastructures and facilities than slower growing economies. If the capital investment of the fast growing states cannot keep pace with its economic growth, their energy consumption may be less efficient (Metcalf, 2008). The intuition of his research is that slower turnover of the capital stock means lower energy efficiency and higher turnover of capital stock indicates higher energy efficiency. He assumes that the "energy intensity first increases and then decreases with the capital-labor ratio" (Metcalf, 2008). However, his result shows that capital has little impact on energy intensity.

Stern (2012) includes both physical capital and human capital in his model. His results show that physical capital and human capital-intensive economies tend to be less energy intensive, which means high energy efficiency. In analyzing the energy intensity in China, Song and Zheng (2012) also choose capital labor ratio and annual investment as two important explanatory variables, but Fisher-Vanden, Jefferson, Liu, and Tao (2004) use R&D expenditures as a proxy of capital investment on energy efficiency technologies. They find that R&D expenditures are largely responsible for the decline of energy intensity in China at firm level. Rühl et al. (2012) also express similar opinion in his research on economic development and energy efficiency.

2.4.2 Energy Prices

Energy prices can influence energy supply and demand directly. When the price is high, consumers will have stronger motivations to use energy more efficiently. That's the reason that Metcalf (2008) believes that price can predominantly influence energy intensity through changes of energy efficiency instead of economic activity. He uses the average weighted price of energy at state level on fuel uses computed by U.S. Energy Information Administration. Stern (2012) proposes to use each country's average energy prices to represent the level of technology, because higher real energy prices are expected to result in greater energy efficiency. Hannesson (2009) chooses to use oil price in his linear regression on energy growth. He thinks that many energy resources mainly come from oil and their prices are largely influenced by changes of the oil prices. He also believes that the influences of oil prices are different in oil-exporting countries and oil-importing countries. Due to the domestic oil price subsidies, energy consumption is less sensitive to oil prices in oil-exporting countries. Therefore, energy price may be a main driver in non-oil-exporting countries, but have little impact on oil-exporting countries. Interestingly, Song and Zheng (2012) conclude that the effect of energy price on energy intensity is limited. Due to the limited data availability of energy prices, Thaler (2011) gives .60 weight to gasoline prices and .40 weight to diesel prices to calculate the energy prices.

2.4.3 Energy Composition

Different energy resources have different efficiency, so the composition of energy resources of a country can influence the country's total energy efficiency. Stern's (2012) research shows that coal has lower quality than the natural gas in terms of production and efficiency. Therefore, if the share of coal in total energy usage is larger, it is very likely that total energy efficiency will be lower. If the share of natural gas is larger, the total energy efficiency will be higher. Globally, the fastest growing category is renewable energy, and the fastest growing fossil fuel is natural gas (Rühl et al., 2012) due to their clean and efficient attribute. Energy composition can also be treated as an indicator of energy efficiency. (Rühl et al., 2012).

2.4.4 Industry Structure

Even though, generally speaking, the industry sector is energy intensive, the energy usage efficiency in different sectors of industry is also different. Many economists focuses on the relationship between energy efficiency and industry structure only. To study structural change and energy efficiency in industry, Jenne and Cattell (1983) divide industry into 9 sectors: food drink and tobacco, chemicals and allied trades, iron and steel, engineering and other metal trades, textiles leather and clothing, bricks and miscellaneous building materials, pottery glass and china, cement, and paper printing and publishing. It shows that iron and steels production consume the most energy in industry. China's National Bureau of Statistics (NBS) dataset classifies industry into 37 sectors (Fisher-Vanden et al., 2004). Some analyses are based on the intuition that electricity generation requires more energy than food processing (Fisher-Vanden et al., 2004). By using China as an example, Fisher-Vanden et al. (2004) conclude that shifts in output across industry is one of the contributors of changes of energy intensity.

2.4.5 Productivity

Productivity is also a reflection of the level of technology. Stern (2012) says that a general total factor productivity (TFP) variable can represent human capital, technology factors and openness to trade. His result on TFP is consistent with his hypothesis that high TFP leads to high efficiency. It shows that 1% increase in TFP in the United States can improve energy efficiency by 1.3% (Stern, 2012). They find that beside exchange rate to the PPP ratio, TFP is the most important variable explaining and affecting energy efficiency in the United States.

2.4.6 Exchange Rate

The exchange rate of most countries deviates from their purchasing power parity, which indicates the market exchange rate that would exist if the country's commodity price were the same as similar goods in the United States. Therefore, if a country's exchange rate is different from the purchasing power parity, it means that its energy price converted to U.S. dollars is different from the energy price of the United States. Stern (2012) states that the deviation of each country's exchange rate from purchasing power parity is one of the main factors that affect the effective price of imported energy across countries. He says that if the exchange rate lower than the purchasing power parity, the imported energy is more costly compared with domestic goods and services. Therefore, he includes the ratio of a country's prices to PPP as an auxiliary variable. His concludes that a higher exchange rate relative to the PPP level results in less energy efficiency. From this result, he also reaches the conclusion that a more open economy leads to energy inefficiency, which is contrary to their original assumption and to the conclusion most economists would reach. He thinks the reason is that more open economies are more economic active in energy intensive sub-industries within the mining and manufacturing sectors. According to his research, the ratio of the exchange to the PPP exchange rate is one of the most important variables affecting the state of energy efficiency.

Ang (2006) also explains the difference between exchange rate and purchasing power parity converted GDP. He holds the opinion that "exchange rate converted GDP tends to exaggerate the real income differences between the developing countries and industrial countries", but purchasing power parity which "reflects the relative purchasing power of different currencies" can partly solve this problem.

2.4.7 Transportation

In some countries, energy usage in transportation sector is relatively large. For example, in China, transportation was responsible for 38% of petroleum consumption in 2009 (Liu et al., 2013). If it is the case in China, it may apply to other countries as well. They use the billion person*km as their measurement unit. They point out that road sector is responsible most transportation demands and the transportation demand of the aviation sector is relatively low (Liu et al., 2013). Additionally, increase of income may lead to more leisure time and transportation demand (Liu et al., 2013) , and urbanization may increase car ownership which may increase the transportation demand potentially (Tang, Wu, & Zhang, 2013).

2.4.8 Population Density

Masayuki (2013) analyzes the effects of urban density on energy intensity in the service sector. The analysis shows that energy consumption in service establishments is more efficient in densely populated cities. The quantitative result demonstrates that when the municipality population density doubles, energy efficiency will increase about 12% after controlling for differences among industries (Masayuki, 2013). Karathodorou, Graham, and Noland (2010) estimate the effects of urban population density on fuel demand. Their results suggest that urban population density influences fuel demand by mainly affecting car stock and the distances travelled by car. It also demonstrates a negative relationship between population density and fuel demand. Brownstone and Golob (2009) find that a decrease of 1000 housing units per square mile in density can result in an increase of 1200 miles driven per year and 65 more gallons of fuel used per household. They also point out that the decrease of residential density increases fuel usage by increasing mileage and lowering the fleet fuel economy. All this evidence shows that population density has a negative impact on energy consumption. Depending on how transportation is affected, increasing population density may also influence energy intensity negatively.

2.4.9 Winter Temperature

Residential consumption is listed as one of the six main energy consumption sectors by Song and Zheng (2012). Heating system is also very influential in energy consumption. Stern (2012) finds that higher winter temperature is farther from the efficiency frontier, which means lower energy efficiency. Metcalf (2008) also states that energy intensity is higher in states in years with higher heating degree days. Thaler (2011) uses heating degree days and cooling degree days to measure extreme climate. Heating degree days is used to reflect the energy used to heat a building (Wikipedia, 2013c), and it is calculated by subtracting the temperature of a building that doesn't need heating from the outside temperature (Wikipedia, 2013c). Thaler (2011)'s regression analysis shows that extreme climate inserts the greatest influence on energy intensity.

2.4.10 Qualitative Determinants of Energy Efficiency

Even though quantitative drivers of energy efficiency play important roles in determining energy efficiency, some qualitative drivers may influence energy efficiency indirectly. These qualitative drivers explain the political, societal and economic situations of countries. For example, if a country's politics and macroeconomics are stable, they may be more likely to use energy more efficiently. Ineffective or corrupt political process could prevent adopting energy efficient technology (Parente & Prescott, 2002). Fredriksson, Vollebergh, and Dijkgraaf (2004) find that policy makers' greater corruptibility make energy policy less stringent. Similarly, Stern (2012) also chooses to include corruption and inequality variables as auxiliary variables when modeling the international trends in energy efficiency. His analysis shows that corruption is negatively correlated with energy efficiency, even though this relationship is not very significant. He also states that firms and households are highly likely to make inefficient choices during times of market failure. Therefore, a well-functioning government, stable macroeconomic environment and high-quality consumer behaviors can facilitate the improvement of energy efficiency.

2.5 Methodologies Exploring Energy Efficiency

Generalized regression, causality and indexdecomposition are three main mythologies that economists have used to study energy efficiency. Metcalf (2008) first decomposes energy intensity into two components: energy efficiency and economic activity, and then he regresses a list of explanatory variables, such as price, income per capita, heating and cooling degree days, capital-labor ratio, and investment-capital stock ratio in natural logarithmic forms, and population growth in its original form, on energy intensity, efficiency and economic activity respectively at the state level. Thaler (2011) also uses the multiple linear regression method to find the relationship between energy intensity and explanatory variables. Stern (2012) does the regression on the energy efficiency frontier. Song and Zheng (2012) also use both decomposition and regression methods. They employ the Fisher Ideal Index in the family of index decomposition analysis to explore drivers of China's energy intensity changes at the provincial level. Energy intensity is decomposed into energy efficiency improvements and structural change in their research. Again, econometric regression is applied to analyze how different drivers influence energy efficiency improvements, structural change and the whole energy intensity respectively. Zhang (2003) uses the decomposition method to investigate how the structural change in the industrial sector influences energy intensity in China in 1990s. Ang (2006) decomposes total energy consumption into three factors: industrial activity effect, structural effect and sectoral energy effect. Masayuki (2013) also employs regression analysis in exploring the relationship between energy efficiency and population density. In general, economists tend to combine decomposition and regression methods to analyze energy efficiency.

There are also lots of papers using various causality methods to explore the causal relationship between energy consumption and economic growth. In general, there are four hypothesis: growth hypothesis (energy consumption leads to economic growth), conservation hypothesis (economic growth results in energy consumption), feedback hypothesis (there exists bi-directional causality between energy consumption and economic growth), and neutrality hypothesis (there is no causality relationship between energy consumption and economic growth) (Tugcu, Ozturk, & Aslan, 2012). Huang et al. (2008) use GMM-SYS approach to test the causal relationships between energy consumption and economic development in low income, lower-middle income, upper-middle income and high income counties. They find that there is no causality between energy consumption and economic growth in low income countries; economic growth leads energy consumption positively in middle income countries; economic growth leads energy consumption negatively in high income countries. Tugcu et al. (2012) investigate the causality of renewable and non-renewable energy consumption and economic growth based on evidence from G7 countries. They employ Autoregressive Distributed Lag (ARDL) approach to determine which type of energy matters more on economic growth in G7 countries, and causality developed by Hatemi to investigate the causal relationships between renewable and non-renewable energy consumption and economic growth. They find that in the long run, neither renewable energy consumption nor non-renewable energy consumption has causal relationship with economic growth, and bi-directional causality exists among all the G7 countries.

The goal of this research is to explore the determents of energy efficiency across countries. Causality between energy consumption and economic growth is not a main goal here. Regression analysis should be a better methodology in this research.

CHAPTER 3. DATA

This chapter describes the definition of the dependent variable, energy intensity and the definitions of drivers of energy efficiency, the independent variables. These drivers include peoples' living standard, economic structure, investment, productivity, energy features, prices, transportation, winter temperature and population variables. It shows the official definitions of these variables, the hypotheses to be examined in the econometric analysis, and their sources. All the values of each variable of each country are calculated by averaging the values from years 2007 through 2010. If the data of the four years are not all available, the most recent available data is used. The countries with missing values are excluded from the analysis. All the countries' names are listed based on the order provided by the World Bank.

3.1 Energy Intensity

Energy intensity is the dependent variable, and it refers to the total energy consumption per dollar of gross domestic product (GDP) adjusted by purchasing power parity. Energy intensity data in this research is provided by International Energy Agency (IEA). They use total primary energy supply (TPES) as a proxy of total energy consumption, which is calculated by the following equation (International Energy Agency, 2012)

$$\text{TPES} = \text{Production} + \text{Imports} - \text{Exports} - \text{International Marine Bunkers}^{1}$$
$$-\text{international aviation bunkers}^{2} \pm \text{Stock Changes}$$

It includes total primary energy supply of coal and peat, natural gas liquids and feedstocks, oil products, natural gas, nuclear, hydro energy, geothermal energy, solar and wind energy, biofuels and waste. Energy intensity provided by IEA is originally measured by ton of oil equivalent (toe) per thousand constant 2005 U.S. dollars. We converted it to British thermal units (btu) per year constant 2005 U.S. dollars for analysis in this research. This unit can produce larger values of energy intensity and the natural logarithmic form of energy intensity will also be positive. It is convenient for the analysis. Purchasing power parity-converted GDP is used, because it can more objectively reflect a country's income level, and exchange-rate-converted GDP tends to exaggerate the real income differences between the developing countries and industrial countries (Ang, 2006).

3.2 Groups of Countries

All countries' official names and territories come from World Bank. We exclude Singapore due to the limited country functions. Its economy heavily depends on exports and refining imported goods (Wikipedia, 2013e). It has a high level in manufacturing and acts as a financial leader around the world, but it lacks an agriculture sector. Eventually, 213 countries are left. Based on the work of Hannesson (2009), countries are divided into

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[1] International Marine Bunkers covers those quantities delivered to ships of all flags that are engaged in international navigation. Consumption by ships engaged in domestic navigation is excluded. Consumption by fishing vessels and by military forces is also excluded.

[2] International Aviation Bunkers Includes deliveries of aviation fuels to aircraft for international aviation. Fuels used by airlines for their road vehicles are excluded.

four groups: high income countries, upper middle income countries, lower middle income countries and low income countries. Based on World Bank (2013h) data, these four groups of countries are classified based on 2011 Gross National Income (GNI) per capita, which is calculated by using World Bank Atlas method. Low income countries are with the GNI per capita less than $1,025; lower middle incomes countries have GNI per capita between $1,026 and $4,035; upper middle income countries' GNI per capita are greater than $4,036 and less than $12,475; so high income countries are those with GNI per capita greater than $12,476. Since there are some countries without GNI per capita in 2011, they are categorized in the group based on their most recent available GNI per capita. Eventually, low income countries include 34 countries; 56 countries belong to the lower middle income countries; 51 countries are upper middle income countries; high income countries are comprised of 72 countries. Table 3.1 shows the groups of countries by GNI per capita. Ultimately, we combined the two middle income groups into one group for the regression analysis in Chapter 4.

