THE CAUSAL RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND ECONOMIC GROWTH

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BANU ÇEVİRGEN

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Prof. Dr. Sencer Ayata
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Haluk Erlat
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Erkan Erdil
Supervisor

Examining Committee Members

Assoc. Prof. Dr. Nadir Öcal	(METU,ECON)	____________________
Assoc. Prof. Dr. Erkan Erdil	(METU,ECON)	____________________
Assist. Prof. Dr Teoman Pamukçu	(METU,TEKPOL)	____________________

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Name, Lastname: Banu Çevirgen

Signature:

ABSTRACT

THE CAUSAL RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND ECONOMIC GROWTH

Çevirgen, Banu
M.S., Department of Economics
Supervisor: Assoc. Prof. Dr. Erkan Erdil

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The causal relationship between energy consumption and economic growth has been a controversial subject of the empirical literature. However, there is no common consensus neither on the existence nor on the direction of the causal relationship between energy consumption and economic growth. The purpose of this study is to investigate the causal relationship between energy consumption and economic growth using a consistent data set**.** Recently developed Granger causality tests in panel data models are used to uncover the existence and direction of causality between energy consumption economic growth in 21 low-income, 35 middle-income, and 26 high-income countries over the period 1990–2004. The empirical results explicitly support that the Granger causality from energy consumption to economic growth is more common in high-income countries than low-income and middle-income countries. Furthermore, the Granger causality from economic growth to energy consumption is more common in low-income and middle-income countries than high-income countries.

Keywords: Energy Consumption; Economic Growth; Causality; Panel Data

ÖZ

ENERJİ TÜKETİMİ VE EKONOMİK KALKINMA ARASINDAKİ NEDENSEL İLİŞKİ

Çevirgen, Banu
Yüksek Lisans, Ekonomi Bölümü
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Enerji tüketimi ile ekonomik kalkınma arasındaki nedensel ilişki kapsamlı bir uygulamalı literatürün tartışmalı bir konusudur. Ancak ne nedenselliğin varlığı ne de yönü açısından ortak bir görüş yoktur. Bu çalışmanın amacı tutarlı bir veri seti kullanılarak enerji tüketimiyle ekonomik kalkınma arasındaki nedensel ilişkiyi incelemektir. 21 düşük gelirli, 35 orta gelirli ve 26 yüksek gelirli ülkede 1990-2004 dönemini kapsayarak enerji tüketimiyle kalkınma arasındaki nedenselliğin yönünü ortaya çıkarmak için panel veri modelleri için yeni gelişmiş yeni Granger nedensellik testleri kullanılmıştır. Ampirik sonuçlar enerji tüketiminden ekonomik kalkınmaya doğru Granger nedenselliğin yüksek gelirli ülkelerde düşük ve orta gelirli ülkelere göre daha yaygın ve ekonomik kalkınmadan enerji tüketimine doğru Granger nedenselliğin düşük ve orta gelirli ülkelerde yüksek gelirli ülkelere göre daha yaygın olduğunu açık olarak destekliyor.

Anahtar Kelimeler: Enerji Tüketimi, Ekonomik Kalkınma, Nedensellik, Panel Veri

To My Mother

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CHAPTER 1

INTRODUCTION

Energy is an indispensable factor of production for the continuity of the production process. The importance of the energy as a factor of production was ignored until the oil crisis during 1970s. This situation also affected the scope of the definition of the production function. Thus, in the Cobb-Douglas type production function which was used widely until the oil crisis, output is assumed to depend purely on labor and capital whereas factors like technology and productivity excluded in the model by using the fixed term. Especially after the two oil crises during the 1970s the importance of the energy raised and energy was considered as a factor of production. Thus, it was included in the production function. Henceforth, energy also took its place as a factor of production together with labor and capital in explaining the production function.

Energy is an essential factor of production in addition to capital and labor for the supply side of economy. It is required for all production processes since whole production process involves the transformation and motion of matter. Therefore, increased energy consumption boosts economic growth. On the other hand, for the demand side of the economy it is also one of the products that households consume to maximize their utility. An increase in the living standard of population causes an increase in demand for energy-consuming goods and services such as plasma television and wireless. Higher demand for these goods and services stimulates energy consumption. For this reason, economic growth gives rise to energy consumption.

