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Assessing the Relationships between Economic Output and Energy Consumption, Energy Efficiency, and Renewable Energy Consumption for Twelve Southeast Asia and Oceania Nations

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This thesis is submitted in partial fulfillment of the requirements for the course Senior Seminar (EC375), during the Spring Semester of 2019.

While writing this thesis, I have not witnessed any wrongdoing, nor have I personally violated any conditions of the Skidmore College Honor Code.

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Abstract

Energy is an essential input for creating economic output. Increasing energy access, diversifying energy portfolios, and becoming more energy efficient are all believed to be requirements for fostering economic growth worldwide. This research analyzes at the macroeconomic level the correlations and the direction of implied causalities which exist between economic output and energy consumption, energy efficiency, and renewable energy consumption. These relationships are analyzed with considerations for energy access rates and attention devoted to political conditions, a key differentiator in the literature on energy economics. Analysis is conducted using a multivariate panel data set comprised of statistics for twelve ASEAN Plus Six nations located in Southeast Asia and Oceania and dynamic panel models. Findings indicate implied short-term bidirectional causalities exist between total final energy consumption and economic output, supporting the feedback hypothesis, while short-term neutrality relationships were discovered to be implied between economic output and energy efficiency and the renewable energy share of total final primary energy consumption. In addition, considerations for political conditions and energy access were found insignificant in all dynamic models run.

I. Introduction

Energy consumption and carbon emissions typically bear the brunt of the blame for being the driving force behind environmental degradation and climate change. Efficient energy consumption, sufficient access to energy resources, and diversity in energy resources are all cited by many national and international bodies as being essential for national and regional economies to develop and thrive. In order to determine whether this is really the case, it is important to examine whether changes in economic output are correlated with and potentially caused by changes in energy consumption, efficient energy use, and changes in the share of renewables in total final energy consumption. As such, the question that this study aims to answer is this; what types of correlations and implied causalities exist, if any, between economic growth and energy consumption, energy efficiency, and renewable energy consumption while considering for political climate and energy accessibility?

Kraft and Kraft (1978) wrote the seminal piece analyzing the economic growth-energy consumption nexus in the United States, finding unidirectional causality that economic growth caused increases in energy consumption. Following Kraft and Kraft (1978), most analyses have focused on the energy production function derived from the ecological perspective, which includes energy alongside labor and capital as being inputs. More recently, studies have begun to expand their considerations to include sectoral and industry considerations. Studies conducted by Binh, (2011), Shuyn and Donghu (2011), and Sinha (2015) report mixed results, finding evidence for some of the countries included in this study supporting all types of causalities

The purpose of this paper is to utilize the theories and methodologies which drive the study of the relationship between economic output and energy use to study the relationships between economic output and energy efficiency, economic output and renewable energy use on a macroeconomic scale, and to further study the relationship between economic output and energy consumption. This is done by compiling macroeconomic statistics and country-level energy statistics into a panel data set. Dynamic panel models are then used to estimate the regional impacts, determine the significance of correlations, and to use hypothesis testing so as to test whether or not there are any implied causalities between the relationships in question. Should estimates prove to be significant, and significantly greater than zero, then implied causalities could exist.

The contributions of this work extend what is possible for the analysis of the relationship between economic output and energy use. Where the standard is to analyze a model of economic output, energy use, capital, and labor using only either the neoclassical and ecological production functions, this study expands the scope of analysis to include considerations for energy accessibility and political conditions. The evidence provided by this study will form a basis of understanding for future research. This study contributes to laying the groundwork for future comprehensive study in the ASEAN region concerning each of the relationships in question. No other study in has focused solely on the ASEAN Plus Six region in studying the energy economic relationships this analysis focuses on.

The evidence presented by this research can help to inform policy debates worldwide. Neoclassical economists argued largely that production and economic growth largely depends on labor and capital. Over time, the role energy plays as an input in production has become more and more evident. Previously published studies in this realm of literature has helped to shape to direction of policy debates for governments all around the world. Studies such as this can also inform the direction of policy debates in intergovernmental organizations such as the United Nations. Understanding the linkage between energy usage and economic growth is important for creating beneficial governmental policies. These policies can include everything from subsidizing low-cost commercial energy suppliers or easing the process through which investment in energy can be done by foreign entities.

The findings of this paper demonstrate implied bidirectional causality running between economic output and total final primary energy consumption for the region studied. An absence of implied causality was found between economic output and energy efficiency, as well as between economic output and the renewable energy share of total final energy consumption. It could very well be that there is truly a lack of any significant correlation among the variables in question. Other reasons for the absence of correlation among variables and of implied causality could be attributed to a number of factors such as, among others, the macroeconomic focus of this study, the conflicting trends among variables in question, or the use of short-term dynamic panel models for producing estimations. In addition, considerations for political climate were found to be insignificant, indicating that the political make up of a nation may not have significant macro-level effects on GDP, total final energy consumption, energy efficiency, or the renewable energy share of total final energy consumption. Energy accessibility also did not prove to be significantly correlated with GDP, total final energy consumption, energy efficiency, or the renewable energy share of total final energy consumption.

The remainder of this paper is organized as follows; Section II) Literature Review, Section III) Analytical Framework, Section IV) Results and Discussion, Section V) Conclusions and Policy Implications, VI) Appendix.

II. Literature Review

Universal energy access has been identified by the United Nations (UN) and the International Energy Agency (IEA) as a prerequisite for poverty alleviation. Goal 7 of the UN's

Sustainable Development Goals is focused on achieving affordable and clean energy for all. It is important to understand why the UN has made clean energy paramount and to continue to study the connections that exist between energy use and economic progression. The energy access question has increasingly become one of the most widely studied questions in the fields of developmental economics and resource economics. Existing literature has defined the achievement of energy access as the attainment of modern energy services. The lack of such modern energy services is called energy poverty (Pachauri, 2011; Ouedraogo, 2013). The International Energy Agency defines access to modern energy services as having reliable and affordable access to clean cooking facilities and a public electricity supply connection (IEA, 2012). Per this definition of energy accessibility, 1.18 billion people are without access to modern energy services, which is roughly 14 per cent of the global population. Additionally, 84 per cent of people lacking access to modern energy services live in rural areas of the world (IEA, 2017).

i. Theories of Production and Growth

Understanding the relationship between economic output and energy consumption has been studied largely from two theoretical standpoints; neoclassical theory and ecological theory. According to Stern (2004), factors of production can be thought of as either reproducible or non-reproducible. Reproducible inputs are not entirely used up in the production of goods and services and can be used again. Most often, reproducible inputs are thought of as being labor and capital. Non-reproducible inputs are often considered to be intermediate inputs as they are used up entirely in production.

For much of the history of economic thought, energy resources have been thought of as intermediate inputs to production and not much thought is given to energy resources when standard production theories or economic growth theories are conceived. Neoclassical economists often work using the standard economic production function which does not consider for energy consumption as a significant factor of production. However, ecological economists have conversely emphasized the importance of energy in the economy as well as its availability, the efficiency of its use, and the diversity of energy resources that are used in production.

The historical neoclassical position views energy simply as an intermediate input of economic production and general productivity, and is less important than land, labor, and capital in creating economic output (Binh, 2011). Where land, labor, and capital are the primary factors of production, energy is a secondary or intermediate input along with other materials needed in the production of goods or services. The classical production function often takes the form of economic output as a function of labor and capital:

$$Q = (K, L)$$

This mainstream view downplays the role of energy resources in economies worldwide. From this perspective, economic growth can be maintained in the face of resource scarcity. As was argued by Stern (2004), many basic macroeconomic models and their applications do not consider the importance of resources at all, which appears to be true. An example would be the Solow neoclassical growth model, which considers technological progress as the only cause for sustaining any kind of long-term economic growth. Innate in this idea is the concept that technological improvements increase the rate of return to capital and counters any diminishing returns to capital. These technological improvements should also theoretically reduce the need for energy as an intermediate input and reduce the overall amount of energy used.

The positions of the UN and the IEA with the Sustainable Development Goals are positions which are in line with the ecological economic theory of energy consumption and economic growth. This theory states that the lack of or low energy consumption is an inhibitor of economic growth in the modern world (Stern, 2004). Under this theory, the impact of energy on the economy is accepted as logical and paramount. To put it simply, the ecological perspective operates under the assumption that there is no substitute for energy in production. The role of energy cannot be substituted by technological progress or any other tangible factors of production and the necessity for an energy source for production cannot be overcome. In addition, ecological economists will argue that energy is one of the primary sources of value in an economy. The basis for this argument is that labor and capital as factors of production cannot operate independent of energy. From this perspective, the classical production function can be altered to include energy as a key input to creating economic output:

$$Q = (K, L, E)$$

Opposite the mainstream view, the ecological view includes energy as an input of the production function for economic output alongside capital and labor. Additionally, the ecological economic perspective also draws a clear boundary between what is economic output and what is economic development where the neoclassical perspective views economic output and economic development as one and the same. For an ecological economist, economic output is a quantitative metric whereas economic development is more qualitative than quantitative.

ii. The Four Hypotheses

The results of studies examining the relationship between economic output and the various classifications of energy consumption can be categorized by four hypotheses. As listed by Jakovac (2018), the hypotheses are as follows: i) the growth hypothesis, ii) the conservation hypothesis, iii) the neutrality hypothesis, and iv) the feedback hypothesis. The conservation hypothesis is supported where causality is determined running from economic growth to energy consumption. The growth hypothesis is opposite the conservation hypothesis, where unidirectional causality is from energy consumption to economic growth. The neutrality hypothesis suggests no causal relationship exists between economic growth and energy consumption. Lastly, the feedback hypothesis suggests a bidirectional causality and interdependent relationship between economic growth and energy consumption. As one may determine from reading, the conservation and neutrality hypotheses support the neoclassical perspective on the lack of importance of energy as a factor of production, where either economic output drives energy use or an absence of a causal relationship exists. The ecological economic perspective is supported by the growth hypothesis and the feedback hypothesis, where such evidence would indicate the importance of energy as a factor of production alongside labor and capital, displaying that energy has causal effects on economic output. As it stands, the empirical research conducted thus far has yielded mixed results but leans towards the growth hypothesis and the feedback hypothesis, and the notion that energy availability is a prerequisite for a functioning economy.

iii. Studying the Linkage Between Energy Consumption and Economic Growth

Kraft and Kraft (1978) is widely recognized as being the first study to methodically analyze the linkage that exists between energy consumption and economic output. In their seminal study, they utilized annual GNP and energy consumption data from the United States for the time period 1947-1974. The results of their analysis indicated a unidirectional causality existed from GNP to energy consumption and indicated no causality from energy consumption to GNP. These empirical results were determined using the Sims (1972) method, which is a direct test for only unidirectional causality. The evidence found by the Kraft and Kraft (1978) study has been both confirmed and challenged empirically since its publication. As was noted by Soytas and Sari (2003), the confirmations and the contradictions of the Kraft and Kraft (1978) study are due to a number of reasons which should be considered when comparing and contrasting the evidence of different studies.

The differing results of a number of studies which find wide-ranging results is certainly the result of the differing methodologies used, the differing time frames for data used for single countries or across a number of countries, and the differing regional focuses across countries or within countries. For example, one study could focus on the economic growth and energy consumption nexus for a single country using simple regression techniques, and another study will focus on the same nexus for an entire region of countries using panel data and cointegration techniques. Most studies analyzing the energy use-economic growth linkage can fall into one of two streams of current literature; cross-country or within country panel studies or single-country case studies (Ouedraogo, 2013).