Table 3.1 Groups of Countries by GNP per Capita

Low-income Countries (34)			
Afghanistan	Congo, Dem. Rep.	Kyrgyz Republic	Rwanda
Bangladesh	Eritrea	Liberia	Sierra Leone
Benin	Ethiopia	Madagascar	Tajikistan
Burkina Faso	Gambia, The	Malawi	Tanzania
Burundi	Guinea	Mali	Togo
Cambodia	Guinea-Bissau	Mozambique	Uganda
Central African Republic	Haiti	Myanmar	Zimbabwe

Table 3.1 Continued

Chad	Kenya	Nepal	
Comoros	Korea, Dem. Rep.	Niger	
Lower-middle-income Countries (56)			
Albania	Georgia	Micronesia, Fed. Sts.	Sri Lanka
Angola	Ghana	Moldova	Sudan
Armenia	Guatemala	Mongolia	Swaziland
Belize	Guyana	Morocco	Syrian Arab Republic
Bhutan	Honduras	Nicaragua	Timor-Leste
Bolivia	India	Nigeria	Tonga
Cameroon	Indonesia	Pakistan	Tunisia
Cape Verde	Iraq	Papua New Guinea	Ukraine
Congo, Rep.	Kiribati	Paraguay	Uzbekistan
Cote d'Ivoire	Kosovo	Philippines	Vanuatu
Djibouti	Lao PDR	Samoa	Vietnam
Egypt, Arab Rep.	Lesotho	Sao Tome and Principe	West Bank and Gaza
El Salvador	Marshall Islands	Senegal	Yemen, Rep.
Fiji	Mauritania	Solomon Islands	Zambia
Upper-middle-income Countries (51)			
Algeria	Costa Rica	Macedonia, FYR	Serbia
American Samoa	Cuba	Malaysia	Seychelles
Antigua and Barbuda	Dominica	Maldives	South Africa
Argentina	Dominican Republic	Mauritius	St. Lucia
Azerbaijan	Ecuador	Mexico	St. Vincent and the Grenadines
Belarus	Gabon	Montenegro	Suriname
Bosnia and Herzegovina	Grenada	Namibia	Thailand
Botswana	Iran, Islamic Rep.	Palau	Turkey
Brazil	Jamaica	Panama	Turkmenistan
Bulgaria	Jordan	Peru	Tuvalu

Table 3.1 Continued

Chile	Kazakhstan	Poland	Uruguay
China	Lebanon	Romania	Venezuela, RB
Colombia	Libya	Russian Federation	
High-income Countries (72)			
Andorra	Equatorial Guinea	Korea, Rep.	San Marino
Aruba	Estonia	Kuwait	Saudi Arabia
Australia	Faeroe Islands	Latvia	Sint Maarten (Dutch part)
Austria	Finland	Liechtenstein	Slovak Republic
Bahamas, The	France	Lithuania	Slovenia
Bahrain	French Polynesia	Luxembourg	Somalia
Barbados	Germany	Macao SAR, China	South Sudan
Belgium	Greece	Malta	Spain
Bermuda	Greenland	Monaco	St. Kitts and Nevis
Brunei Darussalam	Guam	Netherlands	St. Martin (French part)
Canada	Hong Kong SAR, China	New Caledonia	Sweden
Cayman Islands	Hungary	New Zealand	Switzerland
Channel Islands	Iceland	Northern Mariana Islands	Trinidad and Tobago
Croatia	Ireland	Norway	Turks and Caicos Islands
Curacao	Isle of Man	Oman	United Arab Emirates
Cyprus	Israel	Portugal	United Kingdom
Czech Republic	Italy	Puerto Rico	United States
Denmark	Japan	Qatar	Virgin Islands (U.S.)

3.3 Variables and Hypotheses

3.3.1 GDP per Capita

GDP per capita is a measurement of average living standard of a country. It also refers to the average income per capita of a country. The data of GDP per capita are provided by the World Bank Development Indicators and in constant 2005 US dollars. "It is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources." (World Bank, 2013f)

Based on the literature review, most economists believe that GDP per capita has quadratic relationship with energy intensity. This means that when a country is extremely poor, higher GDP per capita will lead to more energy-intensive economic activity, thus higher energy intensity; when a country is extremely rich, higher GDP per capita will make them invest more on energy efficient technology.

3.3.2 Economic Drivers

3.3.2.1 Centrally-planned Economies vs. Market-driven Economies

Many economists point out the difference in energy-usage situations between centrally planned economies and market-driven economies. Hannesson (2009) says that the centrally-planned economies are less influenced by the fuel prices and "Soviet style economies seemed to become more parsimonious in their use of energy as they made the transition to a market economy". Rühl et al. (2012) states that centrally planned countries tend to have high energy intensity due to its unresponsiveness to fuel prices and its bias towards heavy industry. This analysis accepts the statement made by Rühl et al..

A dummy variable is introduced to indicate the centrally planned economies. The list of centrally-planned economies is adjusted based on several web sources and Wikipedia (2013d). Finally, centrally-planned economies consist of 25 countries, they are Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, China, Croatia, Cuba, Czech Republic, Georgia, Hungary, Kazakhstan, North Korea, Kosovo, Kyrgyz Republic, Macedonia. FYR, Moldova, Montenegro, Romania, Russian Federation, Serbia, Slovenia, Tajikistan, Turkmenistan, Ukraine. They are mainly from Soviet Union and Yugoslavia.

3.3.2.2 Economic Structures

Variables in the category of economic structure include agriculture value added, industry value added and service value added which are all measured by percentage of total GDP. The data for all three variables comes from World Bank Development Indicators.

According to the World Bank definition, agricultural sector includes forestry, hunting, fishing, as well as cultivation of crops and livestock production (World Bank, 2013b). Industry sector comprises mining, manufacturing, construction, electricity, water, and gas (World Bank, 2013i). Service sector is composed of "wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services" (World Bank, 2013p). They also include "imputed bank service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling." Value added is calculated by adding up all output and subtracting all intermediate inputs (World Bank, 2013b).

Since agriculture, service and industrial sectors are highly correlated with each other, only two sectors are picked—agriculture and industry sector. At the early stage of the development, the agriculture sector is extremely large, and the energy intensity is low. With economic development, the agriculture sector shrinks, and industrial sector expands. Economic activity more heavily weighted towards industry tends to be energy intensive, and the country has higher energy intensities. After the country's energy intensity reaches a certain point, its energy intensity falls due to energy efficiency improvement. At this point of time, the industry sector will shrink and service sector will expand. In addition, most parts of service sector don't use energy intensively. This also explains the fall of energy intensity of a country at higher development stages (Rühl et al. 2012). It is believed that the turning point is where the industrial share is the largest. Agriculture and service sector don't use much energy, so larger agriculture and service sector mean lower energy intensity and smaller industrial sector. Consequently, the hypothesis is that industry value added as a percentage of GDP is positively correlated with energy intensity, and negatively correlated with energy efficiency. Agricultural sector share is negatively correlated with energy intensity and positively correlated with energy efficiency.

3.3.2.3 Capital Investment Information

There are two indicators that are appropriate measurements of capital investment information provided by World Bank. Based on the idea provided by Metcalf (2008) that capital and energy are likely to be substitutes in production. The countries with higher development level tend to invest more on energy efficiency improvements. In theory, more capital per person in labor force indicates more efficient energy use. Similarly, a higher percentage capital in GDP leads to a higher energy efficiency level. The World Bank provides Gross Capital Formation (% of GDP) directly. According to the definition provided by the World Bank (2013g), gross capital formation is also called gross domestic investment.

> "It consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Inventories are stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales, and 'work in progress."(World Bank, 2013g).

Therefore, gross capital formation (% GDP) is presented as a percentage of GDP.

The World Bank also provides data of gross capital formation in constant 2005 US dollars and total labor force. Labor force in the World Bank database indicates the people over the age of 25 who are actively enrolling in economic activity based on the definition of the International Labor Organization. It includes all people who supply labor for goods production or services in a given period of time. This definition includes both employed and unemployed population, first-time job seekers and armed forces, but excludes all unpaid jobs (World Bank, 2013j). Therefore, capital-labor ratio can be derived by dividing gross capital formation (constant 2005 US$) by total labor force. Both variables, capital-labor ratio and gross capital formation, are hypothesized to be negatively correlated with energy intensity.

3.3.2.4 Productivity

As is mentioned in Chapter 2, literature review, Stern (2012) states that total factor productivity is a good measurement of human capital, technological factors, and openness to trade, which, he thinks, are closely related to energy efficiency. There are many papers emphasizing the importance of technological change in energy efficiency improvement. Total factor productivity is definitely a good measurement of technology level. Similarly, labor productivity is also an appropriate measurement of technology. Labor productivity refers to GDP per hour worked. The Conference Board offers data of annual working hours, which refers to “the aggregate number of hours actually worked as an employee or a self-employed person during the accounting period and when their output is within the production boundary” (The Conference Board 2013). The World Bank offers GDP in constant US dollars. Therefore, the labor productivity is derived by dividing GDP by annual working hours of each country. Higher labor productivity means improved technological level, thus higher energy efficiency level. The hypothesis is that GDP per hour worked is negatively correlated with energy intensity. The Conference Board also provides data on growth in total factor productivity. It accounts for the changes in output not caused by changes in labor and capital inputs. It reflects the effect of technological change, efficiency improvements, and the contributions of other inputs

(The Conference Board 2013). It should be also negatively correlated with energy intensity.

3.3.2.5 Exchange Rate/ Purchasing Power Parity

Price is a major influencer of energy efficiency. When energy prices are high, consumers tend to be more fugal in using energy. The deviations of exchange rate from purchasing power parity also insert great influence on the effective price of imported energy (Stern, 2012). The ratio of exchange rate over purchasing power parity is an indicator of this deviation. When the purchasing power parity is higher than the exchange rate, it means the currency is overvalued and the energy price is higher than it should be. Contrarily, lower purchasing power parity compared to exchange rate means the currency is undervalued and the energy price is lower than it should be. If purchasing power parity is higher than the exchange rate, higher energy prices may motivate the countries to use energy more efficiently, like European countries. If the purchasing power parity is lower than the exchange rate, lower energy prices may encourage the countries to consume more energy. Therefore, it is hard to determine how PPP adjustment might influence energy efficiency. World Bank provides PPP conversion factor (GDP) to market exchange rate ratio. The reciprocal of this ratio is what needs to be used.

3.3.3 Energy Characteristics

3.3.3.1 Energy Composition

Different types of energy have different rates of thermal efficiency. Generally speaking, coal has the lowest thermal efficiency. However, coal is also the cheapest fuel type, so countries at lower development levels tend to use more coal to speed up their development process. Heavily reliance on coal can lead to lower energy efficiency. Therefore, the share of coal in total energy usage should be a determinant of energy efficiency. International Energy Agency provides total primary energy supply for coal, coal products and peats. Coal consumption as a percentage of total consumption can be derived by dividing total primary energy supply for coal, coal products and peats by total primary energy supply for all energy types. The coal consumption as a percentage of total energy consumption is assumed to have a positive relationship with energy intensity, which means that it is negatively correlated with energy efficiency.

Similarly with coal consumption share in total energy consumption, fossil fuel consumption in total energy consumption is another indicator of energy composition. Fossil fuel is composed of coal, oil, petroleum, and natural gas products (World Bank, 2014). As is mentioned earlier, burning fossil fuel is responsible for 79% of greenhouse gas emissions (Environmental and Energy Study Institute, 2012), so the consumption of fossil fuel is associated with great energy losses. Therefore, a large share of fossil fuel in total energy consumption possibly suggests lower energy efficiency. The data of fossil fuel consumption share in total energy consumption is obtained from the World Bank.

In contrast, hydroelectric power is cleaner and the most efficient (Agtech Center, 2013). Countries with large hydroelectric power share in total electricity generation should be more energy efficient. This data is also from the World Bank.

3.3.3.2 Energy Reserves

Countries with huge energy reserves tend to be more wasteful in energy consumption. Another aspect that needs to be considered is that oil production is energy intensive, and the governments of oil-exporting countries usually subsidize the domestic use of oil (Hannesson, 2009). A dummy variable is introduced to represent the oil exporting countries. U.S. Energy Information Administration (2012) provides a list of Top World Oil Net Exporters in the year of 2012: Saudi Arabia, Russian Federation, United Arab Emirates, Kuwait, Nigeria, Iraq, Iran, Angola, Venezuela, Norway, Canada, Algeria, Qatar, Kazakhstan, and Libya. All these countries have the value 1 for the variable of net oil exporters. Due to the high oil production and petroleum product subsidies, energy reserve is hypothesized to have a positive relationship with energy intensity.

3.3.3.3 Rents

Rents include forest rents (% of GDP), oil rents (% of GDP), coal rents (% of GDP), and natural gas rents (% of GDP). This data is from the World Bank. The World Bank (2013c) says, “coal rents are the difference between the value of both hard and soft coal production at world prices and their total costs of production.” Similarly, oil rents and natural gas rents also refer to the profits of oil and natural gas respectively. Rents of the fuels may influence energy efficiency with countries' development level. If the rents are high in highly developed countries, the energy intensity may be low due to the higher prices. If rents of the fuels are high in less developed countries, energy intensity may be high due to the high supply. However, it is not clear what hypothesis should be established regarding the effects of rents on energy intensity.

3.3.3.4 Energy Depletion

Energy depletion is measured as percentage of gross national income (GNI). Based on the definition of World Bank (2013a), it refers to "the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years)." It includes coal, crude oil and natural gas. All the data come from World Bank. According to the definition, if the value of energy stock per year of remaining reserve life time is higher, it means the energy consumption "budget" is higher, and people can use more energy, given the constant GDP. Therefore, higher energy depletion (% of GNI) should lead to the higher energy intensity.

3.3.4 Price

Due to the data availability, only pump prices for diesel fuel and gasoline of most countries can be obtained. Electricity prices can be calculated based on the data from Global Trade Analysis Project (GTAP).

3.3.4.1 Pump Price for Gasoline

The World Bank provides the data of pump price for gasoline. In real life, consumers use gasoline based on the eventual prices they perceive. It means the price with taxes is the one that needs to be used. Pump price for gasoline from World Bank is measured in US dollars per liter and the gasoline refers to the most widely sold of gasoline (World Bank, 2013m). Therefore, when the price for gasoline is high, the consumers will reduce their gasoline consumption, and the energy intensity will be lower.

3.3.4.2 Pump Price for Diesel Fuel

Similarly, pump price for diesel fuel also refers to the price of diesel fuel with taxes, which can reflect the real reaction of consumers to the actual prices of diesel fuels. Pump prices for diesel fuel of all countries are converted from the local currency to US dollars per liter. Diesel fuel also refers to the most widely sold diesel fuel. The pump price for diesel fuel is also assumed to have a negative relationship with energy intensity.

This analysis adapts the methodology mentioned in the paper of Thaler (2011) which derives prices by giving 60% weight to gasoline prices and 40% weight to diesel prices.

3.3.4.3 Electricity Price

Electricity is a transformed form of energy, whose price changes can also influence consumer behavior. Global Trade Analysis Project (GTAP) provides data on total domestic usage energy commodities of a list of sectors, including electricity, by firms (EDF), by government (EDG), and by private household (EDP) in million tons of oil equivalent. GTAP also provides total output by commodity by region in million US dollars (OUTDISP). The domestic market price can be obtained by the equation: Domestic Market Price=OUTDISP/(EDF+EDG+EDP). The price is expressed in dollars per ton of oil equivalent ($/TOE). Similarly, higher electricity price can push consumers to cut their expenses on electricity, thus the energy efficiency improves and the energy intensity declines.

3.3.5 Transportation

Transportation can be categorized into two sectors: one is goods transported through railway and road; the other one is passengers carried through railway and roads. Since it is hard to determine the energy usage in international air transportation and the share of the energy usage of air transportation is too small to be considered, air transportation data are excluded from the analysis. All the data are from World Bank. Both goods transported through railway and roads are measured in millions of metric tons times kilometers traveled. Passengers carried through railway and roads are measured in the number of passengers transported by road times kilometers traveled. Transportation is the sector that intensively uses fossil fuels, so transportation should have a positive relationship with energy intensity.

3.3.6 Demographic Features

3.3.6.1 Population Ages: 15-65(% of Total)

World Bank offers the share of the population between the age 15 and 64. People with the age between 15 and 64 are the group of population that is the most active in economic activity, which requires energy consumption. Therefore, the higher this share, the higher the expected energy intensity. The World Bank (2013k) states that they adapt the de facto definition of population. It refers to the all residents of a country regardless of their legal status or citizenship, but refugees are excluded.