Many studies have shown the positive correlation between energy consumption and economic growth. This means that countries with high GDP per capita consume high energy per capita. However, this does not imply the causal relationship between energy consumption and economic growth. Policy analysts concern about the existence of the causality and the direction of causation which of two variables take precedence over the other. The direction of the causality is important since the energy conservation policy may be implemented without affecting the economic growth in a negative way.

If there is a unidirectional Granger causality from energy consumption to economic growth, the policies for reducing energy consumption may cause a fall in the economic growth. However, the finding of Granger causality from economic growth to energy consumption implies that these policies may be implemented with little or no adverse effects on economic growth. Finally, if there is no causal relationship between energy consumption and economic growth, these policies do not affect economic growth.

After including energy as a factor of production in production function, the causal relationship between energy consumption and economic growth has been studied for different countries based on different time periods. Previous studies generally focused on single country analysis with different methodologies, data sets, and periods. However, they produced confusing causality results about the existence and the direction of the causal relationship within the same countries. Therefore critical policy implication can not emerge from these studies. In contrast to previous work, the purpose of this thesis is to investigate the existence and direction of Granger causality between energy consumption and economic growth for consistent panel data set by applying recently developed Granger causality tests in panel data models and to produce clear implications for energy conservation policies.

The tested hypothesis is whether there is evidence of Granger causality between energy consumption to economic growth in low-income, middle-income and high-income countries. In particular, this thesis attempts to test the hypothesis that direction of Granger causality is different for each country group.

The rest of the thesis is organized as follows: In Chapter 2 theoretical discussion on energy and economic growth is introduced, while in Chapter 3, the previous empirical literature on causality relationship between energy consumption and economic growth is presented. In the following chapter, the econometric methodology used in the empirical analysis is outlined. Chapter 5 explains the data employed and reports the detailed results of the empirical analysis. We discuss the estimate results and draw a conclusion based on the empirical findings in Chapter 6.

CHAPTER 2

THEORETICAL DISCUSSION ON ENERGY AND ECONOMIC GROWTH

Reviewing the relationship between energy consumption and economic growth is necessary to explain the causality between these variables. For this reason, in this chapter, the theoretical literature related to energy economics is examined. There are different views among economists on the role of energy in the economy. In this chapter, the theoretical literature of energy economics is discussed according to physical theory of production, mainstream theory of economic growth and factors affecting the relationship between energy and economic growth.

2.1 The Physical Theory of Production

Reproducibility is an important concept in the economics of production. Some factors of production such as capital, labor and also natural resources are reproducible in production. On the contrary some of them such as energy are non-reproducible production factors (Stern, 1999). For this reason, natural scientists and some ecological economists have attached importance to the role of energy in economic growth.

The first law of thermodynamics that is the conservation law implies that the mass of inputs and output must be equal in the production process. The second law of thermodynamics that is the efficiency law implies that a minimum quantity of energy is required to carry out the transformation of matter. The whole production process requires the same transformation and motion of matter. Therefore there must be limits to the substitution of others factors of production for energy. Because of the fact that energy is required for all economic processes, energy is an essential factor of production.

The other important distinction for this concept is the difference between the primary factor of production and intermediate inputs. The primary factors of production such capital, labor and land for mainstream economics are not produced within the production period. They exist at the beginning of production and are not directly used up in production process. On the other hand intermediate inputs such fuels and materials are created during the production period and are used up in production process (Stern, 2003).

The prices paid for all the different inputs (for the direct and indirect services provided by intermediate inputs in the production process) are accepted payments for the primary factors of production (Stern, 1999). Consequently, the mainstream theory of growth has focused on the primary factors of production in particular, capital and labor and has given indirect and insignificant importance to energy (Stern, 2003). As a result, energy is not a primary factor of production but rather thought of the intermediate inputs to continue the production process. The quantity of energy available to the economy in any period is endogenous. This quantity depends upon the quantity of natural reserve, the amount and efficiency of installed extraction, refining and generating capacity (Stern, 1999). However, the standard macroeconomic theories of growth focus on capital and labor and do not attach needful importance to energy for production and growth.

Biophysical models of economy (e.g. Gever *et. al.*, 1986) assume that energy is the only primary factor of production. In these models capital and labor are seen as the embodied energy use associated with them. Prices of goods and services are determined by the cost of the embodied energy use associated with them (Hannon, 1973). If quantity of embodied energy of inputs increases, then the price of goods and services increases. According to this approach, the distribution of the surplus depends on the relative bargaining power of the different social classes such as owners of capital, labor and land (Kaufmann, 1987). Since there is a primary factor of production such as energy in the production process and if constant returns to scale are assumed, the Leontief input-output models represent an economy (Stern, 1999).