What is constant through many studies studying economic output and energy use is the utilization of the production function theory conceived from the ecological economic perspective. Doing so has yielded some significant results supporting both the ecological perspective and the neoclassical perspective, albeit these results being found through a number of different empirical methods. More recently, a number of studies have settled on using Granger-causality testing methods and cointegration models testing for estimating the long-run parameters of variables (Erdal et al., 2008; Gelo, 2009; Binh, 2011; Altunbas & Kapusuzoglu, 2011; Shuyn & Donhua, 2011; etc.). This study utilizes short-term dynamic panel models simply because cointegration and Granger-causality methods are beyond the scope of undergraduate econometric ability. The use of dynamic panel modelling is discussed in the Analytical Framework section of this paper.

As was aforementioned, results vary widely depending on the focus of researchers. The largest variations in results are where researchers are focused solely on OECD member countries versus solely on non-OECD member countries. Jakovac (2018) finds that research conducted on OECD member nations pertaining the causality question find mixed results supporting all four hypotheses. Research conducted on non-OECD member nations find evidence largely in support of the growth hypothesis and the feedback hypothesis. Some evidence has been found for the conservation hypothesis for non-OECD member nations, but such evidence can fail to take into account political considerations, like Binh (2011) studying Vietnam in the post-Vietnam War period and Shuyn and Donghu (2011) studying China through reconstruction and the post-Mao era.

Binh (2011) studied the relationship between per capita GDP and per capita energy consumption in Vietnam using cointegration and Granger-causality tests using a log-log model. Binh (2011) conducted his study using data from the post-Vietnam War era in Vietnam from 1976 until 2010. He found evidence to support the conservation hypothesis and posits that energy consumption is not a limiting factor for economic growth in Vietnam. The logarithm of per capita energy consumption and the logarithm of per capita GDP in Vietnam were found to be cointegrated for the time period. Additionally, unidirectional causality was discovered to run from the logarithm of per capita GDP growth and the logarithm of per capita energy consumption. In doing this study, Binh (2011) hoped to demonstrate how energy efficiency is not only possible but can be favorable, supporting the neoclassical perspective of technological progress. However, Binh (2011) fails to take into account any political considerations in his study for a country which was unified in 1976, but was in a state of disarray for nearly a decade following. While Binh (2011) is focused on solely the relationship between energy use and economic output, to not account for the political and social climate can lead to poorly informed policy decisions. The country became unified under communist rule in 1976 and the South Vietnamese became systemically oppressed, and many times wrongly executed. The communist government conducted collectivism campaigns and much of the economic growth was state-owned, outside the realm of control of the Vietnamese people. The experience of Vietnam in the post-Vietnam War era is unique in the world. As such, it can be a stretch to apply the findings of Binh (2011) in many policy debates.

Shuyn and Donghu (2011) analyzed the causality between energy consumption and economic growth in China to demonstrate energy consumption as a necessary element for economic development and economic growth. They find evidence supporting the feedback hypothesis. In using a Chinese provincial data from the National Bureau of Statistics of China to form a panel data set spanning the time period between 1985 and 2007, they find a bi-directional causality between energy consumption and economic growth. Shuyn and Donghu (2011) use provincial GDP change as their indicator of economic progress. They find that a 1 per cent increase in energy consumption was associated with an increase in real GDP by 0.57 per cent. Furthermore, they find that cointegration was present between real GDP, energy consumption, labor force, and real gross fixed capital. Like Binh (2011), Shuyn and Donghu (2011) do not take into account any political considerations that may explain changes in GDP. One such political consideration is the opening of China's economy on the international level that officially began in the post-Mao era. Beginning in 1982, China began the process of becoming a more open economy and expanding its trade relations globally. For a comprehensive study of the economic impacts regarding energy usage, it would be important to consider not just other economic considerations, but political considerations as well.

In addition to political considerations, neither Binh (2011) nor Shuyn and Donghu (2011) account for the role that increased energy accessibility might have played in changes in energy use and economic output over time. Energy access and energy poverty are measured in a number of ways, whether it be energy access rates or a defined level of energy usage and accessibility. Some studies use the raw number of energy consumption as a proxy for energy accessibility. For instance, Ouedraogo (2013) appears to posit that energy access and energy consumption are one and the same. This understanding is derived from a notion that measured levels of energy consumption are those which come from modern energy service providers, and are thus a good indicator of accessibility per the International Energy Agency definition for energy access. While this can be true, energy consumption data does not indicate anything about the number of people with or without access to energy or how those rates change over time.

Despite this, Ouedraogo (2013) does conduct a very comprehensive study of energy use in relation to economic growth in the African context. Her studied period spans from 1980 to 2008 and includes nations from the Economic Community of Western African States (ECOWAS). At the beginning of the time frame being analyzed, modern energy services and access to modern fuels was incredibly low and made up less than 20 per cent of total energy consumption in the region. The study thus aims to understand the long-run relationship that exists between energy access and economic growth in the case of ECOWAS. While noting that generally access to modern fuels was incredibly low, no numbers or rates of access are included. Energy consumption is used to proxy energy access, which makes it difficult to truly understand the situation and extent to which the results of this study can be used in policy debates. In studying both the short-term and long-term, Ouedraogo (2013) finds unidirectional causality from GDP to energy consumption in the short-run and unidirectional causality from energy consumption to GDP growth in the long-run. The short-run findings are particularly interesting as they can assessed against the model used in this analysis.

Ouedraogo (2013) highlights a number of factors which can explain finding evidence for the conservation hypothesis in the short-run as well as a number of factors which can explain finding evidence for the growth hypothesis in the long-run. In the short-run, economic progress can help to create increased demand for energy availability and consumption. Per capita income increases and economic growth also allows for households and organizations to spend new income on modern energy services, thereby increasing energy consumption through increased energy access. The improved access leads to high levels of economic growth in the long-run, as high levels of energy consumption in the case of ECOWAS proves to be an input for high economic growth levels.

While sectoral impacts are not studied in this paper, Nugraha and Osman (2017) approached the question of the economic impacts of increased energy access and usage in the Indonesian sectoral context. Their goal was to study the impact on economic productivity of increased energy access and usage in three developmental economic sectors in Indonesia (agriculture, services, industry). Yet, similar to Ouedraogo (2013), Nugraha and Osman (2017) do not actually use energy access metric or consider energy accessibility rates. Instead, they also use energy consumption as a sort of proxy for understanding changes in energy access. The relevance of the Nugraha and Osman (2017) study to the question in consideration in this paper is the importance of taking into account more considerations beyond overall input and output, beyond what is included in the basic production functions used by neoclassical and ecological economists.

Notwithstanding, in the short-run, Nugraha and Osman (2017) found a bidirectional relationship between energy and economic growth in the services sector. In the long-run, they find the same bidirectional relationship in the industrial sector. This evidence supports the feedback hypothesis and indicates that energy consumption and economic growth are interdependent elements of the Indonesian economy and its sectors. Differences did arise among the sectors that indicate that countries may need to develop different energy policies to cater to specific sectors. For example, in the services sector and the agriculture sector, evidence was discovered to support the conservation hypothesis in the long-run. Nugraha and Osman (2017) noted that such evidence indicates a need for sustainable energy strategies (energy efficiency, renewable energy development) to meet increasing energy demand.

The current energy economics literature analyzing energy consumption's effects on economic output and vice versa leaves quite some room for new contributions. There is a whole absence of any political considerations. Including such considerations could have possibly affected the estimations and evidence found by Binh (2011) and Shuyn and Donghu (2011), as well as possibly Ouedraogo (2013). Additional considerations for energy accessibility would also help to paint a better picture of whether increased energy consumption occurs alongside or independent of changes in energy accessibility as a factor in increased energy demand. Additionally important to note is the lack of research which focuses solely on the ASEAN Plus Six region and the future Regional Comprehensive Economic Partnership region which includes the nations of the ASEAN Plus Six coalition. This lack of research in the region spans across the energy efficiency and renewable energy use aspects in questions as well.

iv. Energy Efficiency and Economic Growth Nexus

Energy efficiency is regarded widely as one of the key mechanisms through which the effects of climate change ca be mitigated. Over 80 per cent of all greenhouse gas emissions come from fossil fuel energy consumption (Chang and Shieh, 2017). Energy efficiency means using less energy as an input for households and businesses to produce the same outputs. In addition to consuming fewer energy resources, energy efficiency is viewed as taking measures which allow for the reduced consumption of energy resources. Examples of such measures are increased home insulation or new industrial technologies which require less fuels.

The energy efficiency-economic growth nexus has comparatively received the least amount of attention in the context of the field of the economics of development. The empirical evidence on the subject is far behind current existing literature concerning energy consumption. Sinha (2015) attempted to change this by modelling energy efficiency and economic growth. Sinha (2015) focused on India between 1971-2010. Energy waste reduction is used as a proxy for changes in energy efficiency. The argument made by Sinha (2015) is that reductions in energy waste are a good indicator for increased energy efficiency levels when energy consumption stays the same or is increasing. However, if metrics for energy use per unit of economic output are available, why use energy waste as an indicator for energy efficiency. Using energy waste as an indicator only works when data for energy consumption is used alongside total energy waste metrics. Utilizing a metric for total energy required per one unit of economic output, as was done by Rajbhandari and Zhang (2017), can arguably create an easier and potentially better understanding as to how efficiently energy is used and the impact of energy efficiency on economic output. Energy used per one unit of economic output is also known as energy intensity, with less energy intense economies typically being more energy efficient economies (Rajbhandari & Zhang, 2017).

Sinha (2015) found a unidirectional causality from economic growth to energy waste (energy efficiency). Furthermore, this unidirectional causality was found to exist both in the short-run and in the long-run, supporting the conservation hypothesis. Sinha (2015) acknowledged how India’s rapid increase in fossil fuel consumption between 1971 and 2010 was not uncommon in the case of a developing nation. Larger investments and more employment come as greater priority than the maintenance of the environment. However, he believes that the results of his study indicate that a sustainable growth objective in India cannot be attained without significant energy efficiency objectives and management despite including zero political or accessibility considerations.

Rajbhandari and Zhang (2017) studied the energy efficiency-economic growth nexus based on a multinational and multisectoral panel dataset involving high-income and middle-income countries. In using a data set spanning from 1978 until 2012, Rajbhandari and Zhang (2017) found evidence supporting both the feedback and conservation hypotheses. Energy intensity was used as the proxy for energy efficiency. Long-run causalities were discovered for high-income nations running from economic growth to lower energy intensity, supporting the conservation hypothesis. For middle-income economies, evidence was discovered that supports the feedback hypothesis. Bidirectionality was present between lower energy intensity and GDP growth. The results of this study imply that for middle-income and high-income countries, increased energy efficiency measures actually lead to long-run economic growth. The results of this study are even more profound because of their consideration for the macroeconomic and sectoral structures of each of the 56 economies studied, further solidifying the argument that the analysis of any economic output and energy relationship must consider exogenous factors as well as any endogenous factors.