3.3.6.2 Population Density

Population density refers to the population per square kilometer of land area. This dataset is also from World Bank. It is calculated by using midyear population divided by land area in square kilometers. The population is also defined by the de facto definition and the land area refers to "a country's total area, excluding area under inland water bodies, national claims to continental shelf, and exclusive economic zones" (World Bank, 2013l). If a country's people are distributed sparsely, more transportation energy will be required to meet people's daily needs. It indicates that high population density leads to the low energy intensity.

3.3.6.3 Urban Population (% of Total)

Urban population refers to the share of population living in urban areas, and it is a good indicator of development levels. Since there are lots of electronic facilities and machineries in urban areas, urban areas are the places that use more energy. However, the energy usage in urban areas is more efficient due to the aggregate energy systems and advanced technology. Therefore, it is hard to determine the effects of urban population (% of total) on energy intensity. The data is provided by the World Bank.

3.3.7 Winter Temperature

A country's temperature or climate pattern can greatly influence its energy usage. For example, countries with long winter will rely more on the heating system, which increases energy usage. People in extreme climates tend to be economic inactive (Angwin, 2012). Not only they need to use more energy to make the temperature back to normal, but also the value of GDP created is lower. Consequently, the energy consumption per dollar of GDP is higher, and the energy efficiency is lower. Weatherbase provides the average temperature of each month of all the countries around the world in Fahrenheit. In this analysis, January's average temperatures represent the winter temperatures of the countries in Northern Hemisphere and summer temperatures of the countries in Sothern Hemisphere; July's average temperatures represent the summer temperatures of the countries in Northern Hemisphere and the winter temperature of the countries in Southern Hemisphere. Since heating systems require far more energy than cooling systems, and cooling systems only require a small level of energy, this analysis only considers the winter temperatures of all the countries.

3.3.8 Political Strengths

Political strength reflects the political situation of an economy. Different from score variables mentioned under economic efficiency, political variables are provided by the World Bank. These indicators are called Worldwide Governance Indicators. Each of these variables ranges from -2.5 (weak performance) to +2.5 (strong performance).

3.3.8.1 Political Stability and Absence of Violence

Political stability and absence of violence refers to “perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism.” If the political environment is unstable, the government will not be able to focus on development and improvement of energy efficiency. Unstable political situations may give speculators great opportunities to use energy prodigally. Therefore, political stability should negatively correlate with energy intensity. That is, the more politically stable a country, the less intensive energy use would be expected to be.

3.3.8.2 Regulatory Quality

“Regulatory quality captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development” (World Bank, 2013n). If the government fails to make sound policies about energy exploitation, there will be lots of firms will exploit the fossil fuels illegally. They use inefficient and cheap machinery and unreasonable methods to exploit energy resources. It could lead to the large waste of energy. Wasteful and illegal coal mining in Shanxi Province in China is a typical example of low regulatory quality. Large amount of energy is wasted in the process of exploitation. Therefore, regulatory quality is essential for energy efficiency. High regulatory quality usually leads to high energy efficiency and low energy intensity.

3.3.8.3 Government Effectiveness

"Government effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies" If people are more confident about the effectiveness of government, they will have stronger motivation to support and follow the government policies. Therefore the time lags between the issues of policy and economic reaction will be short. It means that economics react to policy more quickly and the economy is very efficient. With efficient economy, the productivity of energy should be higher. As a result, strong government effectiveness leads to higher energy efficiency.

3.3.9 Societal Strengths

3.3.9.1 Control of Corruption

There are some literatures that discuss corruption's potential impeding effects on energy efficiency. For example, some huge projects are assigned to the companies based on the competitive bidding systems. It means the company with the lowest cost and highest efficiency will win. If corruption exists in the procedure, the project may be given to a company with higher cost and lower efficiency. Additionally, corruption may result in tardiness of adoption of new technology. If corruption is well controlled, energy efficiency should be higher.

3.3.9.2 Rule of Law

"Rule of law captures perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence" (World Bank, 2013o). If the law is very authoritative, and everyone has great confidence in it, fewer will violate the law. If the government issues a policy about energy efficiency, people in the society with strong law system are more likely to obey the policy. In other words, strong confidence in rule of law can lead to higher energy efficiency.

3.3.9.3 Quality of Primary Health and Education

Quality of primary education and health is obtained from World Economic Forum. Primary health matters because ill workers are less productive. The quality of primary education determines whether workers can transit to a more advanced and productive job. In addition, energy consumption emits lots of poisonous or harmful gases and particles into the air. With more concerns about health, people tend to have stronger motivation to use energy in a more efficient and cleaner way. The high quality of primary education and health is also important to improve energy efficiency.

3.3.10 Economic Strengths

A highly efficient economy tends to use energy more efficiently. By definition, economic efficiency refers to the state in which the allocation of the resources maximizes the production of goods and services (Wikipedia, 2013b). There are lots of factors that play important roles in enhancing economic efficiency. They include macroeconomic stability goods market efficiency, labor market efficiency, education, financial market sophistication, business sophistication, technological readiness, market size, and innovation. All the variables, except for education expenditures (% of GNI) and domestic credit to private sector (% of GDP) that are provided by the World Bank are offered by the World Economic Forum. All the scores are measured from 1 to 7. 1 indicates the poorest performance, while 7 refers to the best performance. All the scores are averages from the year 2007 to the year 2010.

3.3.10.1 Institutions

The number and quality of institutions can reflect a country's economic competitiveness. Institutions administer economic behavior of individuals, firms and government and make sure that they interact with each other to generate wealth legally (Schwab, 2013). A solid institutional environment is essential for an economy to achieve efficiency by maintaining honesty, transparency and trustworthiness. Therefore, high institution scores indicate efficient market environment and thus energy efficiency.

3.3.10.2 Infrastructure

Extensive and efficient infrastructure is another aspect of competitiveness. It can effectively reduce the effects of distance between regions (Schwab, 2013). It also plays an important role in reducing economic inequality and poverty. For example, a good transportation system increases mobility of an economy, and a well-developed communication system ensures a rapid flow of information, which increases economic efficiency. Thus well-developed infrastructures allows for energy efficiency.

3.3.10.3 Macroeconomic Stability

Macroeconomic stability is important for business. It mainly captures the effects of government budget balance, national savings rate, inflation, interest rate spread, and government debt. Stable macroeconomics may be important for improving energy efficiency and lowering energy intensity

3.3.10.4 Domestic Credit to Private Sector (% of GDP)

"Domestic credit to private sector refers to financial resources provided to the private sector, such as through loans, purchases of non-equity securities, and trade credits and other accounts receivable, that establish a claim for repayment"(World Bank, 2013d). Domestic credit market provides people various ways to make investment, make money and live a better life. It is a critical way to diversify people's wealth and lives. If the people's living standards are improved, they are more likely to be willing to live a more energy efficient and environmental-friendly lives.

3.3.10.5 Goods Market Efficiency

Goods market is efficient only when market competition is healthy. The World Economic Forum assigns a weight of 67% to competition, and 33% to quality of demand conditions, when evaluating the scores of goods market efficiency. When the goods market is efficient, it means the allocation of energy usage maximizes the goods production. In other words, the GDP generated for each unit of energy is high. Therefore, the energy intensity is low.

3.3.10.6 Labor Market Efficiency

An efficient labor market means that all the workers are well allocated so that the productivity is maximized. Therefore, it should be easy for the workers shift from one job to another with low cost and the workers' talents are best used (Schwab, 2013). Energy is heavily used in manufacturing production. If the workers are well allocated, the productivity of the energy usage should be high. Therefore, labor market efficiency should be consistent with energy efficiency, and has a negative relationship with energy intensity.

3.3.10.7 Higher Education and Training

It is widely believed that well educated people tend to use energy more efficiently. This research introduces quantitative variable of education expenditure (% of GNI) provided by the World Bank and qualitative variable of higher education and training. The education expenditures refer to "the current operating expenditures in education, including wages and salaries and excluding capital investments in buildings and equipment" (World Bank, 2013e). The higher education and training is a score variable ranging from 1 to 7 based on the performance from low to high. It composes 33% of quantity of education, 33% of quality of education and 33% on the job training. Higher educated and trained people tend to create more value for the economy. With certain input of energy resources, more efficient economy tends to be more productive. Therefore, education level is negatively correlated with energy intensity.

3.3.10.8 Financial Market Sophistication

Financial market sophistication is another score variable offered by the World Economic Forum. It includes efficiency and trustworthiness and confidence with the same weight. Efficiency comprises financial market efficiency, financing through local market, ease access to loans, venture capital availability, restriction on capital flows, and strength of investor protection. Trustworthiness and confidence refers to soundness of banks, regulation of securities exchanges, and legal rights index (Schwab, 2013). A very sound and efficient financial market can facilitate a company entering into the business market with low cost. Lower barriers of starting business make the market more competitive, and a well-regulated financial system ensures the stability of the business. Consequently, energy-involved business will be more efficient and productive. The hypothesis is that financial market inserts positive effects on energy efficiency and negative impacts on energy intensity.

3.3.10.9 Technological Readiness

Based on the definition of the World Economic Forum, technological readiness refers to "the agility with which an economy adopts existing technologies to enhance the productivity of its industries". When a new technology comes out, a country with the fastest speed of adoption is most likely to improve their economy efficiency first. As a result, the country with high technological readiness tends to be more energy efficient.

3.3.10.10 Market Size

It is believed that an economy with large market size can take advantage of economies of scale. Market size offered by the World Economic Forum includes both domestic and foreign market with the belief that demand from the foreign market is a substitute of domestic market, and they can spur the economy to recover from downturn (Schwab, 2013). In this sense, a country with a large market size tends to have a more stable economy and thus higher energy efficiency. However, large market size may lead to intensive energy usage and high transportation demand, which will increase the energy intensity. Therefore, it is hard to determine that relationship between market size and energy intensity. Also, market size essentially is GNP (Gross National Product), so it will be highly correlated with GDP.

3.3.10.11 Innovation

Innovation is strongly believed among energy economists as one of the most important drivers of energy efficiency. It measures the ability of technological change and indicates the technological level. When measuring innovation, World Economic Forum considers capacity for innovation, quality of scientific research institutions, company spending on R&D, university-industry collaboration in R&D, government procurement of advanced technology products, availability of scientists and engineers, utility patents, and intellectual property protection. It is a comprehensive score variable, and countries with high performance of innovation should have higher energy efficiency (lower energy intensity).

3.3.10.12 Business Sophistication

Business Sophistication measures both networks and supporting industries, and sophistications of firm's operations and strategy. The former part includes local supplier quantity and quality, and state of cluster development. The latter reflects the business structure of operations and management in companies. Sophisticated business structure symbolizes more advanced business pattern and shows a company's ability to innovate (Schwab, 2013). Therefore, business sophistication is hypothesized to be positively correlated with energy efficiency.

3.4 Summary of Hypotheses

Table 3.2 summarizes the independent variables' relationship with energy intensity. It is clear that there will be correlation among some of the variables, especially the qualitative variables. However, that will be sorted out when we undertake the econometric estimation.

Table 3.2 Summary of Hypotheses of Variables

Category	**Sub-category**	**Variables**	**Hypotheses**
Income	GDP per capita	GDP per capita	Uncertain
Economic drivers	Centrally-planned vs. Market-driven economies	Centrally-planned economies (dummy)	+
	Economic structures	Agriculture, value added (% of GDP)	-
		Industry, value added (% of GDP)	+
	Capital investment information	Gross capital formation (% of GDP)	-
		Capital per person in labor force	-
	Productivity	Labor productivity (GDP/hour worked)	-
		Growth in total fator productivity (TFP)	-
	Exchange rate/Purchasing power parity	Exchange rate/Purchasing power parity	Uncertain
Energy characteristics	Energy composition	Coal (% of total)	+
		Fossil fuel energy consumption (% of total)	+
		Electricity production from hydroelectric sources (% of total)	-
	Energy reserves	Oil net exporters (dummy)	+
	Rents	Forest, oil, coal, natural gas rents	Uncertain
	Energy depletion	Energy depletion (% of GNI)	+
Prices	Energy prices	Energy prices (60% gasoline, 40% diesel) US$/liter	-
	Electricity prices	Electricity prices (US$/TOE)	-
Transportation	Goods	Goods transported through railways and roads (million ton-km)	+
	Passengers	Passengers carried through railways and roads (million passenger-km)	+

Table 3.2 continued

Demographic variables	Population ages	Population ages：15-65 （% of total)	+
	Population density	Population density (people per sq. km of land area)	-
	Urban population	Urban population (% of total)	-
Winter temperature	Winter temperature	Winter temperature (°F)	-
Political	Political stability and absence of violence	Political stability and absence of violence	-
	Regulatory quality	Regulatory quality	-
	Government effectiveness	Government effectiveness	-
Societal	Control of corruption	Control of corruption	-
	Rule of law	Rule of law	-
	Quality of primary health and education	Quality of primary health and education	-
Economic	Institutions	Institutions	-
	Infrastructure	Infrastructure	-
	Macroeconomic stability	Macroeconomic stability	-
	Goods market efficiency	Goods market efficiency	-
	Labor market efficiency	Labor market efficiency	-
	Higher education and training	Higher education and training	-
	Financial market sophistication	Financial market sophistication	-
	Technological readiness	Technological readiness	-
	Market size	Market size	Uncertain
	Innovation	Innovation	-
	Business sophistication	Business sophistication	-

Also, as will be shown in the next chapter, most of the variables that are discussed in this chapter will not appear in the final results. This is due to a number of reasons: poor data quality, missing values for some countries, and multicollinearity among variables. However, it was important to accomplish this review of possible explanatory variables before launching into the empirical estimation, which is the subject of Chapter 4.

CHAPTER 4. ANALYSIS AND RESULTS

This chapter presents the analysis procedure and the results of this research. Multiple linear regressions are used in this research. All countries are divided into three income groups: high-income group, middle-income group and low income group based on World Bank Criteria. Regression analyses are presented respectively by income groups. Policy implications are provided at the end of each income group section.

4.1 Methodology

4.1.1 One Group or Three Income Groups

Based on the literature review, it is clear that GDP per capita is an important driver of energy efficiency. However, should all countries be treated as one group or divided into three income groups? Is GDP per capita able to explain energy efficiency for all the countries? In order to answer these questions, energy efficiency is expressed as a function of GDP per capita: $\log(energy\ intensity) = f(GDP\ per\ capita)$. And the regression result for the entire group of countries is shown below:

$$\log(\text{energy intensity}) = 9.02 - 9.2 * 10^{-6} GDP\_CAP$$

$$\text{t} - \text{value} = -2.89 \ \ \text{P} - \text{value} = 0.0046 \ \ R^2 = 0.0649 \ \ \bar{R}^2 = 0.0571$$

This result means that GDP per capita is significant in explaining energy efficiency for all the countries. However, the R-Square is quite low, which means other variables also play important roles in influencing energy efficiency. Some variables may be important in one group of countries, but may not be in other groups of countries. In fact, we did some tests and found this to be true. If we used one model to explain energy efficiency for all countries, some important variables will be lost. For example, winter temperatures are important to high-income countries because of the high latitudes, while it is not an important driver of energy efficiency for low-income countries due to many being in equatorial locations. To better capture the effects of different variables on different income groups, all countries are divided into three income groups: high-income group, middle-income group and low-income group. Given the missing value issues among variables, upper-middle-income group and lower-middle-income group are combined into one middle-income group.

4.1.2 Estimation Issues

Energy intensity is the dependent variable, which is the opposite of energy efficiency. Since energy intensity is highly positively skewed, the natural logarithmic form is used to make it normally distributed (see Figures 4.1 and 4.2).