2.2 The Mainstream Theory of Growth

2.2.1 Growth Models without Natural Resources

The most simple growth model which examines the hypothetical economy is the Solow growth model (1956). To think about growth, the Solow model focuses on three variables output (Y), capital (K) and labor (L). The production function is $Y = F(K, L)$. The model's critical assumptions are that the production function has constant returns to scale, exhibits positive and diminishing marginal products with respect to each input and satisfies the properties that are the marginal product of input approaches to infinity as inputs go to 0 and approaches to 0 as inputs go to infinity. These last properties are called Inada conditions, following Inada (1963). In addition, labor grows at a constant rate (n).

Output is divided between consumption and investment. The saving is constant proportional to income. The fraction of output devoted to saving, s, is exogenous. The investment is equal to saving since the economy is closed with no government.

$$I = sY = sF(K, L) \tag{2.1}$$

Capital depreciates at a constant rate ($\delta > 0$) in each period of time. Investment is denoted by I and net addition to capital stock is denoted by $\dot{K}$.

$$I = \dot{K} + \delta K \tag{2.2}$$

Then, when equation (2.1) and (2.2) are combined, equation (2.3) can be obtained.

$$\dot{K} = sF(K,L) - \delta K \qquad (2.3)$$

When both sides of equation (2.3) are divided by L, equation (2.5) can be obtained.

$$\dot{K} = sLF\left(\frac{K}{L},1\right) - \delta K \qquad (2.4)$$

$$\left(\frac{\dot{K}}{L}\right) = sF\left(\frac{K}{L},1\right) - \delta \frac{K}{L} \qquad (2.5)$$

Since $k = {K}/{L}$ is the capital per labor, equation (2.6) can be obtained.

$$\frac{\dot{K}}{L} = sf(k) - \delta k \qquad (2.6)$$

By using chain rule, equation (2.7) can be obtained.

$$\dot{k} = \overset{\bullet}{\left(\frac{K}{L}\right)} = \frac{\dot{K}}{L} - \frac{K}{(L)^2}\dot{L} = \frac{\dot{K}}{L} - k\left[\frac{\dot{L}}{L}\right] = \frac{\dot{K}}{L} - kn \qquad (2.7)$$

Then, when equation (2.6) and (2.7) are combined, equation (2.8) can be obtained.

$$\dot{k} = sf(k) - (n+\delta)k \qquad (2.8)$$

This is called law of motion for k. $\dot{k}$ is the function of k. Break-even investment, $(n+\delta)k$, is proportional to k and actual investment, $sf(k)$, is a constant times output per unit of labor. The state in which output per labor and capital per labor are no longer changing is called the steady state of the economy. The equation (2.8) then says that the capital per labor and output per labor are in equilibrium (and unchanging in size) when actual investment equals to break-even investment. In the steady state, output and capital grow at the same rate as labor, thus at a rate equal to the growth rate of the labor. The equation (2.8) tells us that if actual investment exceeds break-even investment, then capital per labor increases since its derivative with respect to time $\dot{k}$ will become positive. It continues to rise until it reaches the steady state level. The equation (2.8) tells us that when break-even investment exceeds actual investment, capital per labor decreases since $\dot{k}$ will become negative. It continues to fall until it reaches the steady state level.

The rate of output growth in steady state is independent of the saving rate. However, the saving rate affects the steady state level of output per labor. A permanent increase in the saving rate produces a temporary increase in the growth rate of output per labor. If the saving rate is risen over and over again, the growth rate of output per labor grows forever. The saving rate is a number between zero and one. If people could save all their income, the saving would equal to break-even saving and as a result long-run output per labor growth would stop. The reason is that diminishing returns to capital finally brings the zero growth rate level.

A decrease in growth rate of labor lead to an increase in the steady state levels of capital per labor and output per labor but the long-run growth rates of capital per labor and output per labor remain zero.

On the other hand, technological progress causes a continuing economic growth. Increase in the level of technological progress shifts the production function upwards and the steady state level of capital per labor and output per labor are raised. However, in the long-run there are no changes in per labor growth rates of capital and output. The key difference between level of technological progress and saving rate is that the level of technological progress is not bounded. When the level of technological progress increases, same quantity and quality of inputs can produce greater quantities and better qualities of output.