Similar to energy economics literature analyzing energy consumption-economic output nexus, political conditions and energy accessibility are left unconsidered. It would be interesting to see how energy accessibility affected energy efficiency in the study by Sinha (2015). In 1990, India had a 43.3 per cent energy access rate, increasing to 84.5 per cent by 2016 (World Bank Global Tracking Framework). The data set used by Rajbhandari and Zhang (2017) includes nations which have undergone significant political transformation, such as Russia, Slovenia, Croatia, Georgia, and Albania. Analyzing economic output and income for these nations would be heavily influenced by their political climates and should certainly be considered in the creation of empirical models.

v. Renewable Energy Consumption and Economic Growth Nexus

This stream of literature is comparatively new in the realm of energy economics as compared with the energy consumption and energy efficiency analyses. As a result, the number of studies available to review the renewable energy consumption and economic growth linkage is much more limited than the previous linkages discussed. In reviewing, the focus has largely been on finding cases similar to those already discussed. What is immediately clear in reviewing Apergis and Payne (2009), Tucgu, Ozturk and Aslan (2012), Inglesi-Lotz (2015), and Ntanos et al. (2018) is how much room there is for contribution and new studies, not dissimilar to what has been previously discussed.

Apergis and Payne (2009) examined this nexus by studying a panel dataset of twenty OECD countries over the period of 1985 to 2005. Unsurprisingly, cointegration tests indicated a long-run equilibrium relationship between renewable energy consumption, real GDP growth, real gross fixed capital formation, and labor force considerations. In going a step further than is usual in studying energy economy, Apergis and Payne (2009) examined more than the causality between renewable energy consumption and economic growth. They tested for the causalities between renewable energy consumption and real gross fixed capital and the labor force as economic indicators. Typically, real gross fixed capital accumulation and labor force size are used as indicators for capital and labor when studying causality using production function relationships like most neoclassical and ecological economists do.

Apergis and Payne (2009) found bidirectional causalities for total renewable energy consumption and real GDP growth, with additional bidirectional causalities found between renewable energy consumption and the labor force as well as renewable energy consumption and real gross fixed capital. These results not only highlight the importance of having renewable energy sources on the national energy portfolio, but point to the potential feasibility of renewable energy as a reliable energy source that can drive economic growth.

Tucgu, Ozturk and Aslan (2012) investigated renewable and non-renewable energy consumption and economic growth for G7 countries using causality methods as well as the classic production function including energy and an expanded production function including energy as well as considerations for technological progress with a research and development variable. One might argue that the expanded production function including technological progress considerations does little to change the classic production function, which assumes technological progress as being required for sustained economic growth. Tucgu, Ozturk and Aslan (2012) found only one significant causal relationship to exist between non-renewable energy consumption and economic growth using the expanded production function, in Japan. Less significant evidence from the expanded production function supported the feedback hypothesis in England and Japan and supported the conservation hypothesis in Germany. When using the classical production functions, evidence for the feedback hypothesis was found in all countries for both renewable and non-renewable consumption in relation to economic growth. These results offer little insight in contribution to previous literature due to their lack of significance, and do little to explore the expansion of the production function for additional considerations. However, these results leave room for further exploration into expanded production functions such as the ones used in to study the question of this paper.

Inglesi-Lotz (2015) and Ntanos et al. (2018) had very different approaches in studying the renewable energy consumption and economic output relationship. Aimed to determine what impact renewable energy consumption had on economic welfare across all OECD nations for the twenty-year time period spanning 1990 to 2010, Inglesi-Lotz (2015) determined a long-run equilibrium relationship between real GDP or real GDP per capita, total renewable energy consumption or share of total renewable energy consumption, real gross fixed capital formation, employment and the research and development expenditures of all of the OECD countries. In realizing a long-run relationship among each of these variables, it is important to further understand their relationship in the short-term and medium-term, which Inglesi-Lotz (2015) does not study. In addition, Inglesi-Lotz (2015) did not attempt to determine causality amongst the studied variables. Inglesi-Lotz (2015) does estimate that a 1 per cent increase in renewable energy consumption will increase GDP of the OECD countries by 0.105 per cent. Inglesi-Lotz (2015) also estimated that a 1 per cent increase in the share of renewable energy consumption as a proportion of a nation's total energy consumption increased GDP by 0.089 per cent.

Ntanos et al. (2018), rather than attempting to determine causality, they attempted to determine what types of correlation exists, if any, between energy consumption deriving from renewable energy sources, and countries' economic growth expressed as GDP per capita. Ntanos et a. (2018) notes what has already been determined that in most studies done on the renewable energy consumption and economic growth nexus, GDP is the common dependent variable, while energy consumption, gross fixed capital formation, and labor force are usually the only examined predictors. An argument can be made that while yes, it is important to determine if energy should be considered a part of the production function, a production function analysis should consider other factors which could affect estimations. The analysis done by Ntanos et al. (2018) suggests a correlation exists between change in GDP and both renewable energy consumption and non-renewable energy consumption. Interestingly, the same analysis discovered a higher correlation between renewable energy consumption and the economic growth of nations with a higher GDP than those nations with a lower GDP.

III. Analytical Framework

This paper utilizes a multivariate panel dataset to run dynamic model regressions in order to determine what implied causalities exist, if any, between economic growth and energy access, energy efficiency, and renewable energy consumption. Ordinary least squares (OLS) and generalized least squares (GLS) models do not allow for the determination of causality, but significant correlation and further hypothesis testing can imply that causality may exist and can be determined through further research. Using this type of model allows us to understand the short-term instantaneous and one-year lagged effects of the variables in question. The estimates produced by the dynamic panel models will also provide an understanding of the correlation between each of the variables in question, and will provide a basis of understanding for more efficient analysis beyond the scope of what capable undergraduate students can do econometrically. Typically, in order to answer the question this paper is concerned with, it is not only important to determine whether there is causality between variables, but also that the variables in question move together over time. This is usually done by running tests for cointegration prior to determining causality. Running such tests require vector autoregression models which are beyond the capacity of understanding for undergraduate econometrics.

The focus of this study is primarily devoted to determining the cross-country effects and estimating implied direction of causality for the period 1990-2015 between economic output and energy consumption, energy efficiency, and renewable energy consumption.

i. Area of Study

The geographical area of focus for this study will be the ASEAN Plus Six nations (including observers). ASEAN is an intergovernmental organization made up of ten core Southeast Asian nations. The ASEAN partnership promotes intergovernmental cooperation with the goal of fostering healthy economic, political, social, and military relationships among member nations as well as the larger Asian-Pacific region. Improved and developed relations between ASEAN and India, China, Japan, Australia, South Korea, and New Zealand has resulted in what has come to be known as ASEAN Plus Six. The ASEAN Plus Six nations comprise the proposed Regional Comprehensive Economic Partnership across Asia.

Removed from the data set due to lack of available metrics and statistics are Brunei, Cambodia, Burma, Laos, and the observer nations Papua New Guinea and Timor-Leste. This leaves the nations of Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam as the core ASEAN nations being studied. Observer nations include China, South Korea, Japan, India, Australia, and New Zealand. ASEAN nations have seen significant energy development and economic progress over the time period in question. However, there is little attention devoted to studying the region's economic growth and energy development nexus, and even less attention devoted to the relationships between economic output and energy efficiency and the renewable energy share of total final energy consumption. In addition, the selection of nations in the panel data set include a variety of systems of government. Nations in this study vary from democratic (i.e. New Zealand, Australia, Philippines) to autocratic (i.e. China, Vietnam). The nations of the ASEAN Plus Six region have experienced incredible transformations in energy accessibility rates, with some nations accomplishing 100 per cent energy accessibility within the time frame of this study.

ii. Data

This study uses annual data from the period 1990-2015 drawn from the World Bank open database, the United Nations Development Programme, and from CEIC Data. The data for this study is compiled from each of these sources into a single multivariate panel data set. The World Bank open database includes the Global Tracking Framework (GTF). The World Bank GTF helps the World Bank measures how the world is progressing towards the Sustainable Energy for All objectives put. Included in the database are measures for rates of energy access, total final energy consumption, energy efficiency, renewable energy consumption as a share of total final energy consumption. Each of these measures are utilized to answer the research question.

The World Bank Group also compiles macroeconomic indicators and country characteristic indicators which focus on overall economic output as well as sectoral outputs. In addition, data is available for labor force considerations, purchasing power, price indices, human development, climate, and education. World Bank Open Data is used for each nation's GDP from year to year, which serves as the economic indicator. Population and labor force size data are also drawn from the World Bank Open Data database. Gross fixed capital formation data was also able to be drawn from the World Bank. To fill in the gaps of what was not available at the World Bank, data was drawn from CEIC Data's data archives. CEIC data was largely used to fill the gaps in data from other sources for metrics on output, gross fixed capital formation, and labor force size. Data was also drawn from the Center for Systemic Peace and the United Nations Development Programme for government and institutional considerations.

iii. Variables and Theoretical Framework

To answer the question this paper is concerned with, it is important to understand the variables included in each model and the theoretical framework which justifies their inclusion. The purpose is to determine an answer to the question of what types of causalities exist, if any, between economic growth and energy consumption, energy efficiency, and renewable energy consumption while considering for political climate and energy accessibility. Our model allows us to estimate the size of impact for each variable on the selected dependent variable as well as estimate and test for the direction of causality, if there is causality implied. Studying how economic growth and different types of energy use affect one another and perhaps move together absolutely requires more than just economic output and energy use indicators. The variables in this study include macroeconomic measures, country characteristics such as population, national and human development scores, country identifier dummies, and energy use and energy progress indicators.

The gross domestic product (GDP) of each country is measured in 2010 U.S. dollars. This variable (GDP) serves as the indicator of economic change from year to year for each country. Economic output is the dependent variable when assessing for the effects different types of energy consumption have on economic changes for each country. It is also used as an independent variable for assessing the effect of economic output on energy usage among other considerations. Falling in line with both neoclassical economic theory and ecological economic theory, other macroeconomic variables include gross fixed capital formation in 2010 U.S. dollars (KF) and the size of labor force (LAB). Natural logs of each macroeconomic variable are used in this study to better analyze the relationships in questions as ratios rather than as differences.

The World Bank's Global Tracking Framework tracks country level indicators for total energy consumption, energy access, renewable energy, and energy efficiency. Energy access (EACC) is measured as a percentage of total population with access to modern energy sources. Studies intended to inform how to best strengthen global health and educational services have approached the question using percentages of population with access (Adair-Rohani et al., 2013).

Others have used total energy consumption as a proxy for greater energy access (Ouedraogo, 2013). However, greater energy consumption does not necessarily mean a reduction in energy poverty and actually fails to provide insight as to whether energy poverty was actually reduced (Pachauri & Spreng, 2004). Given the lack of literature focusing on considering for and controlling for energy access, it is important to now include energy accessibility considerations to not only contribute to the energy economics literature, but to also provide a foundation upon which this research can develop.

Total final primary energy consumption (TFEC) is the indicator for the amount of all primary energy consumed in a nation for a given year, measured in terajoules (TJ). Per the International Energy Agency, 1 terajoule is equal to 163.5 barrels of oil equivalent. Binh (2011), Shuyn and Donghu (2011), and Ouedraogo (2013) all used measures of total final primary energy consumption as their energy indicator in their analyses of the energy consumption-economic growth nexus.

Energy efficiency (EEFF) is a metric for energy intensity which is measured as the units of energy per unit of GDP. In other words, energy intensity is measured as how many terajoule's of energy are used to produce one unit of economic output. The World Bank's Global Tracking Framework creates the energy efficiency metric as the ratio between energy supply and GDP measured at the purchasing power parity of the nation. Using energy intensity as a proxy for energy efficiency has been done by Sinha (2015) and Rajbhandari and Zhang (2017).

This study uses the renewable energy share of total final energy consumption (RESTFEC) to account for increases in the use of renewable energy as the primary energy source. The larger portion of studies analyzing the linkages between economic growth and renewable energy use measure for total renewable energy consumption. Similar to the logic of Inglesi-Lotz (2015), this study has elected to analyze the impact of renewable energy share of total final energy consumption in order to determine the influence of increased or decreased renewable energy in the total energy consumption mix.