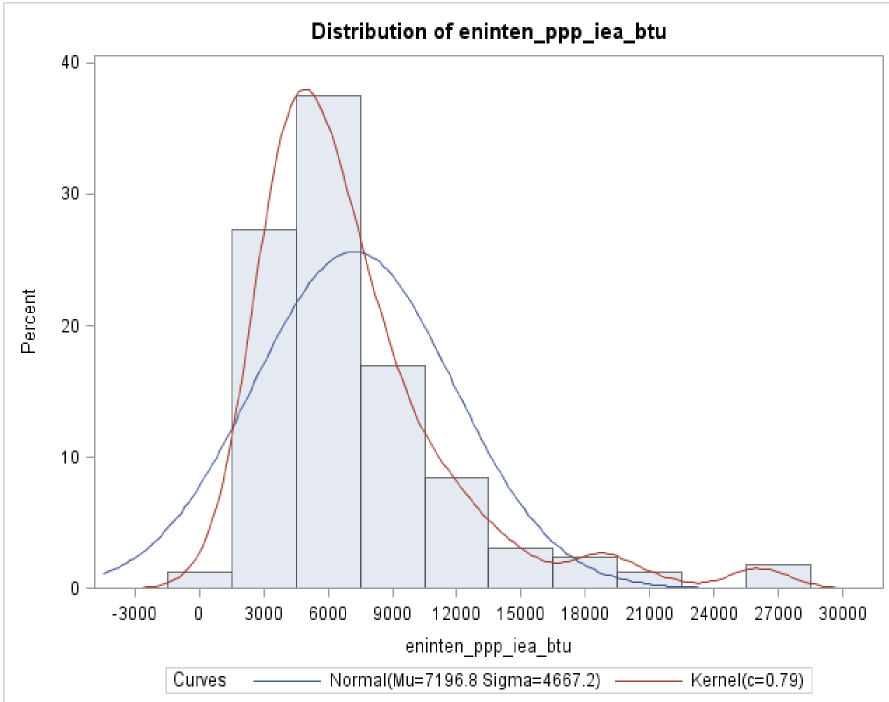

Figure 4.1 Distribution of Energy Intensity

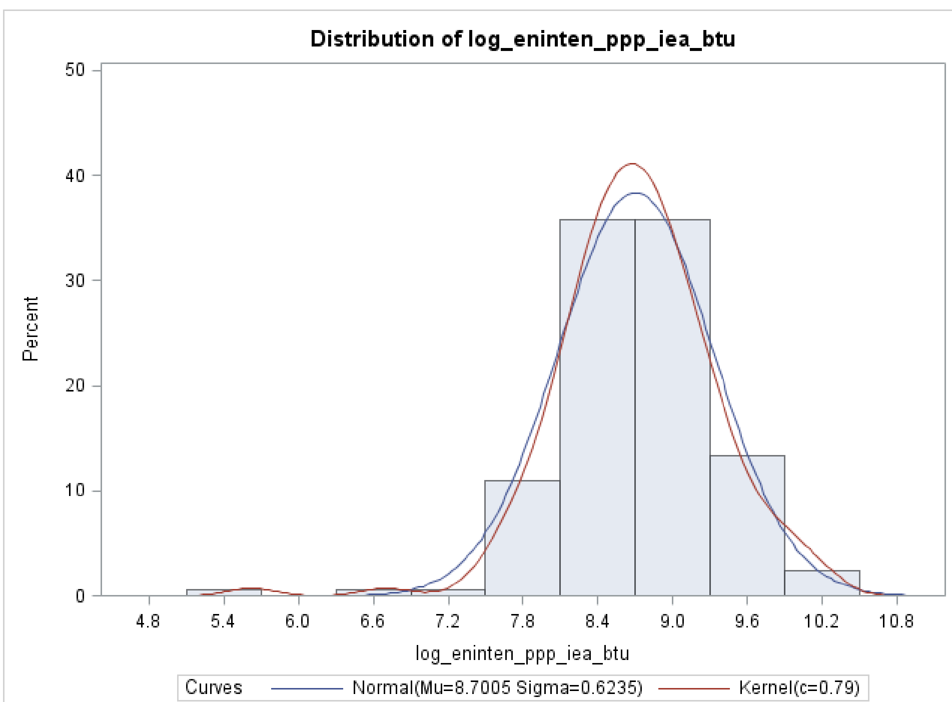

Figure 4.2 Distribution of the Natural Logarithmic Form of Energy Intensity

There are many economic development indicators included as independent variables in this research. Some variables are highly correlated with each other and may cause mulicollinearity problems. To detect this issue, correlation matrix of all the variables for each income group are constructed and variance inflation factors are calculated.

4.1.3 Qualitative Variables

Qualitative variables that measure macroeconomic, societal and political strengths are also considered in this analysis. The correlation matrixes of these qualitative variables (see Table 4.1-4.3) suggest that some variables are highly collinear with each other in each income group. Therefore, multicollinearity is an important issue for qualitative variables. Additionally, qualitative variables turn out not to be significant in high-income countries, which will be discussed later in the high-income countries section.

4.2 High-income Countries

4.2.1 Model

Various models were tried to determine the most important drivers of energy intensity for high-income countries. The results show that the natural logarithmic form of energy prices, winter temperature and coal share and service plus industrial share are all significant at $\alpha=0.01$ levels in determining energy intensity in high-income countries. Since the signs of all the variables are consistent with the original hypotheses, one-tailed test is used calculate all the P values. In addition, in the regression analyses, Iceland, Luxembourg and Cyprus are treated as outliers and deleted due to the corresponding largest outlying residuals, irregular DFFITS values (greater than $0.89 = 2\sqrt{5/25}$) and DFBETA values (greater than $0.4 = 2/\sqrt{25}$). Table 4.1 presents the final model for high-income countries. This model explains 80.5% variations in energy intensity in high-income countries. Since only 25 out of 72 high-income countries have values for these four variables, the total number of observations used in the model is only 25. The diagnostic plots in Figure A.1 and A.2 suggest that all the residuals are consistent and normally distributed. All Cook's D values are smaller than 50 percentile of F value which is 0.87. It suggests that there is no country's value can have significant influence on the fitted values of log_energy_intensity. This model is reasonable.

Table 4.1 Regression Results for High-income Countries

Variable	Unit	Hypothesis	Coefficients	Standard Error	t Value	P Value	VIF
INTERCEPT			+14.743***	2.171	6.79	<.0001	0.00
ENERGY_PRICE	Log(US$/ liter)	-	-0.324***	0.124	-2.61	0.0083	1.05
WINTER_TEMP	°F	-	-0.017***	0.003	-6.83	<.0001	1.02
COAL_SHARE	%	+	+0.636***	0.172	3.70	0.0007	1.03
SEVICE_INDUS_SHARE	%	Uncertain	-0.057**	0.022	-2.57	0.0184	1.00

N=25
R-Square=0.805
Adj.R-Square=0.766
F Value=20.64
*** Significant at the α=0.01 levels
** Significant at the α=0.05 levels
* Significant at the α=0.10 levels

4.2.2 Quantitative Variable Analyses

The regression model shows that the increase of energy prices drives down energy intensity, which is consistent with the original hypothesis. Energy prices are composed of 60% of gasoline prices and 40% of diesel fuel prices. Gasoline and diesel fuel are two main types of fuels in transportation. Car ownership rates in high-income countries are higher than those in middle-income and low-income countries. The transportation system is highly developed and widely dispersed in high-income countries. Due to the higher dependence on transportation in high-income countries, people tend to be more sensitive to gasoline and diesel fuel prices. As a result, the increase of the energy prices leads to more frugal consumption of energy resources and thus lowers energy intensity.

As is mentioned previously, most high-income countries, such as United States, Canada, European countries, and Australia, are located in higher latitudes. These countries heavily rely on heating systems which consume large quantities of energy without generating large shares of GDP. In addition, if winter temperatures are relatively low, the economic activities tend to be less efficient. Therefore, if the weather is colder, energy consumption will be less efficient. The sign for winter coefficient is also the same as the original hypothesis.

It is obvious that larger coal share leads to higher energy intensity. The regression result supports the original hypothesis. It is worthwhile to investigate the reason that Coal/TPES is significant in high-income countries. As is shown in Table 4.2 high-income countries have the lowest standard deviation in this variable, which means there are not large variations for coal share within high-income countries. Therefore, if one country has higher coal share, its energy efficiency may decrease significantly. Coal is also known as a less efficient energy source which produces higher levels of waste heat (Wikipedia, 2013a). This result suggests that if high income countries want to reduce greenhouse gas emissions, they will need to switch to cleaner, more energy efficient and renewable energy resources. Since some middle-income and low-income countries have no values for Coal/TPES ratios, coal share in these countries cannot accurately represent actual coal consumption.

Table 4.2 Statistics of Coal Share for Three Income Groups

Group	Mean	Std Dev	Minimum	Maximum
High Income	0.17	0.15	0.0061	0.66
Middle Income	0.18	0.22	0.0001	0.72
Low Income	0.10	0.23	0.000045	0.84

The sum of service and industrial share in total GDP is another important driver of energy intensity. It indicates the size of service and industrial sector in high-income countries, and it is the opposite of agricultural share. Table 4.3-4.5 show that high-income countries have the largest service share and smallest agricultural share, while low-income countries have the smallest service share and the largest agricultural share. This is consistent with the economic development theory. After long-term development, most high-income countries' agricultural sectors are extremely small (see Table 4.3). In early stages of development, the shrink of agricultural sector means lower energy efficiency due to the expanding energy intensive industrial sector. After the industrial sector grows, the service sector begins to expand more, and the agricultural share remains small. At this point of time, energy efficiency improves due to the higher technological level and larger service sector. Therefore, larger industrial and service sector means lower energy intensity in the high-income group. However, the original hypothesis states that industrial sector is positively correlated with energy intensity and service sector is negatively correlated with energy intensity. It neglects the fact that the influence of economic structure on energy intensity varies based on different development levels.

Table 4.3 Percentages of Agricultural Value Added in Total GDP for Three Income Groups

Group	Mean	Std Dev	Minimum	Maximum
High Income	2.12	1.32	0.06	6.39
Middle Income	12.12	8.18	1.76	41.50
Low Income	32.83	12.25	13.07	62.03

Table 4.4 Percentages of Service Value Added in Total GDP for Three Income Groups

Group	Mean	Std Dev	Minimum	Maximum
High Income	66.77	16.75	2.53	92.78
Middle Income	55.90	14.14	19.18	82.62
Low Income	45.99	8.47	30.77	61.78

Table 4.5 Percentages of Industrial Value Added in Total GDP for Three Income Groups

Group	Mean	Std Dev	Minimum	Maximum
High Income	31.10	16.50	7.16	95.14
Middle Income	31.83	13.37	6.00	77.31
Low Income	21.12	9.44	6.22	51.55

4.2.3 Qualitative Variables

This research tries to introduce qualitative variables, which are index variables that measure the societal, macroeconomic and political strengths of a country, into the model for high-income countries. However, none of the combinations of qualitative variables displays high significance levels or reasonable signs. As is shown in Table 4.6, high-income countries have the highest values and low-income countries have the lowest values for all the qualitative variables. Therefore, the macroeconomic, political and societal situations in high-income countries are very stable. They are not drivers of energy efficiency in high-income countries as expected. This is mainly because they have attained the levels of education, political stability, etc. needed for energy efficiency.

Table 4.6 Statistics of Qualitative Variables for Three Income Groups

	High-income	Middle-income	Low-income
Variables	**Mean**	**Mean**	**Mean**
institutions	4.95	3.68	3.54
infrastructure	5.08	3.25	2.50
macroecon_stab	5.22	4.60	3.93
health_primedu	6.08	5.12	4.02
highedu	4.97	3.70	2.82
goods_mkt_eff	4.80	4.00	3.74
labor_mkt_eff	4.72	4.14	4.28
finan_mkt_devlop	4.91	3.99	3.66
tech_ready	4.82	3.19	2.57
mkt_size	4.19	3.60	2.71
busi_sophi	4.80	3.77	3.42
innovation	4.11	2.97	2.81
politic_stab	4.16	3.31	2.64
govt_effec	4.51	3.17	2.49
regu_quality	4.51	3.16	2.57
rule_law	4.49	3.15	2.52

4.2.4 Policy Implications

Energy prices are significant drivers of energy efficiency in high-income countries. However, governments may have good reasons for limiting energy taxes, which would lead to higher prices. Even though increasing energy prices can facilitate efficient use of energy, it also can hurt the prosperity of transportation and the economy, so a balance needs to be achieved. It is also impossible for governments to control winter temperature. However, they can develop more efficient heating systems. More funding can be invested to develop more energy efficient heating systems or look for a renewable energy resource for heating.

Governments can make policies to reduce the share of coal usage in their total energy consumption. They can implement taxes on coal or on CO_2 emissions. Government policies can also influence the agricultural sector (the opposite of service and industrial sector). They can make policies to improve agricultural productivity so that more resources can be freed and allocated to economic development.

4.3 Middle-income Countries

4.3.1 Model

The group of middle-income countries is composed of both upper-middle-income countries and lower-middle income countries. It contains the largest number of countries. These countries are under different development stages and display more diverse characteristics. They have different energy usage situations, but they have diverse political, societal and macroeconomics conditions. Therefore, energy usage indicators and qualitative variables are actively involved in influencing energy efficiency of middle-income countries. After numerous regressions, the model shown in Table 4.7 turns out to be the best fit. In addition, only 55 out of 107 middle-income countries have values for these four variables, the total number of observations used in the model is only 55. All diagnostic plots are presented in Figures A.3 and A.4.

Table 4.7 Regression Results for Middle-income Countries

Variable	Unit	Hypothesis	Coefficients	Standard Error	t Value	P Value	VIF
INTERCEPT			+10.077***	0.368	27.35	<.0001	0.00
ENERGY_PRICE	Log(US$/ liter)	-	-0.201***	0.051	-3.97	0.00010	1.24
WINTER_TEMP	°F	-	-0.013***	0.002	-6.92	<.0001	1.37
FOREST_SHRE	%	+	+0.508***	0.090	5.67	<.0001	1.33
HYDRO_ELEC_SHARE	%	-	-0.005***	0.001	-3.76	0.00025	1.16
MACROECON_RULE	Score	-	-0.093**	0.044	-2.14	0.01875	1.18

N=55
R-Square=0.672
Adj.R-Square=0.639
F Value=20.07
*** Significant at the α=0.01 levels
** Significant at the α=0.05 levels
* Significant at the α=0.10 levels

Since all variables' signs support the original hypothesis, one-tailed test is used to calculate the P values. Energy prices, winter temperature, forest share and hydroelectricity share are significant at α=0.01 levels, but the sum of macroeconomic stability and rule of law score is significant at α=0.05 levels. The model explains 67.2% of variations of energy intensity in middle-income countries.

Figures A.3 and A.4 suggest that the residuals have consistent variances and are normally distributed. All the Cook's D values are small and reasonable. The influential statistics also show that all DFFITS values are smaller than 0.66 ($= 2\sqrt{6/55}$) and all DFBETAS are no greater than 0.27 ($= 2/\sqrt{55}$). Therefore, there is no influential observation in the model. This model is reasonable enough to explain energy intensity.

4.3.2 Explanations of Quantitative Variables

Similar to high-income countries, middle-income countries are also highly rely on transportation systems. For example, China has the largest population and third largest territory size, which demands intensive and extensive public transportation systems. Russian Federation has the largest territory and low population density, which requires developed transportation system. In addition, some oil net exporters are also middle-income countries, of which the oil prices' subsidies insert great influence on energy efficiency. It is shown that the correlation parameter between the natural logarithmic form of energy prices and net oil exporter dummy variable is -0.596. Net oil-exporting countries tend to have lower energy prices and these countries usually have lower energy efficiency due to their lower prices. There are only 7 out of 15 net oil exporting countries have values for all significant variables in the middle-income group. Various regressions show that the net oil exporter dummy variable is not significant in determining energy intensity in the middle-income group. Consistent with the original hypothesis, lower energy prices can motivate lower energy intensity.