Neoclassical growth model treats technological progress as an exogenous variable. Thus, it does not explain how improvements in technological progress come out. In the endogenous growth models the key property is non-existence of diminishing returns to capital. The production function is as follows;

$$Y = AK \tag{2.9}$$

where,

A : Level of technology that is a positive constant
K : Broad sense of capital that includes physical and human capital

$$\frac{Y}{L} = \frac{AK}{L} \tag{2.10}$$

Since $y = {}^{Y}\!/\!_{L}$ is the output per labor and $k = {}^{K}\!/\!_{L}$ is capital per labor

$$\dot{k} = sf(k) - (n + \delta)k \tag{2.11}$$

$$\dot{k} = sAk - (n + \delta)k \tag{2.12}$$

$$\frac{\dot{k}}{k} = sA - (n + \delta) \tag{2.13}$$

Unlike neoclassical growth model, growth can continue indefinitely. A higher saving rate and a higher level of the technology lead to higher long-run growth rates of capital per labor and output per labor. Furthermore, the growth rate of the labor and the depreciation rate can permanently affect long-run per labor growth rates.

According to endogenous growth models, technological knowledge is thought as a form of capital. A firm increases technological knowledge through investment in capital. Each firm’s technological knowledge is a public good that is available to others at zero cost. Moreover, it generates positive externalities in production process. A piece of knowledge spills over across the whole economy. As a result, social benefits of innovation exceed the private benefits to the original innovator. The technological knowledge through investment in capital exactly offsets the diminishing returns to manufactured capital and the economy can sustain a constant growth rate. If the saving rate increases, the long-run growth rate increases.

2.2.2 Growth Models with Natural Resources and no Technological Change

All natural resources are finite. Some of the resources are non-renewable, and many renewable resources are finite. Finiteness and exhaustibility of resources creates problems about economic growth.

The neoclassical literature about economic growth is mainly concentrated on which conditions permit continuing growth. Technical and institutional conditions determine whether growth is continuous or not. Technical conditions cover renewable and non-renewable resources, the initial endowment of capital and natural resources and the ease of substitution among the inputs. On the other hand, institutional conditions cover market structure, the system of property rights and the system of values towards future generation.

When the natural resources are exhausted, they are replaced by their substitutes or equivalent artificial capital for production. Neoclassical economists concern with what institutional arrangements provide continuing economy, on the other hand they neglect technical arrangements. That is, they assume that, sustainability is technically feasible, and they are interested in which institutional arrangements provide continuing economic growth.

2.2.3 Growth Models with Natural Resources and Technological Change

The increase in the total factor productivity technically increases the ease of sustainability of economy and sustainability can be possible even with the elasticity of substitution being less than 1. However, technical feasibility does not mean that there will be sustainability. Technological improvement means the increase in the quantity of output for each unit of input.

Studies that examine the roles of resources in growth models with endogenous technological change such as Aghion and Howitt (1998) and Smulders (2004) have been less than the studies with the exogenous technological change or no technological change assumptions. Studies with endogenous technological change have not yet provided conditions for the achievement of sustainability (Stern and Cleveland, 2004).

In a study of Aghion and Howitt (1998) about the role of natural resources, whether the sustainable growth will be achieved or not is investigated with four different models. First two models cover renewable resources, the other two cover non-renewable resources. In the models which cover non-renewable resources, it is assumed that non-renewable resources are important for production. Conversely, in the models which cover renewable resources, the resource which decreases the amount of pollution of the environment has more importance than non-renewable ones.

Tahvonen and Salo (2001) developed a model which covers renewable and non-renewable energy resources at the same time. This model is more realistic than the previous neoclassical approach. They intend to see how the growth process would actually work. The extraction costs for fossil fuels and the costs of production for renewable resources are included in the model. This model also investigated the situations in which there is no any technological change, technological change is exogenous or endogenous. It is assumed that increase in extraction leads to increase in technological knowledge in extraction and that technological knowledge increases the capital stock. The optimal development such an economy appears to mimic history much more effectively than the neoclassical models. When the economy is divided by pre-industrial, industrial and post-industrial eras, fossil fuels usage rises in the first two eras and then falls and capital accumulation rises. The price of non-renewable energy resources first falls and then rises (Stern and Cleveland, 2004).