In order to take into account governmental and institutional considerations, this study uses the Polity IV scoring system from the Center for Systemic Peace. The Polity Scoring system focuses specifically on the qualities of democratic and autocratic authority in governing institutions rather than on the form of government for each nation. Scores are generated ranging from -10 (fully autocratic) to 10 (fully democratic). The types of institutions which make up a government and their stability can have serious implications on the energy policies and energy outcomes of a nation. Understanding the institutional make-up of a state can aid in creating an understanding of empirical results. As argued by Fix (2018), theories of institutional size provide an explanation for how the types of institutions which make up a government and their stability can have serious implications on the energy policies and energy outcomes of a nation. Increases in energy use often go along with or require increases in the scale of institutional organization. Summary statistics and unit descriptions are included in Table 2 found in the Appendix.

Neoclassical economists have long maintained the importance of capital and labor in an economy, but discount the importance of energy (Stern, 2004; Dogan & Deger, 2018). On the other hand, ecological economists emphasize the importance of energy as an input alongside capital and labor (Stern, 2004). The basis of understanding that is used for this study is derived from ecological perspective; the pro-energy approach and the pro-energy production function. Early studies by Hamilton (1983) and Burbridge and Harrison (1984) were able to discern the importance of energy alongside capital and labor. As argued by Ghali and Sakka (2004), if the amount of energy used in an economy increases, so then does economic output. Under this assumption, the production function for an economy can be written as (using the abbreviations for variables in this study:

$$Q = f(KF, LAB, TFEC),$$

where Q is economic output, KF is gross fixed capital formation, LAB is labor force size, and TFEC is total final energy consumption. This theoretical understanding provides the basis for the empirical framework. The use of gross fixed capital formation as a proxy for capital in an economy is justified by Narayan and Smyth (2008), Soytas and Sari (2006), and Lee (2005). This justification is based on the notion that gross fixed capital formation is a reliable proxy for changes in a nation's capital stock. Labor force size is commonly used in the energy economics literature as an indicator for labor or as a labor variable. This is justified by the works of Binh (2011), Shuyn and Donghu (2011), and Ouedraogo (2013), and Chang and Shieh (2017). The production function has long been a mainstream concept for describing the output obtainable for given inputs, and is a concept often taught early on in undergraduate study and harkened back to throughout the course of pursuing an undergraduate economic degree.

iv. Analytical Model and Method

While much of the analysis conducted in the realm of energy economics uses cointegration and causality panel data methods, this study will be able to benefit from using standard OLS and GLS models. It is understood that standard OLS and GLS can yield a biased estimate of what the true causal effect is, but the decision to use standard OLS and GLS models and testing is the result of time constraints, constraints in econometric understanding at levels beyond undergraduate econometrics, and technology constraints.

The main variables in question are economic output, energy access, energy efficiency, and renewable energy share of total final energy consumption. Each of the energy variables can be estimated in relation to economic output individually. For example, the impact of total final energy consumption on economic output can be measured as economic output as a function of total final energy consumption, gross fixed capital formation, and labor force size while controlling for the strength of institutions, energy access, and the population of nations included in the study:

$$GDP = f(\,TFEC, POL, POP, KF, LAB, EACC) \quad .$$

A standard OLS model analyzing this relationship would take form similar to the following example:

$$Y_{\ln(GDP)} = \beta_0 + \beta 1_{TFEC} + \beta 2_{POL} + \beta 3_{\ln(POP)} + \beta 4_{\ln(KF)} +$$
$$\beta 5_{\ln(LAB)} + \beta 6_{EACC} + \varepsilon_i \quad ,$$

where each variable is in natural logarithm form to determine the size of impacts as their percentage change, save for our Polity score variable, and renewable energy share of total final energy consumption and energy access variables. Energy access is already measured in percentage units so there is no need for natural log transformation. The same goes for the renewable energy share variable. Similar equations can be written where the variable for total final primary energy consumption is substituted by either the variable for energy efficiency or the variable for renewable energy share of total final energy consumption.

Using dynamic models is advantageous under the assumption that current values are influenced by past values. In other words, economic output for a given year is not instantaneous and is influenced by previous year outputs and energy usage. A simple dynamic model can take the following form:

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 X_t + \beta_3 X_{t-1} + \varepsilon_t \quad .$$

The simplest dynamic model is really an equation in which the current value of the dependent variable is a function of current values of a main independent value, a lagged value of a main independent variable, and a lagged value of the dependent variable itself.

To answer the question posed in this study, the basic lagged identification equation is transformed as a log-log function so as to befit the needs of this analysis:

$$\textit{Reg. 3:}\ \ ln(GDP)_t = \beta_0 + \ \beta_1 ln(GDP)_{t-1} + \beta_2 \ln(EEFF)_t + \beta_3 \ln(EEFF)_{t-1} +$$

$$\beta_4 POL_t + \ \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 DACC_t + \varepsilon_t \quad ,$$

where past values of economic output and past and current values of energy efficiency are evaluated alongside current values of institutional scores, population, labor, and capital for their impact on current economic output. The written forms of each regression can be found in the Appendix. Hypothesis testing will help us to determine overall significance. After conducting Hausman tests for robustness and determining between fixed effects and random effects, F-tests are used to test for whether the estimations for the coefficients on current and past energy are significantly greater than zero. Such a hypothesis would take the following form:

$$H_O\!: \beta_2 = \ \beta_3 = 0$$

$$H_A\!:\ \beta_2 \neq \ \beta_3 \neq 0$$

The null hypothesis being that each of the estimates are not significantly greater than zero, with the alternative being that both of the estimates are significantly greater than zero. If current energy efficiency and past energy efficiency are significantly greater than zero, we can then say that energy efficiency has biased causation effects on economic output. In order to determine the direction of causality, we can evaluate current energy efficiency against current and past economic output. For example:

$$Reg.\ 4\text{: } \ln(EEFF)_t = \beta_0 + \beta_1 \ln(EEFF)_{t-1} + \beta_2 \ln(GDP)_t + \beta_3 \ln(GDP)_{t-1} + \beta_4 POL_t + \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 DACC_t + \varepsilon_t \quad ,$$

where past values of energy efficiency and past and current values of economic output are evaluated alongside current values of institutional scores, population, labor, and capital for their impact on current economic output. The same method can be used for examining the economic output and total final primary energy consumption relationship and the economic output and renewable energy share of total final energy consumption. The equations for those estimations are the same as above, substituting for the energy efficiency and its lag.

v. Expectations

A number of very general trends exist for energy use and economic output throughout the region. Throughout the ASEAN Plus Six region, GDP has grown steadily between 1990 and 2015, as has total final primary energy consumption (See figures 1 & 2 in Appendix). All other nations held steady over time in their economic output and total final primary energy consumption. In considering these trends, acknowledging China's influence on aggregates in the region, and in examining the results of Shuyn and Donghu (2011), the expectation is that evidence will support the feedback hypothesis between economic output and total final primary energy consumption throughout the region. As such, the estimations on the energy consumption variables in Reg. 1 and the GDP variables in Reg. 2 are all expected to be significant and significantly greater than zero.

As a whole, the ASEAN Plus Region is becoming more energy efficient as GDP increases, despite increases in total energy consumption. Each nation in the region, and especially China, was more energy efficient in 2015 than they were in 1990 (Figures 3 and 4 in Appendix). However, similar to the trends in economic output and total final energy consumption, energy efficiency among many nations has changed very little, whereas China has become notably more energy efficient. Many nations in the region started off being significantly less energy intense than China was in 1990, whereas now most nations are on par with China's overall energy efficiency. Similar to Sinha (2015) and Rajbhandari and Zhang (2017), the expectation is that unidirectional causality exists running from economic output to energy efficiency, supporting the neoclassical conservation hypothesis, where only the estimations on GDP variables in Reg. 4 are significant and significantly greater than zero.

There has been an overall trend of reduced renewable energy share of total final energy production between 1990 and 2015 among the 12 studied nations. The overall share of renewable energy in the total final energy mix has decreased regionally from over 30 per cent in 1990 to just under 20 per cent in 2015. This trend runs opposite the increasing trends in economic output, total final energy consumption, and overall energy efficiency. What is expected, however, is that an absence of causality will exist between economic output and the renewable energy share of total final energy production. This would be in line with the findings of Tucgu, Ozturk and Aslan (2012) and opposite of those by Apergis and Payne (2009). Apergis and Payne (2009) examined solely the long-run, finding a long-run causality relationship.

IV. Results and Discussion

In order to determine the correlations and implied causalities between energy variables and economic growth, as well as the direction of said causalities, this study utilizes dynamic panel models and hypothesis testing on the estimated coefficients produced by the dynamic models. The analyzed period is between 1990 and 2015, meaning that the time dimension of the panel used is 26. The analysis is done using Stata created by StataCorp. All variables used in each model are logarithmic in form. For example, ln(GDP) represents the log transformation of GDP measured in constant 2010 U.S. dollars. Additionally, GDP1 represents a log transformation of GDP measured in constant 2010 U.S. dollars lagged one year. The same methods of log transformation are done with each variable except for the variables which represent the renewable share of total final energy consumption and its lag, the Polity IV scores of each country for each year, and the variable for energy access achievement. Log transformation and then lagging one year is done only for each of the energy related variables and for the economic output indicator GDP.

Per Jakovac (2018), causalities can be categorized in four ways: i) the growth hypothesis (unidirectional causality from energy use to economic change), ii) the conservation hypothesis (unidirectional causality from economic change to energy use), iii) the neutrality hypothesis (absence of causality), and iv) the feedback hypothesis (bidirectional causality). These four causality hypotheses can be transposed to apply to the relationships between economic output and energy efficiency and renewable energy use (Apergis & Payne (2009); Tucgu, Ozturk & Aslan (2012); Sinha (2015)).

Results of the six main regressions and their robustness checks can be found in Table 3 in the Appendix. Reg. 1 and Reg. 2 represent the pair of regressions analyzing the relationship between economic output and total final primary energy consumption across the twelve nations being analyzed in this study. Reg. 3 and 4 analyze the relationship between changes in economic output and changes in energy efficiency. Lastly, Reg. 5 and 6 look at the relationship between changes in economic output and changes in the renewable energy share of total final primary energy use. Hausman tests indicated that the fixed effects model is efficient for each of the dynamic panel models used in this study. The results of these robustness checks can also be found in the Appendix (Tables 5-10). The null hypothesis of the Hausman test is that the random effects model is preferred when both random effects and fixed effects are efficient estimators, whereas the alternative hypothesis implies the fixed effects model should be chosen as random effects is not an efficient estimator. A p-value less than 0.05 indicates that the coefficient estimates from the fixed effects model are preferred.

i. Energy Consumption and Economic Output

The expected relationship between economic output and energy consumption is one that is highly correlated and indicates an implied bidirectional causality. As can be discerned from the results of Reg. 1 and Reg. 2, total final primary energy consumption appears to be correlated with GDP and GDP appears to be correlated with total final energy consumption. Per Reg. 1, a 1 per cent change in the current year total final primary energy consumption significantly raises GDP 0.320 per cent in the current year. Interestingly, a 1 per cent change in the previous year total final energy consumption significantly reduces GDP by 0.321 per cent in the current year. Additionally, previous year GDP, population, and gross fixed capital formation were also found to significantly affect GDP alongside current and lagged total final primary energy consumption. Important to note is the size of the impact of previous year GDP on current year GDP, estimated to be a positive correlation where a 1 percent increase in previous year GDP increases current year GDP by 0.944 per cent. It is not surprising to see that gross fixed capital formation and GDP have a significant positive correlation. The accumulation of capital over a time period should typically serve to increase GDP regardless of where that capital is flowing to.