Most middle-income countries are Asian Countries and South American Countries which are located in the higher latitude Temperate Zone. Therefore, they also have longer winters which require energy-intensive heating systems.

Forest share in total GDP is an indicator of forest consumption share in the economy. People in some rural areas in middle-income countries still use wood as an energy resource, which is inefficient. Thus larger forest share in total GDP indicate lower energy efficiency in middle-income countries. It is consistent with the original hypothesis.

Large hydroelectric power stations are common in middle-income countries. For example, China has Three Gorges Dam, Longtan Dam, Laxiwa Dam and Xiaowan Dam; Brazil has Itaipu Dam, Tucurui, and llha Solteira Dam; Venezuela has Guri and Macagua; Russia has Bratsk, Sayano–Shushenskaya and Ust Ilimskaya. In addition to these countries, Pakistan, Argentina, Turkey, Mexico, and Malaysia all have large hydroelectric power stations (Wikipedia, 2014). Therefore, hydroelectric power share in total electricity generation is an important energy efficiency driver for middle-income countries. Hydroelectric power is a clean and renewable energy resource. It is the most efficient power capable of converting 90% of the energy into electricity, while the most efficient fossil fuel plant is only 60% efficient (Agtech Center, 2013). Accordingly, in middle-income countries, large hydroelectricity share in power generation means high energy efficiency as is expected.

4.3.3 Explanations of Qualitative Variables

The variable macroecon_rule measures the total effects of macroeconomic stability and indexes of rule of law. Macroeconomic stability reflects the business environment for companies. If the macroeconomic environment is stable, the companies' efficiency would be high, thus their energy efficiency would be higher accordingly. Therefore, more stable macroeconomic environment indicates higher energy efficiency and thus lower energy intensity. The indexes of rule of law measure the capability of enforcing laws of a government. If a government promulgates a coal tax law to improve energy efficiency, and the government has a high capability to enforce this law, the country will be more likely to have their energy efficiency improved through this law. It has a negative influence on energy intensity. Therefore, the total effects of macroeconomic stability and rule of law on energy intensity is negative, and this supports the original hypothesis.

4.3.4 Policy Implications

Similar to high-income countries, government can choose reasonable increases in energy prices and induce energy efficiency. For net oil exporters, reducing or cancelling subsidies in oil prices can also improve their domestic energy efficiency. Improving the efficiency of winter heating systems is also another choice for middle-income countries. Since forest rents share in total GDP and hydroelectricity share in total electric power generation are shown to be significant, it is essential for middle-income countries to switch the energy usage structure from traditionally inefficient energy resources to renewable, clean and efficient energy resources. The total effects of macroeconomic stability and rule of law suggest that a stable economic, societal and political environment is imperative for middle-income countries. In middle-income countries, their economic, societal, and political situations can be further improved. After the improvements, their energy usage should be more efficient.

4.4 Low-income Countries

4.4.1 Models

There are many missing values for the low-income country group. Therefore the model generated for energy efficiency in low-income countries is not representative. After various models are tried, two models are shown to explain energy efficiency best. The regression results are presented in Tables 4.8 and 4.9. The corresponding diagnostic plots are presented in Figures A.5-A.8.

Table 4.8 Regression Results of Model 1 for Low-income Countries

Variable	Unit	Hypothesis	Coefficients	Standard Error	t Value	P Value	VIF
INTERCEPT			+11.507***	0.310	37.06	<.0001	0.00
FOSSIL_SHARE	Log(%)	+	-0.498***	0.066	-7.56	<.0001	1.62
POP_DENSITY	Log(people/square km)	-	-0.175***	0.058	-3.02	0.0065	1.46
URBAN_SHARE	%	-	+0.019***	0.005	3.97	0.0026	1.49
POLITIC_STAB	Score	-	-0.140*	0.078	-1.80	0.0511	1.55

N=15
R-Square=0.920
Adj.R-Square=0.887
F Value=28.57
*** Significant at the α=0.01 levels
** Significant at the α=0.05 levels
* Significant at the α=0.10 levels

Table 4.9 Regression Results of Model 2 for Low-income Countries

Variable	Unit	Hypothesis	Coefficients	Standard Error	t Value	P Value	VIF
INTERCEPT			+11.811***	0.330	35.84	<.0001	0.00
FOSSIL_SHARE	Log(%)	+	-0.570***	0.038	-15.03	0.0006	2.87
POP_DENSITY	Log(people/square km)	-	-0.132***	0.025	-5.29	0.0066	1.78
URBAN_SHARE	%	-	+0.041***	0.005	9.07	0.0028	3.80
POLITIC_STAB	Score	-	-0.248***	0.045	-5.52	0.0059	3.19
INSTITUTIONS	Score	-	-0.166*	0.083	-2.01	0.0693	1.64

N=9
R-Square=0.993
Adj.R-Square=0.982
F Value=88.94
*** Significant at the α=0.01 levels
** Significant at the α=0.05 levels
* Significant at the α=0.10 levels

The only difference between model 1 and model 2 is the inclusion of institution variable in model 2. Because of the inclusion of institution variable, the number of observations decreases from 15 to 9 due the missing values of the institution variable in 6 countries. They are Democratic Republic of Congo, Eritrea, Haiti, Democratic People's Republic of Korea, Tajikistan, and Togo. The 9 countries in model 2 are Bangladesh, Benin, Cambodia, Ethiopia, Kenya, Kyrgyz Republic, Mozambique, Nepal, and Tanzania. Model 2 has higher adjusted R-Square and F statistics, but the Cook's D values suggest the first three observations may be influential observations. Even though model 1 has a slightly lower adjusted R-square, its residuals have constant variance and normally distributed, and there are no influential observations. However the additional 6 countries' dataset may have potential problems because of the poor data quality. Model 2 may be a better fit from an economic perspective. However there are only three degrees of freedom.

4.4.2 Quantitative Variables

It should be noticed that the R-Squares in the models of low-income countries are extremely high. It is caused by the high correlations between log_energy_intensity and log_fossil (fossil consumption share in the total energy consumption) (see Figure 4.3). Regressing log_energy_intensity on log_fossil yields the following function.

log_energy_intensity=10.93-0.497log_fossil_share

t-value=-6.16 P-value<0.0001 $R^2 = 0.7446$ $\overline{R}^2 = 0.7249$

It turns out that log_fossil_share can explain as much as 72% of log_energy_intensity. However, the negative sign is opposite to the original hypothesis. The correlation matrix in Table 4.10 shows that log_fossil_share is highly negatively correlated with log_forest_share, which approximates forests consumption share in the economy. One possible explanation is that in some low-income countries, people use wood as energy resources. Except for fossil fuels and wood, the shares of other energy resources are small. Therefore, small fossil share means large forest share, which results in energy inefficiency. In this context, fossil share may more accurate in measuring forest product share in energy consumption. It is a better fit to include fossil share in the models to explain energy efficiency in low-income countries. However, this explanation about the negative relationship between energy intensity and fossil share is not very strong and requires further investigation.

In fact, due to very poor data quality and very small number of countries, any interpretation of results from this group of countries must be taken with caution. The bottom line is that paucity of good data may be more important than any of the results reported here.

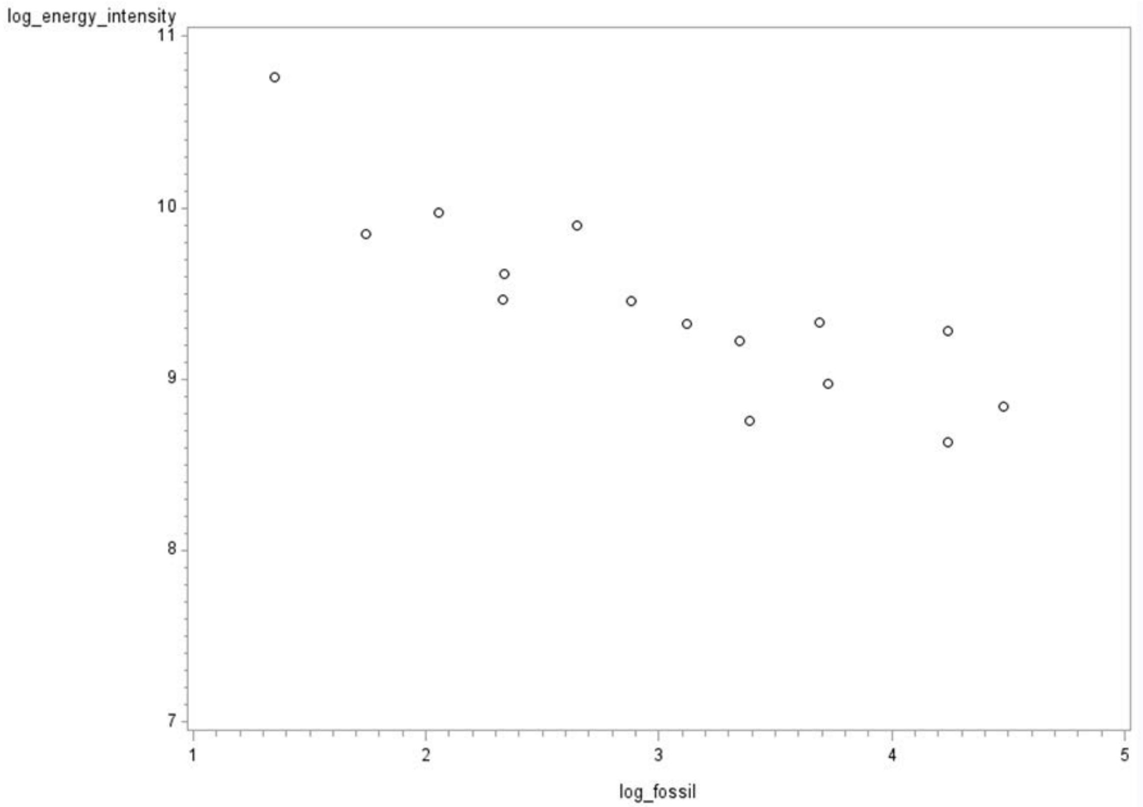

Figure 4.3 Scatter Plot of Log_energy_intensity vs. Log_fossil

Table 4.10 Correlation Matrix of Forest Rents Share in Total GDP and Fossil Consumption Share in Total Energy Consumption

	forest_share	log_forest_share	fossil_share	log_fossil_share
forest_share	1	0.69	-0.55	-0.83
log_forest_share	0.69	1	-0.74	-0.78
fossil_share	-0.55	-0.74	1	0.92
log_fossi_sharel	-0.83	-0.78	0.92	1

Population density has a negative effect on energy intensity as hypothesized. All low-income countries with complete datasets are small countries, and thus the effects of the country size can be neglected. Since they are small, high populated areas indicate a more efficient transportation system, electric system and public facilities. It is reasonable that population density plays an important role in driving energy intensity in low-income countries.

Even though population density positively influences energy efficiency, urban population share in low-income countries doesn't. Urban population share is the percentage of the population living in urban areas. It is an indicator of urbanization. It seems that the population density and the urbanization are similar measurements, but their correlation is only 0.02.The difference between them is that population density has nothing to do with development, but urbanization symbolizes the development levels. Urbanization level is hypothesized to be positively correlated with energy efficiency, because higher urbanization level means more efficient energy supply system. However, in the early stages of development, more people in urban areas usually lead to intensive energy usage. Later, urban population reaches a point where more urban people can improve energy efficiency. Low-income countries are those that are still at the early stage of development. They haven't reached the point where scale of economies can be achieved. Table 4.11 shows the mean levels of three groups of countries. It is obvious that low-income countries have the lowest urbanization level, which supports the explanations above. United States and Bangladesh are picked out as examples of high-income and low-income countries (see Figure 4.4). United States has much higher urbanization level than Bangladesh, but their rates of increase are almost same. United States is a highly developed country, and its energy intensity has been decreasing since 1980. However, Bangladesh's energy efficiency fluctuates and remains constant overall. This supports that the hypothesis between development and urbanization is meaningful.

Table 4.11 Statistics of Urban Population (% of Total)

	Mean	Std Dev	Minimum	Maximum
High-income	73.43	22.20	13.05	100.00
Middle-income	54.40	19.46	12.47	92.89
Low-income	30.18	12.11	10.26	60.09

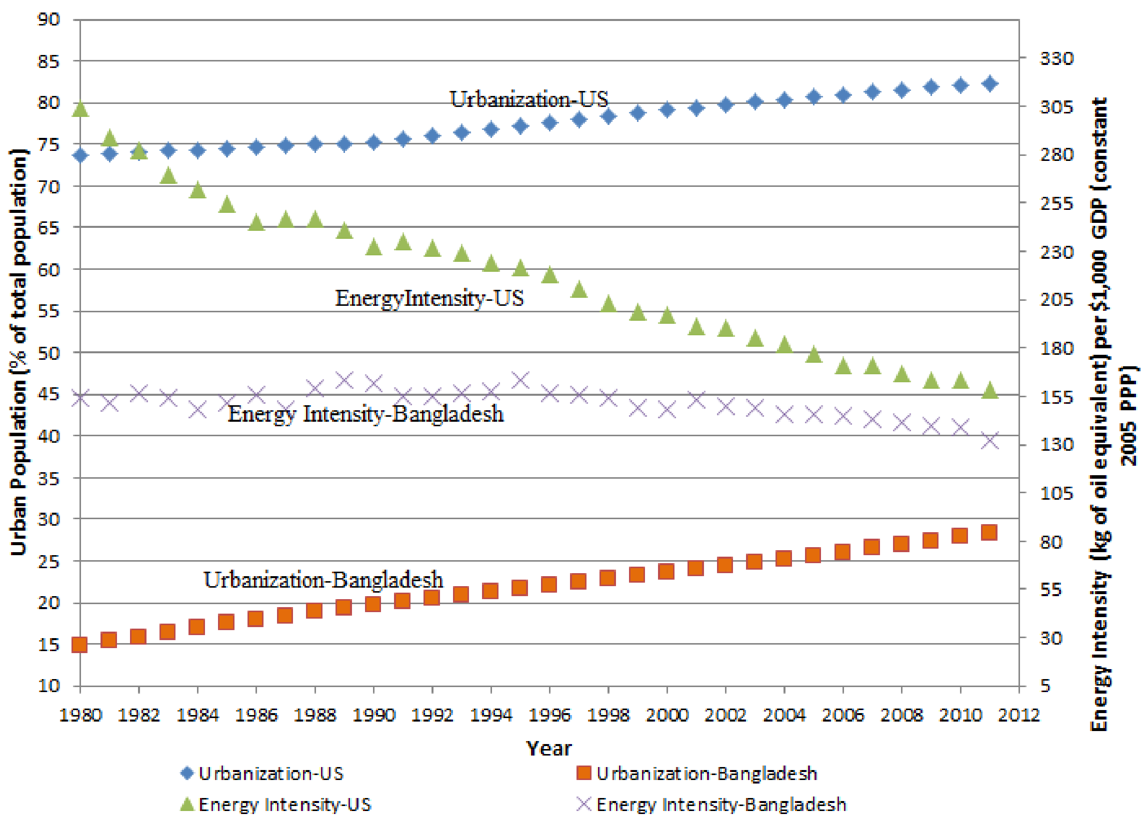

Figure 4.4 Urbanization and Energy Intensity of United States and Bangladesh (1980-2011)

4.4.3 Qualitative Variables

The political situation is unstable in low-income countries. It significantly harms energy efficiency improvements. Stable politics insures stable economic and living environments for the people so that they can focus on developing their economies and thus improve energy efficiency. Consistent with the original hypothesis, politic stability can positively influence energy efficiency.