2.3 Factors Affecting the Relationship between Energy and Growth

Especially after the two oil price shocks of the 1970s, in developed economies there has been an extensive debate about the energy efficiency that is quantity of energy in order to produce a unit of output. The debate was mainly focused on providing energy to maintain continuous growth. It is important to provide required quantity of energy for growth.

From now on, the relationship between energy use and economic activity is investigated starting from the neoclassical perspective. If we define the general production function as follows;

$$(Q_1, Q_2, ..., Q_m)' = f(A, X_1, X_2, ..., X_n, E_1, E_2, ...E_p) \qquad (2.14)$$

where,

Q_i : Various Outputs such as manufacture goods and services

X_i : Various inputs such as capital labor

E_i : Different energy inputs such as oil, coal

A : State of technology (This is defined by the total factor productivity indicator)

The relationship between energy and output depends on substitution between energy and other inputs, technological change, shifts in the composition of the energy input and shifts in the composition of output (Stern, 2003). These topics will be discussed particularly below.

2.3.1 The Relationship between Energy and Capital

There are different results in the econometric studies about whether the relationship between energy and capital is substitutive or complementary. Apostolakis (1990) stated in his studies that, this dichotomy is based on the difference between short-run and long-run results. Input price variations are limited in the short-term. The capital stock is fixed in the short run. For this reason, capital services and energy are likely to be used in fixed proportions. As a result, an increase of energy prices causes a decrease in capital utilization. In contrast to this, capital stocks are flexible in the long run and can be adopted according to price changes Therefore, the relationship between capital and energy is substitutive. When energy prices are increased, more investments are observed in energy-saving technologies. These technologies are characterized by higher capital user costs and lower energy consumption. Frondel and Schmidt (2002) conclude that this relationship is complementary only when the cost share of energy is low. Since the larger the cost share of capital, the harder it is to substitute capital for energy whose price is increasing.

Econometric studies generally estimate the coefficient of elasticity for industry level instead of whole economy. In Stern’s study which was performed for U.S in 1993, it is observed that the relationship between energy and capital is neither substitutive nor complementary (Stern, 1993).

As a result, the relationship between energy and capital can be evaluated as complementary or substitutive at a low level (Stern, 2003). The degree of complementary relationship changes when the industrial sectors are handled totally or separately.

2.3.2 Innovation and Energy Efficiency

Energy efficiency is computed by the ratio of energy to the gross domestic product (GDP). The changes in this ratio are accepted as the changes in autonomous energy efficiency.

Therefore, the production function can be rewritten as follows;

$$Q = f(A_1 X_1, A_2 X_2, ..., A_n X_n, A_E E) \tag{2.15}$$

where,

X_i : Various inputs such as capital, labor, energy and materials.
E : Resource stock.
A_i : Augmentation factors associated with the respective factors of production.
A_E : Augmentation index of the resource base.

Each input is multiplied by their augmentation factor (A_i), so that the units of input are transferred into efficient units of input.

It is difficult to estimate autonomous energy efficiency index as the trend of the change is not constant and changes according to the economic sectors. Jorgensen and Wilcoxen (1993) estimated that autonomous energy efficiency index is decreasing. In the model of Berndt et al., (1993) the index is changed at a constant rate and they determined that between the year of 1965 and 1987 the energy index of U.S. manufacturing industry increased at a rate between 1.75% and 13.09%.

Judson et al., (1999) estimate that the energy consumption of the households increases by time and in the industry and construction sectors, energy consumption decreases by time. As a conclusion, technical innovation causes more energy usage for the households, and less energy usage for the industry due to the improvements in energy-saving techniques.

According to the Khazzoom-Brookes Postulate (Brookes, 1990; Khazzoom, 1980), the money saved due to the technical innovations will be spent on other goods and services which themselves require more energy in their production. This will end up with more energy consumption (Stern, 2003).

An innovation which provides energy saving also causes a decrease in the price of energy. As a result, energy demand increases, the lower price of energy creates income effect which results in an increase in the quantity demand for all goods. Consequently, the energy used for production increases (Stern, 2003).

When endogenous technical change is considered, change in prices can cause technical changes. The increase in the price of energy increases the speed of development of energy-saving technology and there can be an effect of this on total factor efficiency. According to Jorgensen (1984) technical changes are biased and increase energy consumption. If this had been true, lower price of energy would accelerate the growth of total factor efficiency or higher price of energy decelerates the growth of total factor efficiency. However later studies (e.g. Judson *et al.*, 1999) do not confirm this result (Stern and Cleveland, 2004).