Estimates produced by Reg. 2 indicated that current and previous year GDP significantly impacted current year total final energy consumption. A 1 per cent change in the current year GDP significantly raises total final energy consumption 0.614 per cent while a 1 per cent change in previous year GDP decreases total final energy consumption by 0.586 per cent. No other variables in Reg. 2 returned significant estimates. Neither the political nor energy access considerations had any sort of empirical significance in either regression. For a region with varying regimes from democratic to autocratic, the lack of significance for political considerations is interesting. However, it could truly be that energy consumption rates are correlated with GDP and vice versa regardless of regime or political structure. The region has also seen some large transformations in energy accessibility. For example, India has improved from 43.3 per cent accessibility in 1990 to 84.5 per cent accessibility in 2015 and Vietnam has gone from 74 per cent accessibility in 1990 to achieving 100 per cent accessibility in the year 2015. As such, it was surprising to see that energy accessibility had no correlation with either GDP or total final energy consumption.

Hypothesis testing using F-tests indicates the estimated coefficients on total final energy consumption in Reg. 1 and on GDP in Reg. 2 to all be significantly be greater than zero. This indicates an implied short-run causal relationship in each direction running between GDP and total final primary energy consumption. This type of relationship was expected, and is in line with the short-term and long-term findings of Shuyn and Donghu (2011), and Nugraha and Osman (2017). This evidence supports the feedback hypothesis, suggesting an interdependent relationship between overall final energy consumption and economic output in terms of GDP. What is interesting, however, are the differences in effects between current and previous year estimates. Current year GDP is positively correlated with total final energy consumption whereas previous year GDP is negatively correlated. Current year total final energy consumption is positively correlated with GDP while previous year total final energy consumption negatively impacts GDP.

These significant relationships certainly raise more questions than answers, warranting further examination and study. There could be a few reasons for as to why the estimations returned as they did. It could very well be that the relationships are as they are estimated to be. An explanation for these interesting relationships possibly could be found at the country level. The majority of nations included in this study saw overwhelmingly little contemporaneous changes and very little long run change in their GDP and total final primary energy consumption. China and Indonesia stand out to the naked eye as having undergone notably larger changes in energy consumption rates and levels of economic output relative to other nations included in this study. This could mean that despite the large changes long-term for some nations, energy consumption and GDP are affecting one another positively in the current year, but are doing little to build upon previous year changes, resulting in the stagnation from year to year that can be seen graphically in Figures 1 and 2 found in the Appendix. This stagnation could be represented by the negative correlations found with previous year influences. As such there could be effects overwhelming enough to cause the estimate to turn out the way that they do. The ASEAN Plus Six region as a whole has been trending upwards in GDP and total final energy consumption, largely due to China's rapid growth. However, China's large growth does not appear to be enough to offset what appears to be a short-term growth stagnation across the region (long-run determinations would require a different empirical methodology).

There are certainly other factors that could be contributing to these interesting results, such as financial crises. The Asian and Oceania regions have experienced tumultuous crises beyond the dot-com bubble and the global financial crisis, most notably the 1997 Asian financial crisis and the 1990 Japanese asset price bubble burst. Each of these crises severely affected GDP rates throughout the region being studied and could have affected these results. Additional study should consider the potential influence of financial crises on GDP rates in relation to total final energy consumption.

ii. Energy Efficiency and Economic Output

The measurement utilized for energy efficiency in this study is energy intensity, meaning that a reduction in energy intensity is an increase in energy efficiency. As such, results can be interpreted as what would happen with either an increase in energy intensity by 1 per cent or a reduction in energy efficiency by 1 per cent, the former of which is used in this analysis.

Reg. 3 and Reg. 4 on the relationship between energy efficiency and economic output produced somewhat interesting results for correlation, but did not indicate any evidence of significant implied causalities. Estimates from Reg. 3 show that increased current year energy intensity is negatively correlated with GDP while previous year increases in energy intensity is positively correlated with GDP, similar to the estimates from Reg. 1 for total final energy consumption and economic output. A 1 per cent increase in current year energy intensity reduces GDP by 0.08 per cent while a 1 per cent increase in previous year energy intensity increases GDP by 0.07 per cent. These estimates imply that being more energy efficient will increase current year GDP but negatively impacts the following year GDP. However, when conducting F-tests the estimated coefficients on current year energy efficiency and previous year energy efficiency, it is discovered that neither estimated coefficient is significantly greater than zero. This eliminates any possibility of an implied causality in support of the growth hypothesis. It also implies that the coefficient estimates are not truly significantly larger than having no effect on economic output. The estimations in Reg. 3 show that declining energy use per unit of economic output is not having a significant effect on economic output. Similar to Reg. 1, previous year GDP has the largest significant correlation with current year GDP, where a 1 per cent increase in previous year GDP increases current year GDP by 0.926 per cent.

Reg. 4 showed that current and previous year GDP are correlated with current year energy efficiency. A 1 per cent increase in previous year GDP increases energy intensity (reduces energy efficiency) by 0.214 per cent while a 1 per cent increase in current year GDP reduces energy intensity (increases energy efficiency) by 0.243 per cent. This means that increases in previous year GDP result in less energy efficiency whereas increases in previous year GDP improve energy efficiency. Despite this, the estimated coefficients on current and previous year GDP were not found to be significantly greater than zero after hypothesis testing. Thus, GDP does not have any instantaneous or lagged effect on changes in energy efficiency in the ASEAN Plus Six region. What was not surprising to see in Reg. 4 was the impact of increased labor force size on energy efficiency. A 1 per cent increase in labor force size significantly increased energy intensity (reduced energy efficiency) by 0.382 per cent. More workers could indicate increased production which would require more energy to create output. Additionally not surprising was a significant effect on population size, where a 1 per cent increase in a nation's population reduced energy intensity (increased energy efficiency) by 0.671 per cent. An explanation for this could be that increased population size requires increased energy efficiency so as to accommodate for more people. The notion for accommodating for more people by using energy more efficiently across the region would need further study to determine true correlation.

The tested coefficients on energy efficiency and economic output in Reg. 3 and Reg. 4 respectively were not significantly greater than zero, thus there is an absence of implied causality between economic output and energy efficiency. It cannot be said that energy efficiency does not aid or hinder economic output nor does economic output increase or decrease energy efficiency. These results were not what was expected to be discovered. The expectation was that evidence would support an implied unidirectional causation running from economic output to energy efficiency, similar to the findings of Sinha (2015) and Rajbhandari and Zhang (2017). The lack of implied causality in this study could be due to a few reasons. It could be that there just isn't any short-term relationship between changes in energy efficiency and economic output. The whole region has increased their energy use as well as having become more energy efficient (Figure 3).

Other reasons for these results may be that the impact of becoming less energy intense is not enough to significantly change GDP and dwarfs in comparison to other effects. It may also be because either the nations included in this study were already very energy efficient in 1990 and thus saw little improvement, or because nations included in this were not very energy intense in 1990 and only became marginally less energy intense. Figure 4 provides evidence that either countries being highly energy efficient in 1990 or not very energy intense in 1990 could be true. Over time, many nations, save for China, did not see large changes in their energy efficiency rates.

Similar to Reg. 1 and Reg. 2, political considerations were not found to have any significance. No correlation was discovered to run between political considerations and changes in energy efficiency. This indicates that regime structure, institutional makeup, or political climate has no effect on energy efficiency across the region. Energy accessibility rates also did not have any effect on energy efficiency outcomes. This is not entirely a surprise given that it could be increased energy efficiency which results in higher rates of energy access. Energy efficiency reduces the amount of energy needed per unit of economic output, which could mean that surplus energies could be directed towards those which do not have energy, although no research has yet to look at how energy efficiency and energy accessibility are related. Further research would be required to expound upon the idea of a relationship between energy access and energy efficiency.

It is true that a nationwide aggregate energy efficiency metric utilizing energy intensity, such as the metric used in this paper, may not paint the full picture and may not actually be the best indicator for energy efficiency, despite being the only readily available metric. Zhang (2013) found declining energy intensity for Eastern European and Central Asian countries during the early 2000s was largely due to smarter energy usage practices rather than energy intensity changes. This means that rather than adopting less energy intense technology and practices, the region Zhang

(2013) focused on could have pursued resource conservation practices. Thus, there may be no truly comprehensive aggregate of energy efficiency and it is better to study the energy efficiency and economic growth relationship considering different industries and sectors. Similar to Zhang (2013), the data used in this study also exhibits a declining trend of energy intensity. In further studying the energy efficiency and economic output for the ASEAN Plus Six region, it may be prudent to study further sectoral energy intensities and control for technological changes regarding energy consumption in the production process. It may also be prudent to control for the economic composition of economies as well. For example, China is a much more energy intense economy than Australia because China has a large manufacturing sector whereas Australia is more service focused. These differences in dominant sectors mean some economies will be much more energy intense than others, and should be accounted for in further research.

iii. Renewable Energy Consumption and Economic Output

An absence of any significant correlation or relationship was discovered through Reg. 5 and Reg. 6 for the relationship between economic output and the renewable energy share of total final energy consumption. These results are not surprising given what was expected and the trends relating to economic output and renewable energy consumption against total energy consumption (Figures 5 and 6). If anything, negative correlation should run from GDP to the renewable energy share of total final energy consumption. Overall, the region has seen a decrease in the share of renewable energies in the total final energy consumption mix. This could be due to factors inducing divestment or a greater increase in the usage of fossil fuels in relation to the usage of renewables. Given emphatic ASEAN efforts to increase the usage of renewables throughout its region, it seems more likely that the usage of non-renewables has increased more rapidly in relation to the usage of renewables. Further and slightly different research projects would be needed in order to determine the true cause of the decreasing share of renewables in the total final energy mix.

The effect of share of renewables in the total final energy mix on economic output was not significantly greater than zero. The estimated coefficients on the renewables variables in Reg. 5 were actually so close to zero that it is evident that zero correlation exists between the share of renewables in the total final energy mix and GDP when GDP is the dependent variables. Conversely in Reg. 6, however, GDP does appear to be correlated with the renewables share of total final primary energy usage. A 1 per cent increase in current year GDP significantly reduces the renewable share of total final energy consumption by -4.534 per cent. In addition, a 1 per cent increase in gross fixed capital formation significantly reduces the renewables share of total final energy consumption 1.313 per cent. Where gross fixed capital formation effects were uncorrelated with total final energy consumption and energy efficiency, gross fixed capital formation is negatively correlated with the renewable energy share of total final energy consumption. These estimates provide evidence to suggest that the region could be divesting away from renewables in the short-term, despite established ASEAN renewables targets. Additional research would need to be conducted to find the long-term investment effects. However, given that the impact of the lagged GDP variable in Reg. 6 was estimated to be almost the exact opposite of the current year GDP and that neither lagged nor current GDP were significantly greater than zero, we cannot say with any certainty that divestment may be occurring. What can be said is that there is zero implied short-term causality running either direction between economic output and the renewables share of total final energy consumption.