As is defined by Global Competitiveness Report (Schwab, 2013), low-income countries are factor-driven countries. Institutions, infrastructures, macroeconomic stability, primary health and education are important factors in their daily lives. Political stability can potentially influence the macroeconomic stability to some extent. The correlation between Institutions and infrastructures is as high as 0.69 (see Table B.3). Primary health and education has limited effects on energy efficiency.

4.4.4 Policy Implications

Low-income countries need to continue working on energy consumption structure and efficiency. In addition, they need a stable political environment so that they can continue developing their economics and achieving structural transitions. During the development process, they will be able to speed up their urbanization level. A low development level is one of the largest barriers for their energy efficiency improvement.

CHAPTER 5. CONCLUSIONS

This research aims to investigate drivers of energy efficiency for countries with different income levels. This chapter will summarize the findings, and present the limitations of the study and recommendations for future study.

5.1 Summary

This research suggests that energy intensity varies among different income levels. Metcalf (2008) states that energy intensity usually displays a bell-shape curve with the increases of income per capita. Rühl et al. (2012) also hold a similar opinion that energy intensity first increases then decreases with development. Hannesson (2009) and Huang et al. (2008) also suggest that energy and economic attributes vary among different income groups and should be studied respectively. This research divides all countries into three groups: high-income countries, middle-income countries and low-income countries. As is shown in Figure 1.2, energy intensity is the lowest and energy efficiency is the highest in high-income countries; middle-income countries tend to have higher energy intensity and lower energy efficiency. In the long run, the general pattern of energy intensity with development is declining in both high-income and middle-income countries. GDP per capita is a proxy of development levels. This is why GDP per capita inserts a negative effect on energy intensity for all countries. The relationship between energy efficiency and income levels also suggests that economic structure plays an important role in determining energy efficiency, which is confirmed in this research.

Countries with similar energy and economic attributes tend to have the same drivers of energy efficiency. Energy prices and winter temperature are both shown important factors of energy efficiency for high-income and middle-income countries. Both variables are positively correlated with energy efficiency. This result is consistent with conclusions reached by Metcalf (2008), Stern (2012), and Thaler (2011) who believe that higher energy prices predominantly lead to higher energy efficiency. However, this conclusion contradicts Song and Zheng (2012)'s opinion that the effect of energy prices is limited. Energy efficiency is closely related to energy demand, which is determined by energy prices. However, whether energy prices significantly determine energy efficiency also depends on the energy price elasticity of demand. In high-income and middle-income countries, people highly rely on energy intensive transportation systems, and they tend to be more sensitive to gasoline and diesel fuel prices. Song and Zheng (2012) use China as an example in their analysis. China has a large population and extremely high energy demands. They argue that changes in energy prices will not be able to reduce energy demand significantly. However, it is not clear that their hypothesis has been adequately tested with empirical data. Cooler winter leads to energy inefficiency due to heating systems. Most high-income and middle-income countries are located in higher latitudes. It makes sense that winter is an important factor of energy efficiency during winter times. This result is consistent with the findings of Metcalf (2008), Thaler (2011), and Song and Zheng (2012).

Both quantitative and qualitative variables are important in explaining the countries' energy usage. In addition to energy prices and winter temperature, coal/TPES and agricultural value added in total GDP are shown to be significant in the model of high-income countries. Coal is a low energy efficiency resource, so more coal use leads to less efficiency. High-income countries usually have smaller agricultural sectors. The productivity of the agricultural sectors determines how many resources will be freed to support economic growth. The quantitative drivers of energy efficiency in high-income mainly reflect their economic structures and their environmental concerns. Quantitative variables in middle-income countries focus on their energy usage situations. Since lots of rural areas in middle-income countries still use wood as energy resources, forest rent share in total GDP appear as a proxy of forest usage share in the economy. Burning wood is inefficient and thus large forest rent share in total GDP results in energy inefficiency. Hydroelectric power is common in middle-income countries. Therefore, it is also shown as an important factor of energy efficiency in middle-income countries.

It turns out models of low-income countries focus more on demographic features and energy usage situations. Population density and urbanization levels reflect demographic features in low-income countries. Population density positively affects energy efficiency, which supports the results in the literature of Masayuki (2013) and Karathodorou et al. (2010). Urbanization level has a negative effect on energy efficiency in low-income countries, because urbanization in low-income countries is not high enough to employ scale of economies of energy systems. In early stages of urbanization, urban infrastructure is often poor and inefficient. Other quantitative variables that could be important in determining energy efficiency didn't appear in the models due to the problems of missing values and multicollinearity. However, for low income countries the lack of enough observations and poor data quality for the available observations suggest caution in interpreting any of the results.

The regression results about qualitative variables are consistent with the Global Competitiveness Report (Schwab, 2013), that defines high-income countries as factor-driven economies, middle-income countries as efficiency-driven countries and low-income countries as factor-driven economies. The three groups and the corresponding qualitative variables are shown in Figure 5.1. Due to the high levels of qualitative variables and high correlations among qualitative variables, these variables are not significant drivers of energy efficiency in high income countries. Business sophistication is not highly related to energy efficiency, and innovation is captured in energy prices to some extent. Macroeconomic stability and index of rule of law are shown important in middle-income countries. For some lower-middle-income countries, macroeconomic stability is still a critical issue to be resolved to improve the efficiency of the economy. Rule of law determines whether the rules and laws are put into practice effectively to make sure the market is efficient. Institutions and politic stability are basic requirements of an economy and a society. They are reasonable enough to show up in the models of low-income countries.

It also makes sense that intercepts of all models are positive. If all values of predictive variables are zero, there is still a level of energy intensity and there is no negative energy intensity.

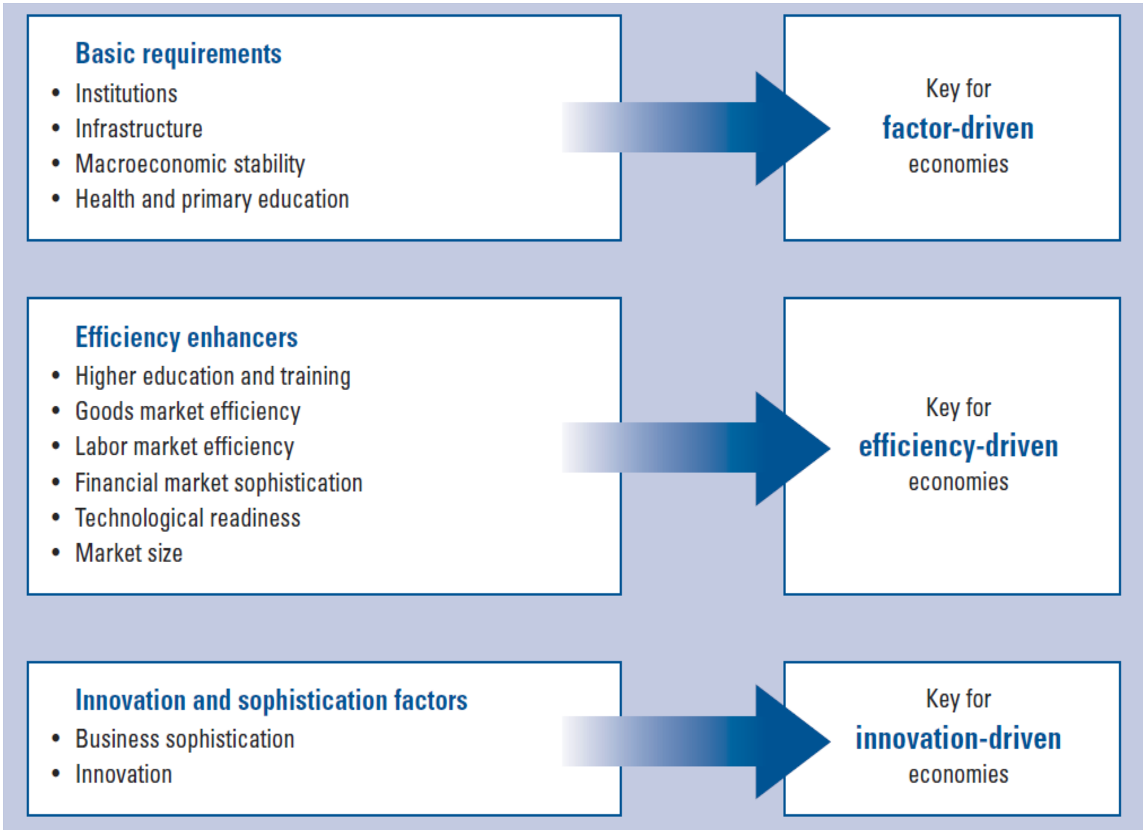

Figure 5.1 Determinant Qualitative Variables in Factor-driven, Efficiency-driven and Innovation-driven Economies
(Source: Schwab, K. the Global Competitiveness Report 2012-2013.)

5.2 Limitations

The current research has significant problems of missing values for some variables. The data quality for low-income countries is very low. For example, energy prices and energy intensity of many low-income countries are missing. In addition, the data only represents the average level of a country. For example, Russian Federation, United States, China, Canada, Brazil are large countries, so heterogeneity exists in economic attributes, demographic features and even politic situations vary in different areas within a country. It is not precise to use one energy price to represent prices of all areas in the country. Countries within the same group also have different economic structures. Some countries and areas, such as Singapore and Hong Kong, have no agricultural sector. They are outliners, and there is no clear cut way to determine which country is an outlier.

5.3 Recommendations for Future Study

This research only focuses on cross sectional analysis of all the countries. More research can be done by using time-series analysis and panel data analysis. Fixed-effects models could also be employed for future study.