2.3.3 Energy Quality and Shifts in Composition of Energy Input

Energy quality is the relative economic usefulness per head equivalent unit of different fuels and electricity. One way of measuring the energy quality is computing the marginal product of energy resource that is the quantity of marginal increase in the quantity of goods and services which is produced by adding a unit of fuel. Some fuels can only be used for specific activities. For instance, a computer can not be operated by means of coal although coal can be used for numerous activities. Physical scarcity, capacity to do useful work, energy density, cleanless, amenability to storage, safety, flexibility of use, cost of conversion… etc. affect the determination of a marginal product of a fuel. In addition to these, in which activities fuel is used and how much labor and capital is used will also affect the marginal product. Consequently, the quality of the energy is not constant over time. Generally, electricity is accepted as the highest quality type of energy and natural gas, oil, coal, wood and biofuels follow electricity respectively (Cleveland, 2007). This idea is supported when prices of these fuels per unit of energy, which is proportional to its marginal product, is considered (Stern, 2003).

The economic importance of energy quality was first used by Schurr and Netschert (1960). The decline of energy intensity in U.S. is sourced by the structural change from lower quality fuels to higher quality fuels (Cleveland et al., 1984). Kaufmann (2004) estimated a VAR model which consists of Energy/GDP ratio, household, energy expenditure, energy consumption and price of energy. In this study, it is stated that shifting from coal usage to oil usage decreases energy intensity. This shift contributed to the decline in the energy intensity between 1929 and 1999.

2.3.4 Shifts in Composition of Output

The composition of the output can change in different periods of economic development. In the early periods of development, there was a shift from agriculture to heavy industry, whereas on the later periods, a shift from heavy industry to services and lighter manufacturing sectors is observed. It is often argued that in the early periods of development, energy used per unit of output increases since heavy industrial sectors use more resources. On the other hand, in later periods of development energy used per unit output decreases as services and lighter manufacturing sectors use less resource (Stern, 2003).

This argument can be followed further to argue that service sector can also require large amount of resource inputs and energy. Although some services do not have a physical existence, in the places where these services are performed such as office towers, shopping malls, warehouses, rental apartments, complexes…etc. large amount of energy can be used. Another service, transportation also requires large amount of energy and resource usage. Additionally, consumers use large energy while they are working, traveling, shopping…etc (Stern, 2003).

When indirect energy and resource embodied in the products is considered, services can not be evaluated as a sector which requires less energy intensity than other sectors for U.S. In the last few decades, there is not a statistically significant proof of decline in the energy/GDP ratio due to change of output mix (Stern, 2000).

The reason for that can be the trend of using more energy by consumers, due to the increase in transportation…etc. consumption. Judson et al. (1999) stated that, consumer sector energy intensity increases by time, while energy intensity of manufacturing sector decreases.

2.4 Energy and Economic Growth

Energy is not the unique input for economic growth; however it is one of the most important inputs. Without using energy, it is not possible to operate a factory, grow crops, travel, transfer services and goods from producer to consumer. Most of the studies (e.g. Stern, 2003) concerning the relationship between energy consumption and economic growth, deals with how economic growth affects energy consumption. Economic growth increases energy consumption at least at the early stages of economic development.

Neoclassical production function explains economic growth in terms of labor, capital and technology. Total factor efficiency is used as a measure of technology and this explains the portion of economic growth which can not be explained by labor and capital. Energy is included in the production function in one of the studies performed by IEA (International Energy Agency) and this study was applied to several developing countries between 1981 and 2000 (IEA, 2004). This function is determined as follows;

$$Y_t = A_t * (K_t)^{\alpha} (L_t)^{1-\beta} (E_t)^{1-\alpha-\beta} \tag{2.16}$$

where,

Y_t : Output

A_t : Economy's total factor productivity

K_t : Stock of capital

E_t : Energy use

L_t : Labor

Table 1: *Contribution of Factors of Production and Productivity to GDP Growth in Selected Countries, 1980-2001*

Countries	Average annual GDP growth (%)	Contribution of factors of production and productivity to GDP growth (% of GDP growth)			
		Energy	Labor	Capital	Total factor Productivity (A)
Brazil	2.4	77	20	11	-8
China	9.6	13	7	26	54
India	5.6	15	22	19	43
Indonesia	5.1	19	34	12	35
Korea	7.2	50	11	16	23
Mexico	2.2	30	60	6	4
Turkey	3.7	71	17	15	-3
United States	3.2	11	24	18	47