A closer look at individual country trends can provide some insight into the results obtained from these models (Figure 6). The renewable energy share of total final energy consumption sees marginal changes over time, albeit marginal decreases. The significant negative coefficient on current year renewable energy consumption does imply that increasing the share of renewables in the total final energy mix has a negative effect on GDP. However, as already mentioned, these results should be understood with a grain of salt as the estimates could not be proven to be significantly greater than zero. A better understanding of the economic impacts of renewable energy usage in the region could be derived from finding metrics for total renewable energy power consumption in terajoules, similar to the total final energy consumption metric used in this paper. If such a metric were freely available for the region, generating a renewables variable by taking the natural logarithm of the raw renewable energy consumption and using that generated variable in the same dynamic panel models should create for a better understanding of the true relationship between the renewable energy usage and economic output in the ASEAN Plus Six countries being studied.

An interesting result was the sizable impact of previous year renewable energy share of the total final energy mix on the current year renewable energy share of the total final energy mix. A 1 per cent increase in the previous year renewables share of the total final energy mix significantly increased the current year share by 0.910 per cent. This could indicate that in the short-term, there is a positive impact from one year to the next on the renewable share of total energy consumption. It could be that this instantaneous positive impact is overwhelmed by the instantaneous negative impacts of GDP and gross fixed capital formation on the share of renewables in the final energy mix.

The results produced by the dynamic panel models are in line with the findings of Tugcu, Ozturk, and Aslan (2012), who found an absence of a long-run causal relationship between economic output and renewable energy consumption. While this analysis is done in the short-term, the absence of any causal relationship is not surprising but does not give the full picture. What has become evident in analyzing the relationship between economic output and the renewable energy share of the total final energy mix is that in addition to using raw renewable energy consumption measurements, there is a need for some comparison studies to be done between the usage of renewables and the usage of non-renewables. Given the heightened importance of sustainable energy development worldwide, these results should be compared against and tested against the non-renewables share of the total final energy consumption mix.

Similar to the previous relationships, political considerations and energy accessibility did not have any correlation with GDP in Reg. 5 and energy efficiency in Reg. 6. These results are not particularly surprising. As this study is focused on the macroeconomic scale and in the short-term, there may be longer-term and microeconomic effects in this relationship that simply cannot be discerned using dynamic panel models. Many renewable technologies, especially in low energy access states, could be geared towards helping those without access to modern energy services on a public grid. An example of such a project would be a community solar micro-grid, which is a closed loop energy system. A micro-grid can essentially be thought of as an off-grid power project that is a standalone energy system that provides power to multiple households, employing a range of renewable energy options. A study analyzing the economic feasibility and impact of such projects as a means to improving energy access while controlling for political factors could potentially provide better insight into this particular relationship than this macro-level panel study could.

V. Conclusions and Policy Implications

This paper analyzes the linkages between economic output and total final energy consumption, energy efficiency, and the renewable energy share of total final energy consumption.

This analysis is conducted on twelve Southeast Asia and Oceania nations, all of which are a part of ASEAN Plus Six and the proposed Regional Comprehensive Economic Partnership. Understanding the relationships between economic output and energy as well as the theoretical basis for this study is derived from understandings of the production function in the neoclassical and ecological perspectives. Efficient energy consumption, sufficient access to energy resources, and diversity in energy resources are all cited by many national and international bodies as being essential for national and regional economies to develop and thrive. Such positions are of the ecological economic perspective. Jakovac (2018) classifies the types of causalities and relationships into four hypotheses. The feedback hypothesis and the growth hypothesis support the ecological view that energy is an essential input for economic output alongside capital and labor. The conservation and neutrality hypotheses support the neoclassical view of energy being an intermediate input for economic output supporting the primary inputs of capital and labor.

Correlation between total final primary energy consumption and GDP and vice versa implies the existence of potential bidirectional causality running between the variables. This evidence goes to support the the feedback hypothesis and the ecological perspective that the production function should include energy as a primary input for economic output. What was interesting about the evidence was the contradictory nature between instantaneous and lagged estimates. It could very well be that this is the nature of the energy consumption and economic output nexus for the ASEAN region, and there is evidence on trends which points to this being the case. Omitted variables and considerations may have also impacted the output of these models.

An absence of correlation and implied causality was discovered between GDP and energy efficiency, as well as between economic output and the renewable energy share of total final energy consumption. Such evidence supports the neutrality hypothesis for these relationships and the neoclassical perspective on the production function which excludes energy as a primary input alongside capital and labor. There may truly be no causal relationship between economic output and energy efficiency and economic output and renewable energy use in relation to total energy use. However, the lack of correlation among variables and of implied causality could be attributed to a number of factors such as, among others, the macroeconomic focus of this study, the conflicting trends among variables in question, or the use of short-term dynamic panel models for estimations.

These results of this study have policy implications regarding the future of the energy economy in the ASEAN region, especially as the countries of ASEAN Plus Six move towards creating the Regional Comprehensive Economic Partnership. Evidence presented by this study has the ability to inform policy makers within the intergovernmental body that is ASEAN itself. Creating new short-term policies and updating existing policies regarding energy use throughout the region should consider these results, especially the implication that increases in current year energy use is implied to positively effect current year GDP. Maximizing GDP could possibly be done by increasing overall energy use while increasing GDP could increase overall energy use. More research is required to understand exactly it is about more energy consumption that is driving higher GDP levels. Conversely, more research is required to understand how a period of increased GDP is increasing total final primary energy consumption.

The lack of established correlation between GDP and energy efficiency provides little policy insights but certainly prescribes future research. One such policy implication could be that energy efficiency has no bearing on GDP and GDP has no bearing on energy efficiency. However, previous research in other areas of the world concerning this relationship provide caution in accepting these results. Further research is required. Studies utilizing different metrics for energy efficiency and having a more sectoral or microeconomic approach may provide more policy information of the economic impacts of changes in energy efficiency.

A similar statement could be made for the relationship between GDP and the renewable energy share of total final energy consumption. The absence of correlation between GDP and the renewable energy share of total final energy consumption implies that GDP and the renewable energy share of total final energy consumption have no impact on one another whatsoever. This should not be understood as a true indicator of the relationship between economic output and renewables for the ASEAN region. Future research should absolutely look this relationship using different metrics for renewable energy. What is available to graduate and institutional researchers for metrics may provide for better estimations using the same models in this study. In addition, a sectoral or household level study may provide better policymaking information for ASEAN and the countries throughout the region.

Further study on these three relationships in the energy economics literature should absolutely use much more efficient methods and models than generalized least squares or ordinary least squares. Cointegration tests and Granger-causality tests are most commonly used to study the relationships between economic output and energy variables. The study of ASEAN Plus Six nations should absolutely benefit from more a more efficient understanding derived from using more advanced methodology. A multivariate panel data study does not come without its limitations and the results of this study should be understood with caution. Generalized least squares and ordinary least squares models cannot determine causality, only correlation. However, causalities can be implied through robust hypothesis testing for the estimated coefficients. These causalities could be further established with cointegration testing and using causality testing methods such as the Granger-causality method.

Additional limitations of this study have to do with the scope of this study. This study focuses on the short-term relationships among the variables in question for an entire region. The results of this study should not be used to justify any within-country relationships, or any relationship encompassing less than the entire region as a whole. Furthermore, the nations analyzed in this study do not include all of the nations which make up ASEAN Plus Six. Four nations were not able to be studied due to lack of available metrics and indicators. As such, the results of this study may not apply to the entire region as a whole, but to only the twelve nations which were studied. There may be additional unmeasured effects on the relationships in question coming from the nations which are not included in this study. This study does not conduct any within-study comparisons, which could be useful for providing additional information. Until further research is conducted, this results of this study should be viewed guardedly. The evidence presented here lays a useful foundation for future work and increased understanding of energy as an input for production.

VI. Appendix

Table 1: Summary Statistics

Variable	Obs	Units	Mean	SD	Min	Max
GDP	312	constant 2010 US$	1.12E+12	1.77E+12	2.95E+10	8.91E+12
TFEC	312	terajoules (TJ)	7272572	1.27E+07	129564.8	7.32E+07
EACC	312	% of total population with access to modern energy services	91.18673	13.28829	43.29156	100
EEFF	312	TJ/GDP	6.002244	2.252549	2.394856	21.17944
RESTFEC	312	% share of renewable energy in TFEC	23.09581	19.25848	0.194834	76.08164
POL	312	Polity scoring system	4.211538	6.536575	-7	10
POP	312	persons	2.53E+08	4.25E+08	3047132	1.37E+09
LAB	312	persons	1.24E+08	2.17E+08	1510932	7.87E+08
KF	308	constant 2010 US$	2.27E+11	3.90E+11	7.21E+09	1.62E+12

Table 2. Regression estimates for dynamic panel models

Variable	(1) GDP	(2) TFEC	(3) GDP	(4) EEFF	(5) GDP	(6) RESTFEC
GDP	-	0.614*** (8.23)	-	-0.243* (-2.34)	-	-4.534* (-2.16)
GDP1	0.944*** (71.30)	-0.586*** (-8.08)	0.926*** (86.62)	0.214* (2.18)	0.923*** (80.06)	4.413* (2.24)
TFEC	0.320*** (8.23)	-	-	-	-	-
TFEC1	-0.321*** (-8.24)	0.946*** (47.72)	-	-	-	-
EEFF	-	-	-0.080* (-2.34)	-	-	-
EEFF1	-	-	0.0687* (2.08)	0.846*** (29.92)	-	-
RESTFEC	-	-	-	-	-0.004* (-2.16)	-
RESTFEC1	-	-	-	-	0.003 (1.73)	0.910*** (57.09)
POL	0.001 (0.96)	0.000 (-0.53)	0.001 (0.86)	0.000 (0.17)	0.000 (0.11)	-0.061* (-2.52)
POP	0.175* (2.16)	0.000 (-0.53)	0.145 (1.49)	-0.671*** (-4.05)	0.198* (2.21)	-1.899 (-0.60)
LAB	-0.090 (-1.48)	-0.002 (-0.02)	-0.099 (-1.40)	0.382** (3.15)	-0.114 (-1.72)	4.355 (1.87)
KF	0.036*** (4.20)	0.023 (1.90)	0.057*** (6.26)	0.007 (0.42)	0.050*** (5.23)	-1.313*** (-3.86)
DACC	0.004 (0.33)	-0.011 (-0.59)	-0.002 (-0.14)	-0.013 (-0.52)	-0.00174 (-0.12)	0.572 (1.11)
cons	-0.947 (-1.93)	0.743 (1.09)	-0.293 (-0.44)	6.313*** (5.73)	-0.719 (-1.32)	-2.915 (-0.15)
N	297	297	297	297	297	297
R-squared	0.996	0.985	0.996	0.921	0.996	0.971

*p < 0.05, **p<0.01, ***p<0.001

Table 3. F-tests for the significance of coefficients 2 and 3 in determining implied causality

Regression Number	F-statistic	Prob.	Direction
1	35.12	0.0000	GDP←TFEC
2	34.00	0.0000	GDP→TFEC
3	2.74	0.0666	-
4	2.88	0.0576	-
5	-	-	-
6	2.51	0.0835	-

Table 4. Hausman Tests for Regression 1

	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
GDP	0.94357	0.99829	-0.05471	0.0124828
TFEC	0.32034	0.41570	-0.09535	0.0040219
TFEC1	-0.32106	-0.41085	0.08979	-
POL	0.00057	-0.00861	0.00143	0.0004772
POP	0.17460	0.03018	0.14442	0.0795246
LAB	-0.08964	-0.02493	0.06471	0.0584344
KF	0.03613	0.04446	0.04446	0.0082855
DACC	0.00431	-0.00848	-0.00848	0.0116174
Chi^2	55.97			
Prob > Chi^2	0.000			

b=consistent under Ho and Ha; obtained from xtreg
B=inconsistent under Ha, efficient under Ho; obtained from xtreg