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APPENDICES

Appendix A Diagnostic Plots

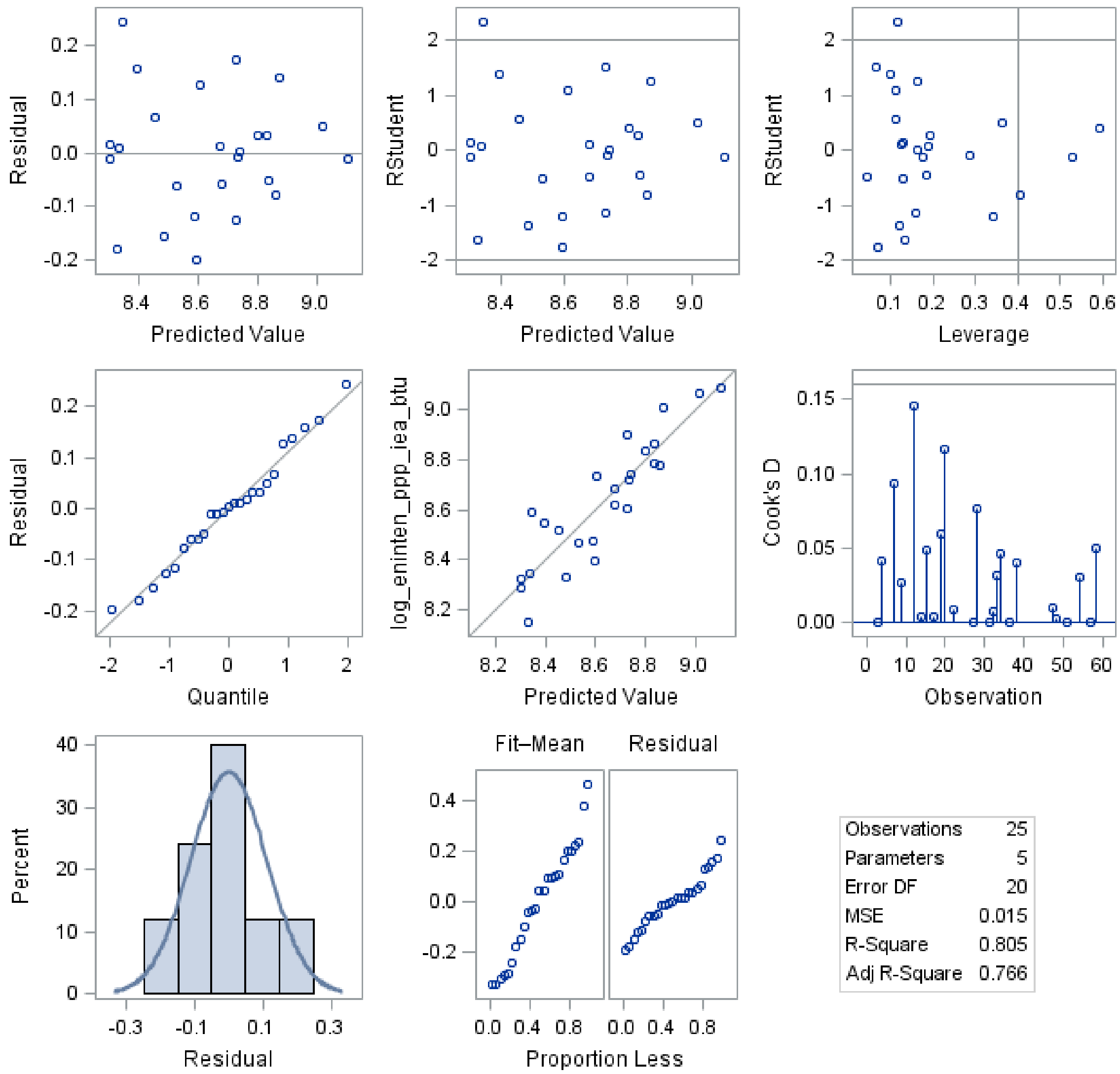

Figure A.1 Fit Diagnostics for Log_energy_intensity of High-income Countries

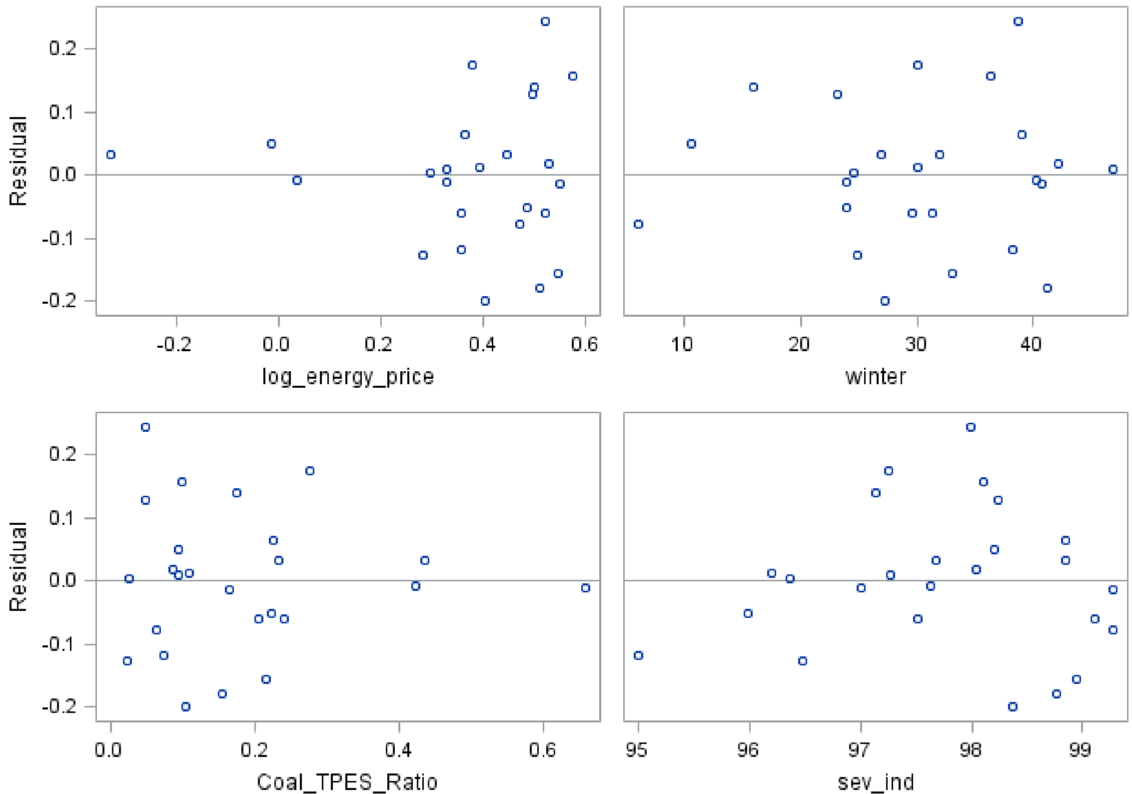

Figure A.2 Residual Plots of Four Independent Variables of High-income Countries

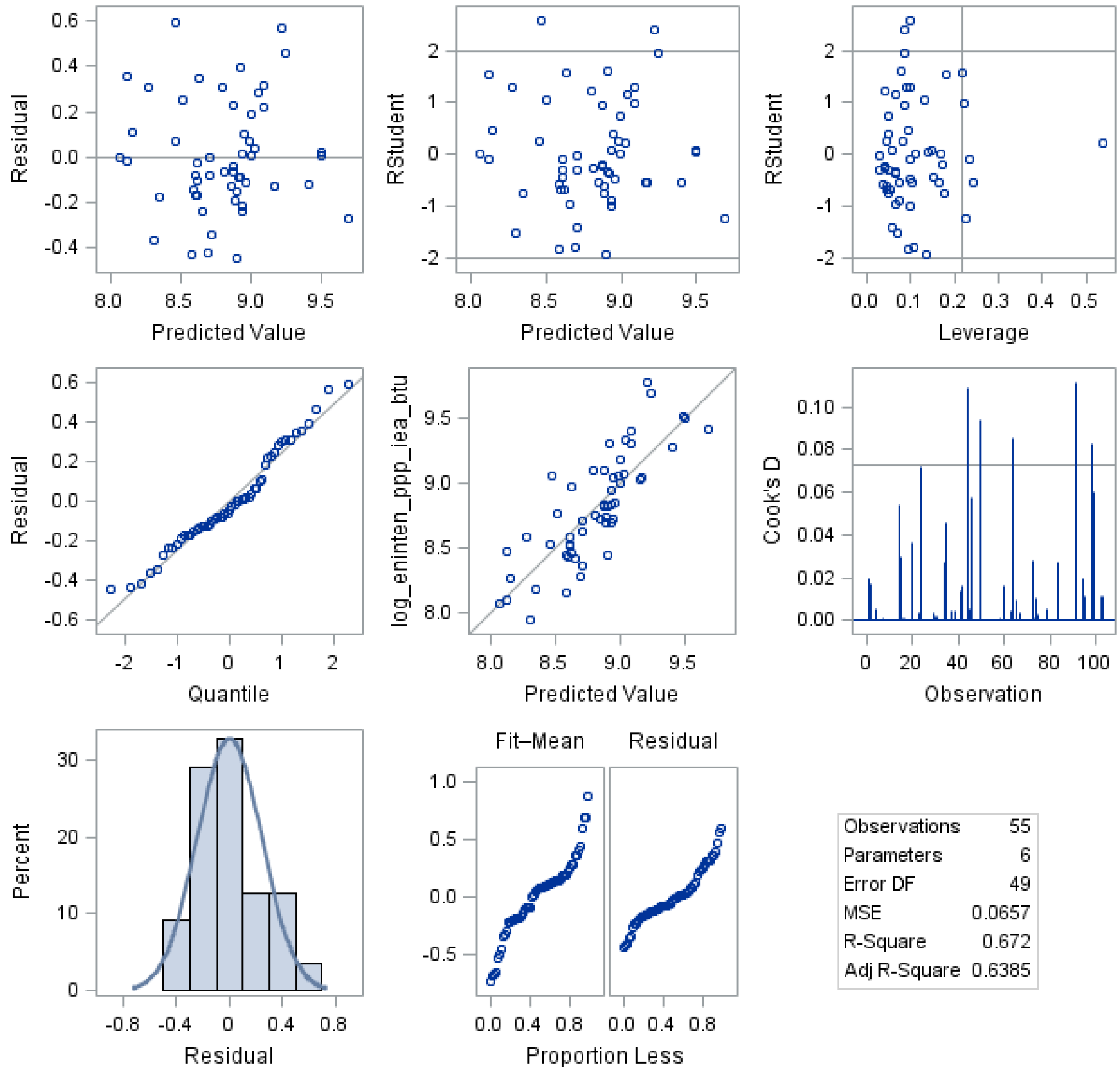

Figure A.3 Fit Diagnostics for Log_energy_intensity of Middle-income Countries

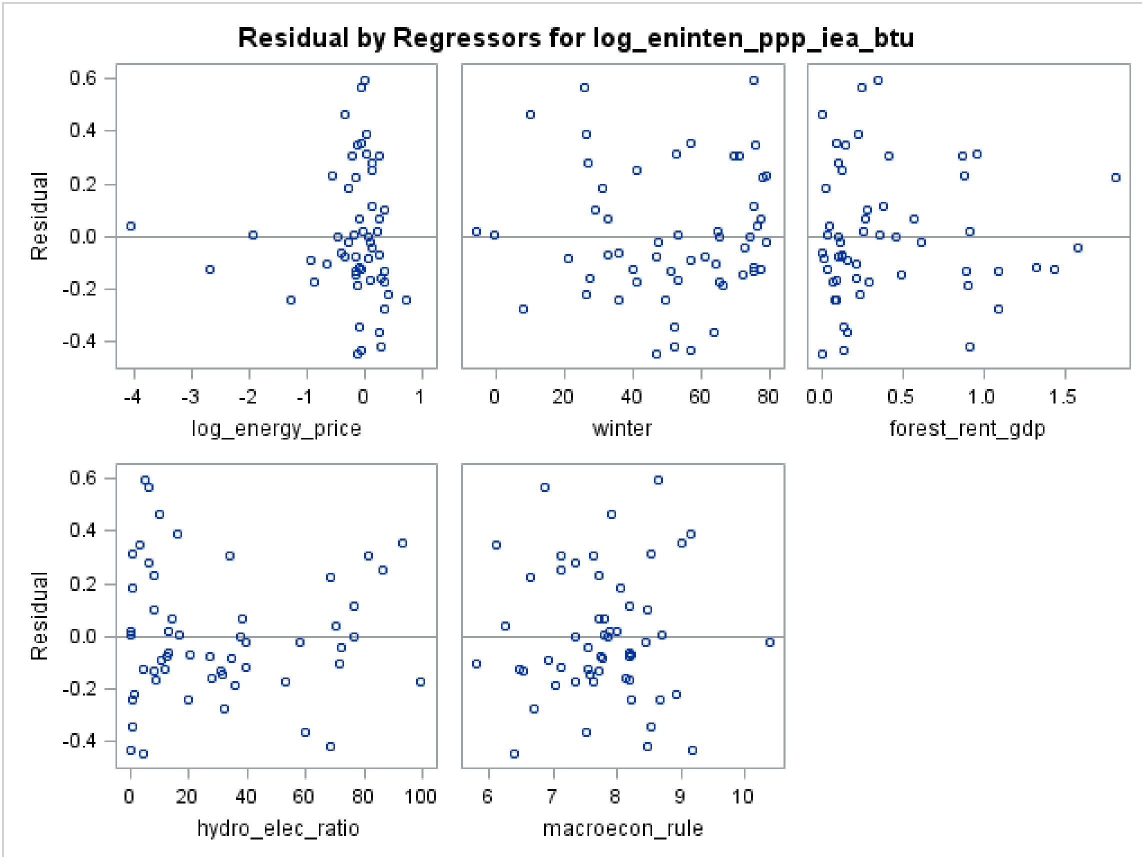

Figure A.4 Residual Plots of Five Independent Variables of Middle-income Countries

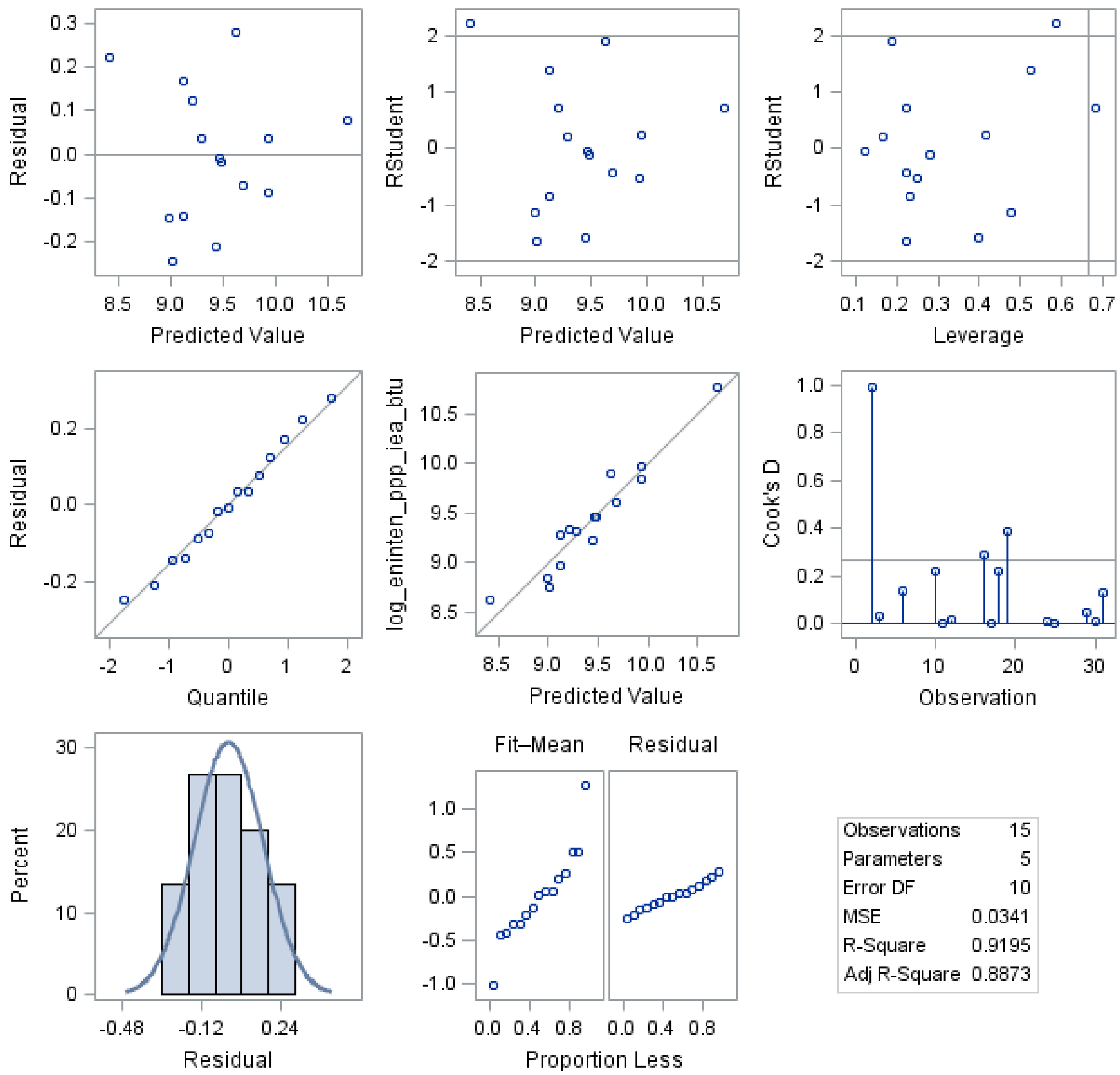

Figure A.5 Fit Diagnostics for Log_energy_intensity in Model 1 of Low-income Countries

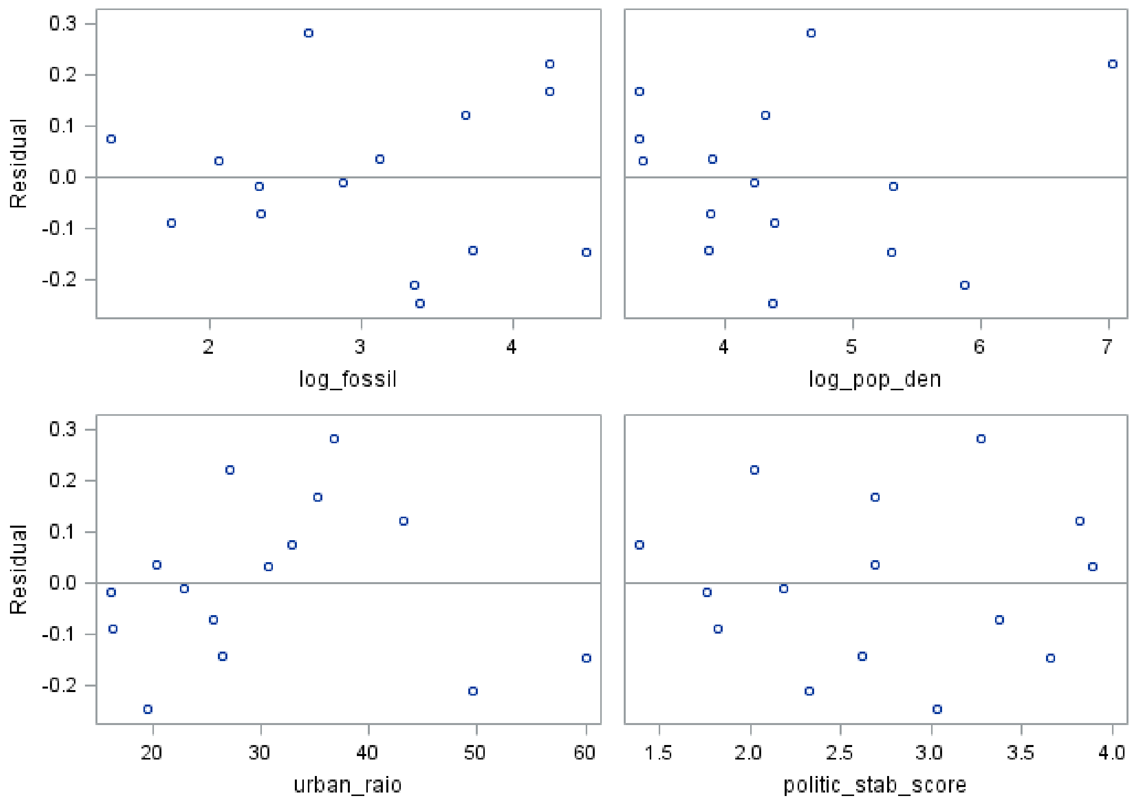

Figure A.6 Residual Plots of Four Independent Variables in Model 1 of Low-income Countries