Sources: IEA, World Energy Outlook 2004

According to the Table 1, capital and energy make more contribution to GDP than total factor efficiency in every country except China. Energy contributes to economic growth meaningfully in all countries. Especially in Brazil, Turkey and Korea energy is the leading driver of growth. Energy’s contribution to economic growth is less in India, China and U.S. According to the results energy plays more significant role in the countries which are at an intermediate stage of economic development. In these countries energy intensity for manufacturing industry is more than the others. It is concluded that in the latter stage of economic development energy intensity will decrease because the technologies which increase the energy efficiency are included.

CHAPTER 3

EMPIRICAL LITERATURE ON THE CAUSAL RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND ECONOMIC GROWTH

The causal relationship between energy use and output growth has been a debated subject of the extensive empirical literature in the past three decades. However, no common consensus neither on the existence nor on the direction of the causal relationship between energy use and output growth has emerged. This depends on institutional, structural, and policy differences of the countries under consideration, variety of variables and data span chosen and methodological differences.

The aim of this chapter is to summarize the empirical literature of causality relationship between energy consumption and economic growth and present the inconsistencies of these studies.

In this chapter, the studies can be classified by the causality test methods. These methods are standard Granger causality test and Sims's technique, cointegration test, cointegration test and error correction model, Hsiao's Granger causality test, Toda-Yamamoto test and panel cointegration and error correction model. The results from these studies are summarized in Table 2 in end of this chapter.

3.1 The Standard Granger Causality Test and Sims's Technique

The pioneering study of Kraft and Kraft (1978) by using Sims' technique finds the unidirectional causality, only running from gross national product (GNP) to energy consumption for the United States (US) over the period 1947-1974. Therefore, the economy is not energy dependent. It implies that the policies reducing energy consumption may be implemented with little adverse or no effect on economic growth.

On the other hand, Akarca and Long (1980) show that there is no causal relationship between energy consumption and GNP when the sample time period is shortened by 2 years in US. Yu and Hwang (1984) find the evidence in support of the neutrality hypothesis that is no causal relationship between GNP and energy consumption in US by using Sims' and Granger test when the sample period is extended by 5 years. It implies that energy consumption is not correlated with GNP, so that energy conservation policies do not affect GNP.

Yu and Choi (1985) examine the causal linkage between GNP and the aggregate and as well as several disaggregate categories of energy consumption including solid fuels, liquid fuels, natural gas, and others (i.e. hydro, nuclear, electricity) for five countries with various stages of economic development for the time period 1950-1976 based on Sims and Granger tests of causality. This study indicates that unidirectional causality from aggregate energy consumption to GNP for the Philippines and from GNP to aggregate energy consumption for South Korea but no causality in either direction for the USA, the United Kingdom (UK), and Poland. If causality only runs from energy consumption to GNP, then it implies that the economy is energy dependent and the shortage of the energy may negatively effect economic growth.

Erol and Yu (1987) use the results of the Sims and Granger causality tests between energy consumption and GNP in some industrialized countries for the period 1950-1982 to conclude a unidirectional causality running from energy consumption to GNP for Canada, from GNP to energy consumption for both West Germany and Italy, neutrality of energy consumption with respect to GNP for France and UK and a bidirectional causality in Japan.

Stern (1993) uses a multivariate approach rather than a bivariate approach to examine the Granger causality between GDP and energy use using vector autoregressive (VAR) model of GDP, energy use, capital stock, and employment for the period 1947-1990 in USA. Stern uses GDP instead of GNP and a quality-adjusted index of energy input rather than gross energy use different from many previous studies. As Glasure and Lee (1997) argue that the use of GDP is better than the GNP since the country's total energy consumption depends on goods and services produced within the country, not outside the country. Stern (1993) finds that energy consumption Granger causes GDP. This result contradicts the previous results for USA. It may be caused by variation in the variables and in the time span.

Previous studies are related to the developed countries, but Ebohon (1996) tests the Granger causation between energy consumption and economic growth that is proxied by GDP and GNP for two developing economies, Tanzania over the period 1960 to 1984 and Nigeria over the period 1960 to 1981. This study reveals the bidirectional causation between energy consumption and economic growth.