Table 5. Hausman Tests for Regression 2

	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
TFEC1	0.94603	0.99901	-0.05298	0.018423
GDP	0.61369	0.68804	-0.07435	0.038119
GDP1	-0.58587	-0.69183	0.10596	0.034006
POL	-0.00044	-0.00099	0.00055	0.000686
POP	-0.06868	-0.01116	-0.05752	0.111170
LAB	-0.00177	0.00445	-0.006229	0.081593
KF	0.02313	-0.01048	0.012645	0.011831
DACC	-0.01082	-0.01871	0.007891	0.016388
Chi^2	21.11			
Prob > Chi^2	0.007			

b=consistent under Ho and Ha; obtained from xtreg
B=inconsistent under Ha, efficient under Ho; obtained from xtreg

Table 6. Hausman Tests for Regression 3

	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
GDP1	0.92629	0.98922	-0.06293	0.009821
EEFF	-0.07978	-0.08029	0.00051	-
EEFF1	0.06871	0.09342	-0.02471	-
POL	0.00056	-0.00120	0.00177	0.000408
POP	0.14462	0.00592	0.13870	0.094107
LAB	-0.09919	0.00121	-0.10040	0.065759
KF	0.05732	0.00373	0.05359	0.007816
DACC	-0.00207	-0.00090	-0.00117	0.009212
Chi^2	7.42			
Prob > Chi^2	0.025			

b=consistent under Ho and Ha; obtained from xtreg
B=inconsistent under Ha, efficient under Ho; obtained from xtreg

Table 7. Hausman Tests for Regression 4

	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
EEFF1	0.84555	1.00234	-0.15678	0.024991
GDP	-0.24252	-0.22393	-0.01860	0.041796
GDP1	0.21412	0.21298	0.00114	0.025084
POL	0.00019	0.00018	0.00001	0.000940
POP	-0.67057	-0.02784	-0.64273	0.163385
LAB	0.38249	0.02708	0.35540	0.118134
KF	0.00714	0.00874	-0.00160	0.016283
DACC	-0.01325	-0.01150	-0.00175	0.021848
Chi^2	49.85			
Prob > Chi^2	0.000			

b=consistent under Ho and Ha; obtained from xtreg
B=inconsistent under Ha, efficient under Ho; obtained from xtreg

Table 8. Hausman Tests for Regression 5

	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
GDP1	0.92304	0.98038	-0.05735	0.009781
RESTFEC	-0.00367	-0.00584	0.00217	0.000178
RESTFEC1	0.00278	0.00487	-0.00209	-
POL	0.00008	-0.00086	0.00093	0.000494
POP	0.19849	0.01657	0.18192	0.086569
LAB	0.11413	0.00285	-0.11698	0.061732
KF	0.04952	-0.00146	0.05099	0.008659
DACC	-0.01082	-0.01871	0.007891	0.010981
Chi^2	23.17			
Prob > Chi^2	0.000			

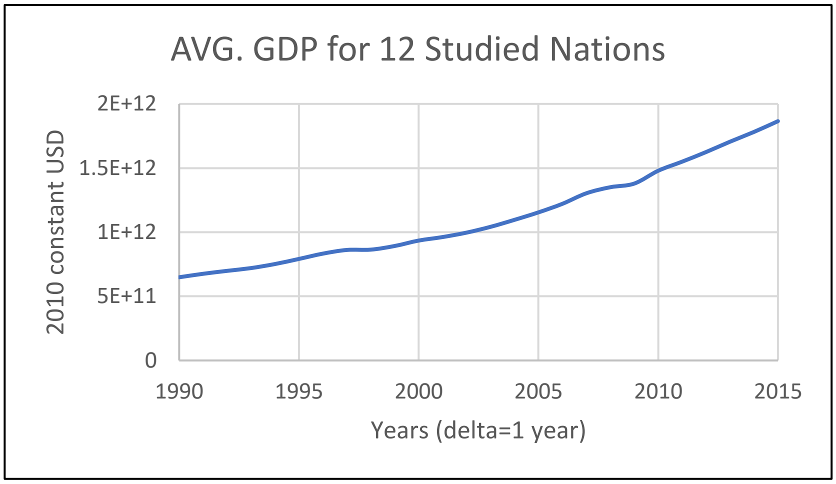
b=consistent under Ho and Ha; obtained from xtreg
B=inconsistent under Ha, efficient under Ho; obtained from xtreg

Table 9. Hausman Tests for Regression 6

	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	Sqrt(diag(V_b-V_B)) S.E.
RESTFEC1	0.90973	0.97817	-0.06845	0.014848
GDP	-4.53426	-5.93686	1.40260	0.777397
GDP1	4.41278	5.98490	-1.57212	0.427899
POL	-0.06112	0.02390	-0.08501	0.020226
POP	-1.89936	-0.24845	-1.65091	3.130565
LAB	4.35542	0.26883	4.08659	2.256258
KF	-1.31274	-0.10410	-1.20864	0.328997
DACC	0.57204	0.22096	0.35108	0.454511
Chi^2	10.00			
Prob > Chi^2	0.007			

b=consistent under Ho and Ha; obtained from xtreg
B=inconsistent under Ha, efficient under Ho; obtained from xtreg

Figure 1.



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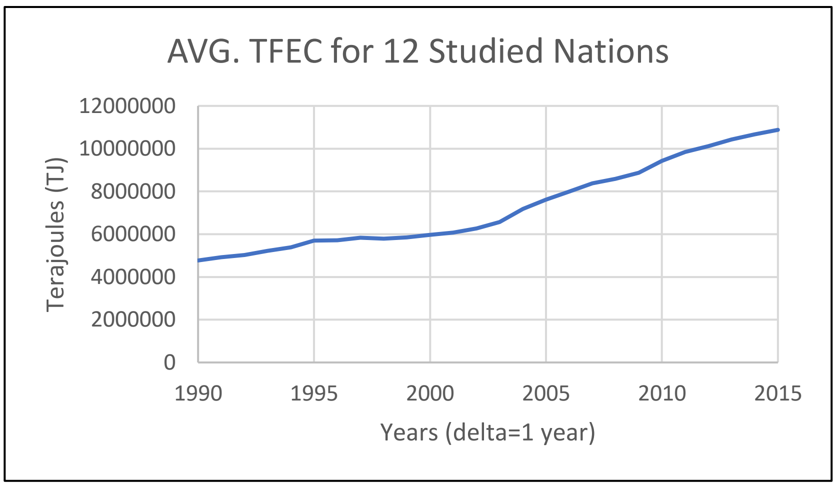


Figure 3.

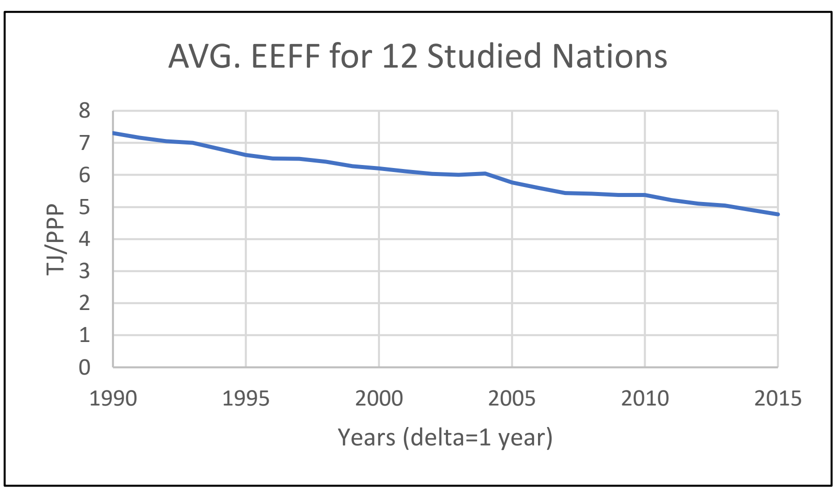
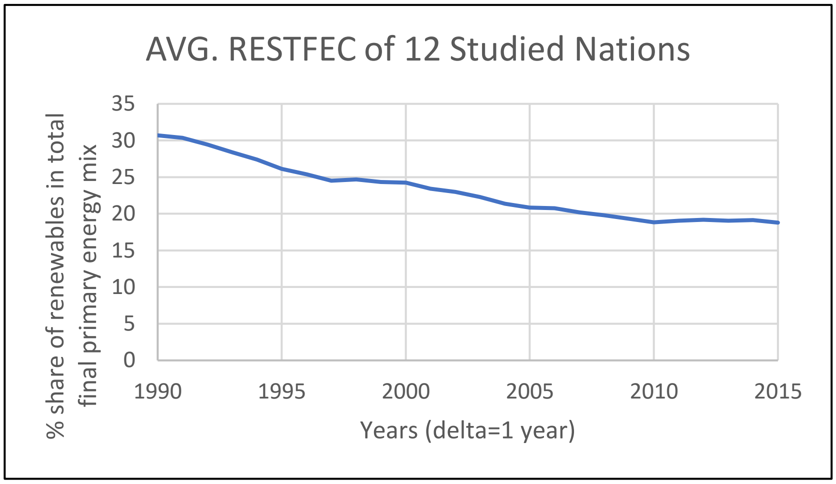


Figure 4.



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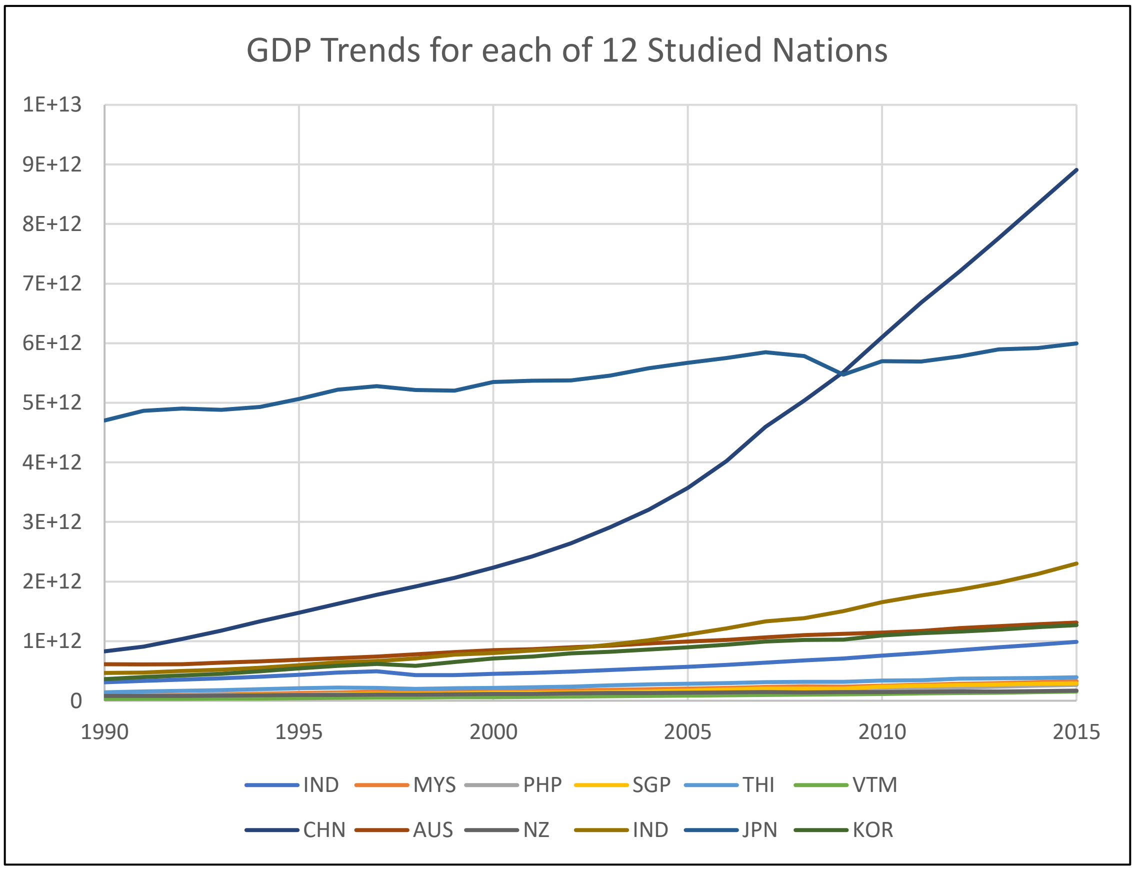