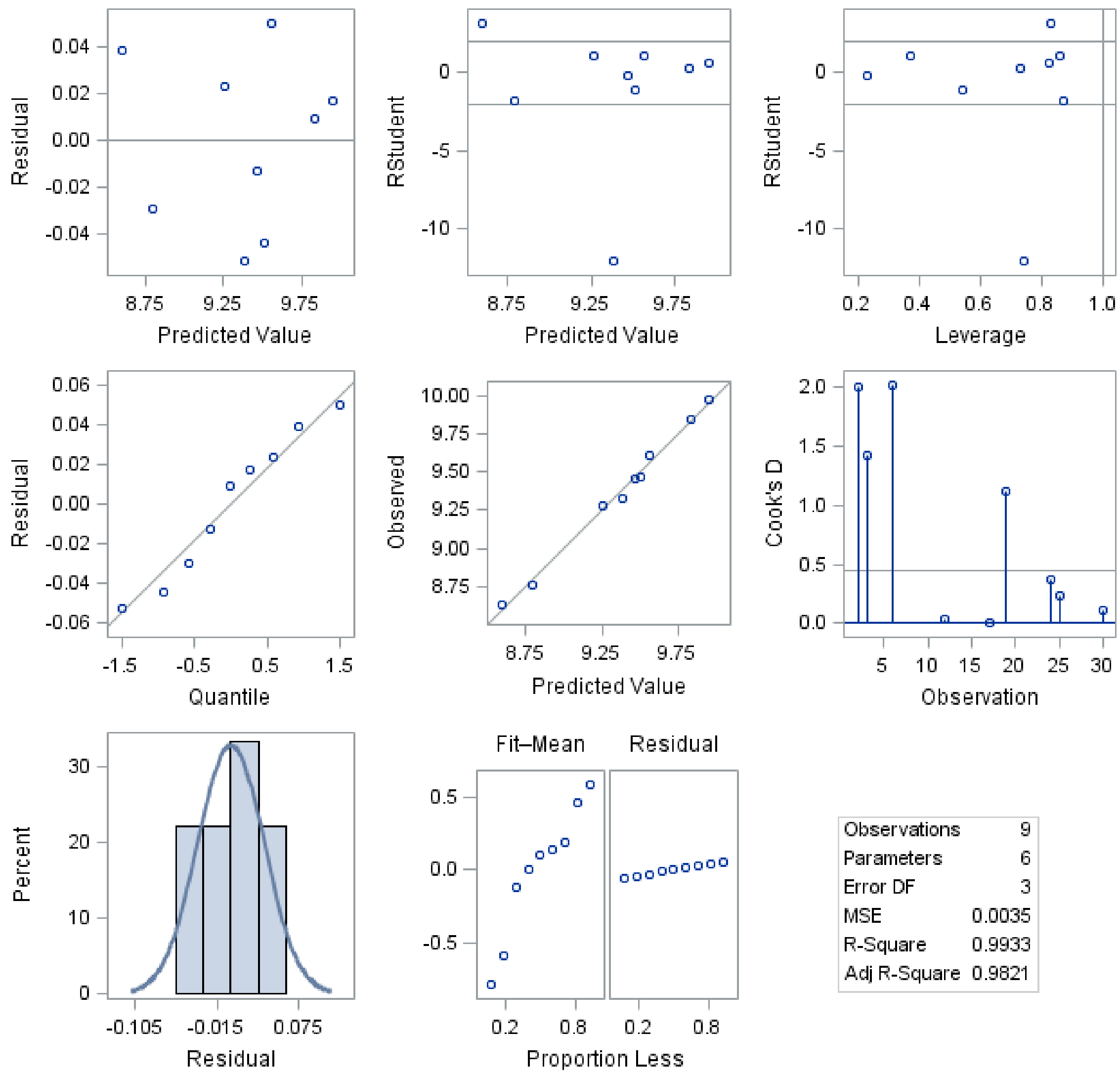

Figure A.7 Fit Diagnostics for Log_energy_intensity in Model 2 of Low-income Countries

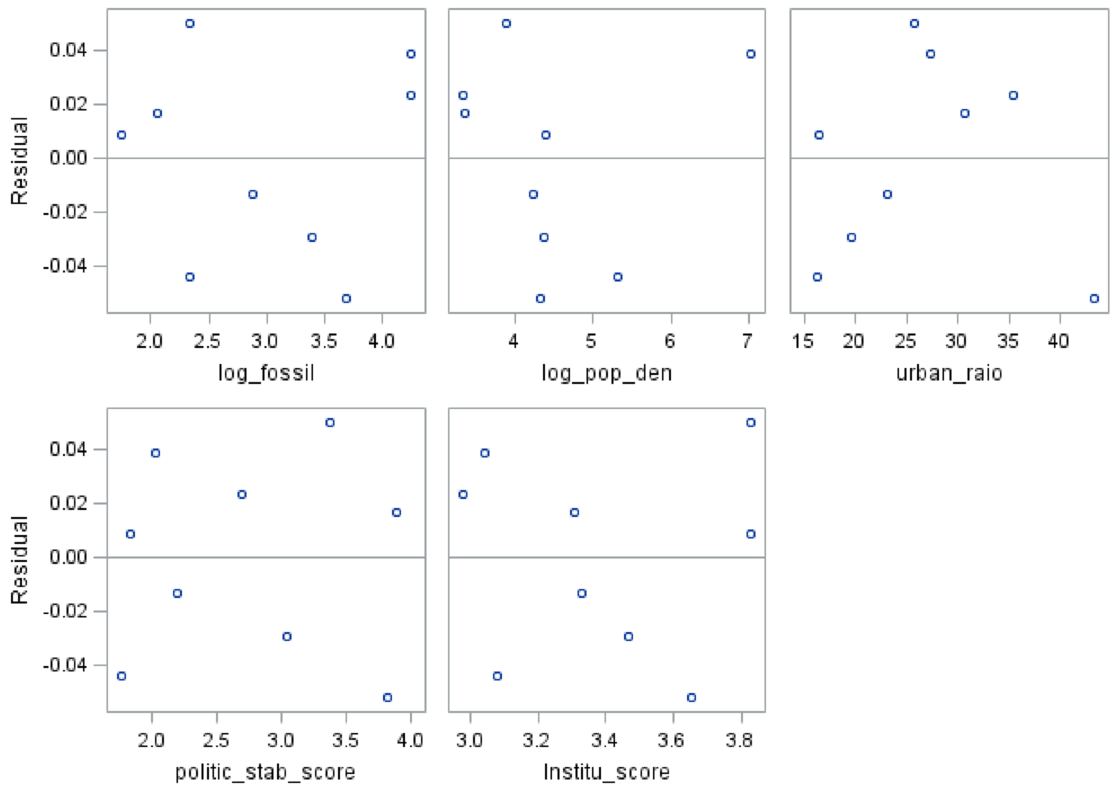

Figure A.8 Residual Plots of Five Independent Variables in Model 2 of Low-income Countries

Appendix B Correlation Matrix of Qualitative Variables

Table B.1 Correlation Matrix of Qualitative Variables for High-income Countries

	institutions	infrastructure	macroecon_stab	health_primedu	highedu	goods_mkt_eff	labor_mkt_eff	finan_mkt_devlop	tech_ready	mkt_size	busi_sophi	innovation	politic_stab	govt_effec	regu_quality	rule_law
institutions	1	0.71	0.38	0.61	0.63	0.81	0.59	0.74	0.74	0.10	0.65	0.63	0.49	0.78	0.60	0.80
infrastructure	0.71	1	0.11	0.53	0.64	0.72	0.45	0.56	0.76	0.51	0.81	0.74	0.27	0.73	0.54	0.67
macroecon_stab	0.38	0.11	1.00	-0.14	-0.07	0.30	0.28	0.31	0.08	-0.09	0.09	0.04	0.16	0.05	0.03	0.05
health_primedu	0.61	0.53	-0.14	1	0.81	0.54	0.33	0.49	0.73	0.16	0.56	0.60	0.45	0.83	0.67	0.76
highedu	0.63	0.64	-0.07	0.81	1	0.67	0.50	0.55	0.84	0.42	0.75	0.83	0.36	0.85	0.73	0.82
goods_mkt_eff	0.81	0.72	0.30	0.54	0.67	1	0.61	0.81	0.81	0.41	0.80	0.72	0.34	0.73	0.71	0.76
labor_mkt_eff	0.59	0.45	0.28	0.33	0.50	0.61	1	0.59	0.56	0.12	0.44	0.53	0.32	0.58	0.50	0.51
finan_mkt_devlop	0.74	0.56	0.31	0.49	0.55	0.81	0.59	1	0.71	0.17	0.54	0.55	0.23	0.73	0.73	0.71
tech_ready	0.74	0.76	0.08	0.73	0.84	0.81	0.56	0.71	1	0.39	0.80	0.81	0.38	0.88	0.78	0.85
mkt_size	0.10	0.51	-0.09	0.16	0.42	0.41	0.12	0.17	0.39	1	0.67	0.61	-0.14	0.26	0.32	0.29
busi_sophi	0.65	0.81	0.09	0.56	0.75	0.80	0.44	0.54	0.80	0.67	1	0.90	0.24	0.71	0.61	0.71
innovation	0.63	0.74	0.04	0.60	0.83	0.72	0.53	0.55	0.81	0.61	0.90	1	0.19	0.76	0.61	0.72
politic_stab	0.49	0.27	0.16	0.45	0.36	0.34	0.32	0.23	0.38	-0.14	0.24	0.19	1	0.69	0.71	0.74
govt_effec	0.78	0.73	0.05	0.83	0.85	0.73	0.58	0.73	0.88	0.26	0.71	0.76	0.69	1	0.94	0.94
regu_quality	0.60	0.54	0.03	0.67	0.73	0.71	0.50	0.73	0.78	0.32	0.61	0.61	0.71	0.94	1	0.94
rule_law	0.80	0.67	0.05	0.76	0.82	0.76	0.51	0.71	0.85	0.29	0.71	0.72	0.74	0.94	0.94	1

Table B.2 Correlation Matrix of Qualitative Variables for Middle-income Countries

	institutions	infrastructure	macroecon_stab	health_primedu	highedu	goods_mkt_eff	labor_mkt_eff	finan_mkt_devlop	tech_ready	mkt_size	busi_sophi	innovation	politic_stab	govt_effec	regu_quality	rule_law
institutions	1	0.72	0.13	0.17	0.40	0.75	0.33	0.64	0.54	0.08	0.55	0.62	0.39	0.70	0.54	0.76
infrastructure	0.72	1	0.25	0.36	0.56	0.70	0.31	0.62	0.67	0.39	0.69	0.68	0.13	0.69	0.50	0.53
macroecon_stab	0.13	0.25	1.00	0.10	0.19	0.05	0.12	-0.05	0.12	0.25	0.08	0.20	0.17	0.09	0.01	0.03
health_primedu	0.17	0.36	0.10	1	0.78	0.35	0.11	0.25	0.60	0.32	0.45	0.38	0.01	0.43	0.34	0.30
highedu	0.40	0.56	0.19	0.78	1	0.56	0.29	0.47	0.77	0.48	0.67	0.67	0.13	0.60	0.49	0.48
goods_mkt_eff	0.75	0.70	0.05	0.35	0.56	1	0.48	0.81	0.68	0.28	0.83	0.72	0.12	0.73	0.68	0.64
labor_mkt_eff	0.33	0.31	0.12	0.11	0.29	0.48	1	0.42	0.35	0.00	0.26	0.36	0.32	0.40	0.54	0.34
finan_mkt_devlop	0.64	0.62	-0.05	0.25	0.47	0.81	0.42	1	0.66	0.20	0.73	0.56	0.17	0.69	0.70	0.61
tech_ready	0.54	0.67	0.12	0.60	0.77	0.68	0.35	0.66	1	0.38	0.73	0.71	0.25	0.74	0.66	0.62
mkt_size	0.08	0.39	0.25	0.32	0.48	0.28	0.00	0.20	0.38	1	0.59	0.61	-0.33	0.22	0.08	0.01
busi_sophi	0.55	0.69	0.08	0.45	0.67	0.83	0.26	0.73	0.73	0.59	1	0.83	-0.07	0.64	0.53	0.48
innovation	0.62	0.68	0.20	0.38	0.67	0.72	0.36	0.56	0.71	0.61	0.83	1	0.06	0.60	0.38	0.51
politic_stab	0.39	0.13	0.17	0.01	0.13	0.12	0.32	0.17	0.25	-0.33	-0.07	0.06	1	0.34	0.21	0.65
govt_effec	0.70	0.69	0.09	0.43	0.60	0.73	0.40	0.69	0.74	0.22	0.64	0.60	0.34	1	0.81	0.77
regu_quality	0.54	0.50	0.01	0.34	0.49	0.68	0.54	0.70	0.66	0.08	0.53	0.38	0.21	0.81	1	0.62
rule_law	0.76	0.53	0.03	0.30	0.48	0.64	0.34	0.61	0.62	0.01	0.48	0.51	0.65	0.77	0.62	1

Table B.3 Correlation Matrix of Qualitative Variables for Low-income Countries

	institutions	infrastructure	macroecon_stab	health_primedu	highedu	goods_mkt_eff	labor_mkt_eff	finan_mkt_devlop	tech_ready	mkt_size	busi_sophi	innovation	politic_stab	govt_effec	regu_quality	rule_law
institutions	1	0.69	0.09	0.17	0.19	0.65	0.68	0.40	0.66	-0.27	0.41	0.55	0.55	0.68	0.35	0.62
infrastructure	0.69	1	-0.17	0.26	0.56	0.54	0.53	0.36	0.65	-0.32	0.53	0.50	0.42	0.37	0.19	0.21
macroecon_stab	0.09	-0.17	1.00	-0.12	-0.17	0.45	0.20	0.17	0.37	0.52	0.31	0.30	0.17	0.44	0.67	0.54
health_primedu	0.17	0.26	-0.12	1	0.48	0.34	0.25	0.28	0.14	0.03	0.16	-0.06	-0.10	0.27	0.12	-0.11
highedu	0.19	0.56	-0.17	0.48	1	0.43	0.29	0.60	0.49	-0.02	0.60	0.36	0.10	0.22	0.22	-0.12
goods_mkt_eff	0.65	0.54	0.45	0.34	0.43	1	0.63	0.66	0.76	0.34	0.77	0.71	0.42	0.76	0.66	0.66
labor_mkt_eff	0.68	0.53	0.20	0.25	0.29	0.63	1	0.37	0.71	-0.01	0.49	0.56	0.27	0.62	0.58	0.44
finan_mkt_devlop	0.40	0.36	0.17	0.28	0.60	0.66	0.37	1	0.62	0.39	0.82	0.60	0.15	0.47	0.29	0.28
tech_ready	0.66	0.65	0.37	0.14	0.49	0.76	0.71	0.62	1	0.07	0.79	0.80	0.48	0.63	0.60	0.49
mkt_size	-0.27	-0.32	0.52	0.03	-0.02	0.34	-0.01	0.39	0.07	1	0.33	0.15	-0.29	0.24	0.22	0.12
busi_sophi	0.41	0.53	0.31	0.16	0.60	0.77	0.49	0.82	0.79	0.33	1	0.78	0.19	0.42	0.42	0.33
innovation	0.55	0.50	0.30	-0.06	0.36	0.71	0.56	0.60	0.80	0.15	0.78	1	0.48	0.60	0.58	0.58
politic_stab	0.55	0.42	0.17	-0.10	0.10	0.42	0.27	0.15	0.48	-0.29	0.19	0.48	1	0.35	0.35	0.67
govt_effec	0.68	0.37	0.44	0.27	0.22	0.76	0.62	0.47	0.63	0.24	0.42	0.60	0.35	1	0.82	0.75
regu_quality	0.35	0.19	0.67	0.12	0.22	0.66	0.58	0.29	0.60	0.22	0.42	0.58	0.35	0.82	1	0.71
rule_law	0.62	0.21	0.54	-0.11	-0.12	0.66	0.44	0.28	0.49	0.12	0.33	0.58	0.67	0.75	0.71	1

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Guolin Yao finished her first two years undergraduate study at China Agricultural University majoring in Marketing. In 2010, she transferred to Department of Agricultural Economics at Purdue University where she began to be interested in environmental and natural resource economics. She obtained her Bachelor's degree from Purdue University in December 2011 and continued her Master's study at Purdue University in August 2012 working on energy economics.