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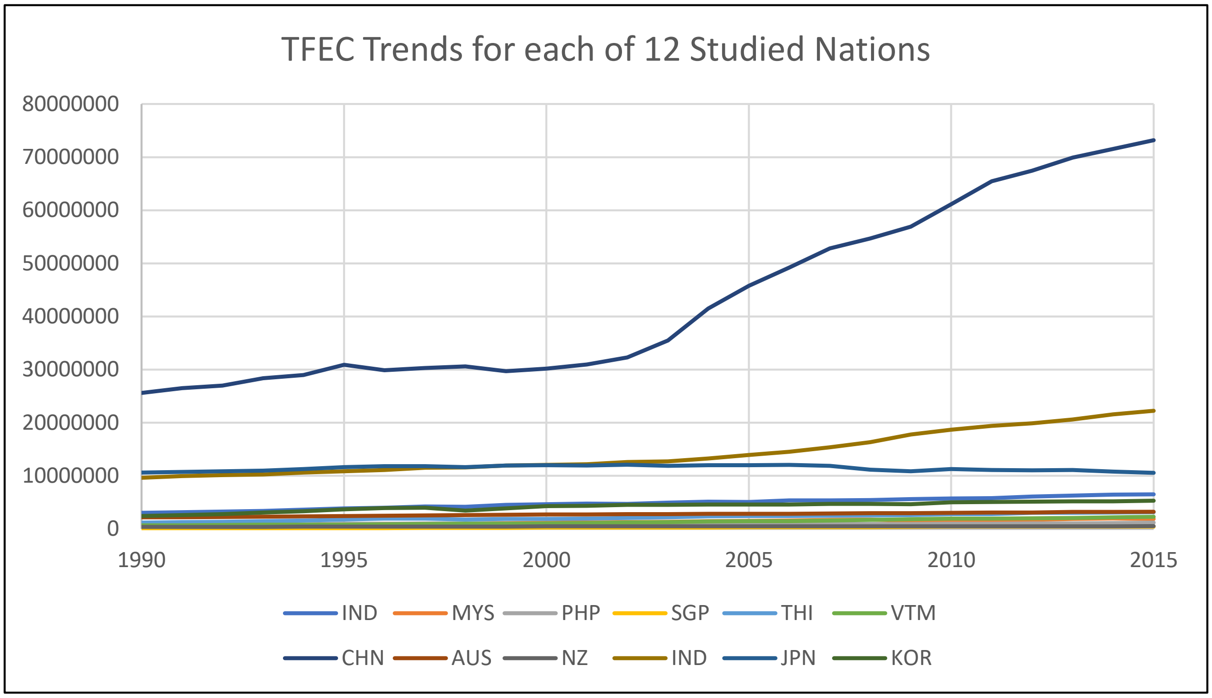

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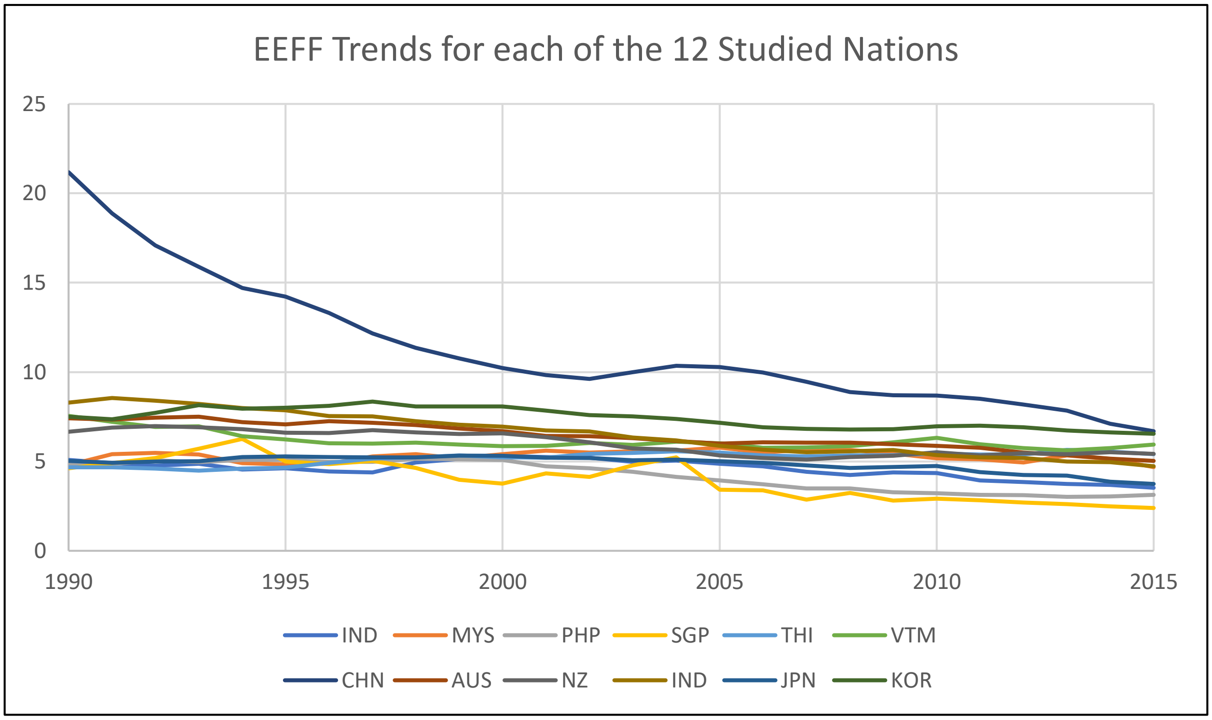

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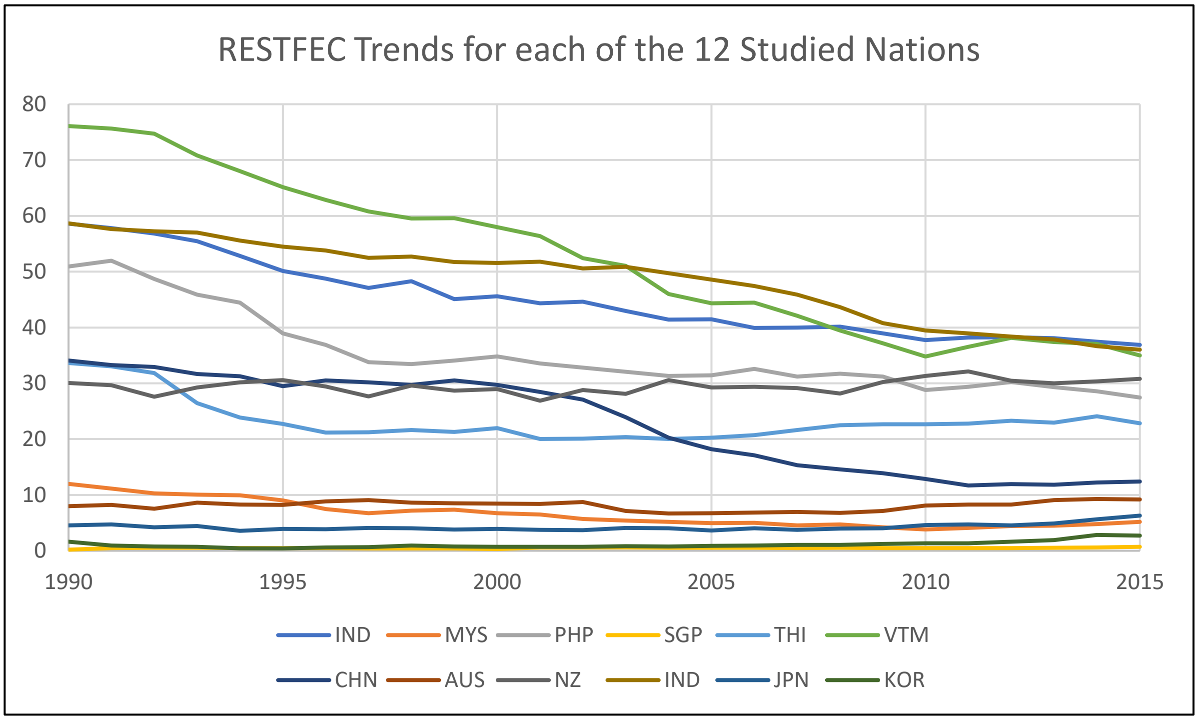

Dynamic Panel Regression Models:

$$Reg.\ 1{:}\ \ ln(GDP)_t = \beta_0 + \ \beta_1 ln(GDP)_{t-1} + \beta_2 \ln(TFEC)_t + \beta_3 \ln(TFEC)_{t-1} + \beta_4 POL_t + \ \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 EACC_t + \varepsilon_t$$

$$Reg.\ 2{:}\ \ln(TFEC)_t = \beta_0 + \ \beta_1 \ln(TFEC)_{t-1} + \beta_2 \ln(GDP)_t + \beta_3 \ln(GDP)_{t-1} + \beta_4 POL_t + \ \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 EACC_t + \varepsilon_t$$

$$Reg.\ 3{:}\ \ ln(GDP)_t = \beta_0 + \ \beta_1 ln(GDP)_{t-1} + \beta_2 \ln(EEFF)_t + \beta_3 \ln(EEFF)_{t-1} + \beta_4 POL_t + \ \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 EACC_t + \varepsilon_t$$

$$\textit{Reg. 4: } \ln(EEFF)_t = \beta_0 + \beta_1 \ln(EEFF)_{t-1} + \beta_2 \ln(GDP)_t + \beta_3 \ln(GDP)_{t-1} + \beta_4 POL_t + \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 EACC_t + \varepsilon_t$$

$$\textit{Reg. 5: } ln(GDP)_t = \beta_0 + \beta_1 ln(GDP)_{t-1} + \beta_2 RESTFEC_t + \beta_3 RESTFEC_{t-1} + \beta_4 POL_t + \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 EACC_t + \varepsilon_t$$

$$\textit{Reg. 6: } RESTFEC_t = \beta_0 + \beta_1 RESTFEC_{t-1} + \beta_2 \ln(GDP)_t + \beta_3 \ln(GDP)_{t-1} + \beta_4 POL_t + \beta_5 ln(POP)_t + \beta_6\, ln(LAB)_t + \beta_7 ln(KF)_t + \beta_8 EACC_t + \varepsilon_t$$

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