The economic structures and policy characteristics are different among countries. Consequently, different causality results for different countries are not surprising. Nevertheless, there exist such conflicting causality results within the same countries for different time period. Because the standard Granger causality and the Sims tests require the stationary data series and generally the economic series are not stationary. The use of non-stationary data in causality tests can produce spurious results. For these reason data series are differenced to eliminate possible unit roots. Although differencing may imply series to be well behaved, this removes any long run information. As a result, these tests indicate only the short run causality relationships between data series. Thus, the results of these tests are often inconsistent. In addition, according to Granger (1986) the standard Granger causality test is valid if the variables are not cointegrated.

3.2 Cointegration Test

Nachane *et al.* (1988) first use the cointegration theory to test existence of the long-run equilibrium relation between energy consumption and GDP. This study also shows the strength of the causal relationship. Conversely, previous studies only indicate the causal relationship between the variables. Nachane *et al.*(1988) study the energy consumption and GDP for 25 countries for the 1950-1985 period but cointegration can be established for only 16 countries (11 developing countries and 5 developed countries). The bidirectional causality is found by using the Sims and Granger causality tests for all countries except Colombia and Venezuela.

Yu and Jin (1992) analyze the bivariate cointegration between energy consumption and income or employment for monthly USA data over the period 1974:01 to 1990:04. They find that cointegration fails to exist between them for either energy consumption-income or energy consumption-employment relationship by using Engle-Granger two step procedure. This implies that energy consumption is neutral with regard to income and employment over the long-run. This analysis is consistent with the earlier conclusions in the literature for the US economy that energy consumption policies do not affect the growth in the short run.

Stern (2000) extends his previous study of USA in the post-war period by adding multivariate cointegration relationship between energy consumption and GDP and concludes that there is a unidirectional causality from energy consumption to GDP. This means that energy consumption is a limiting factor for economic growth. This conclusion is similar to multivariate model of Stern (1993), while it contradicts the bivariate model of Yu and Jin (1992).

Ghosh (2002) has examined Granger causality between electricity consumption and GDP for India in 1950-1997. This study reveals unidirectional causality running from economic growth to electricity consumption without any feedback effect. However, there is no long-run equilibrium relationship between variables.

Unlike the previous study, vector error correction model has also been used in testing Granger causality. Granger (1988) points out that the existence of the cointegration relationship among variables indicates Granger causality in at least one direction. Cointegration does not show the direction of the causal relationship. Conversely, vector error correction model can capture both long run and short run causality relationship between variables and identify the source and direction of causation.

3.3 Cointegration Test and Error Correction Model

Masih and Masih (1996) use the cointegration results between energy consumption and economic growth in testing Granger causality for six Asian countries. Long-run energy-income relationship is only held for India, Pakistan, and Indonesia, but not for Malaysia, Singapore, and the Philippines. With the aid of cointegration and VECM, they find the unidirectional causality from energy consumption to GDP for India, exactly the reverse for Indonesia and bidirectional causality for Pakistan. On the contrary, they do not find any direction of causality between these two variables by applying VAR model for the three non-cointegrated countries.

Glasure and Lee (1997) examine the causal relationship between energy consumption and GDP for South Korea and Singapore over the period 1961 to 1990 by using cointegration and VECM and VAR-based standard Granger causality test. Results of VAR indicate no causality between energy consumption and GDP for South Korea and unidirectional causality from energy consumption to GDP for Singapore. In contrast, results of VECM reveal bidirectional causality between energy consumption and GDP, because standard Granger causality test is not able to estimate long run relationship. The result for Singapore is inconsistent with the findings of Masih and Masih (1996) in spite of the same data span.

Masih and Masih (1997) reexamine the causality analyze of energy consumption and economic growth based on the demand side multivariate model. They use trivariate variables of energy consumption, GDP, and consumer price index as a proxy for real energy price rather than bivariate system of energy consumption and GDP. This trivariate model is different than the production side model which consists of energy consumption, GDP, capital, and labor in Stern's (1993, 2000) studies. His cointegration and VECM results indicate that there exists a long-run equilibrium relationship among energy consumption, GDP, and price and bidirectional causality between energy consumption and GDP for both South Korea and Taiwan. The result is consistent with the results of Glasure and Lee (1997) for South Korea.

Masih and Masih (1998) use multivariate cointegration and error correction modeling techniques to estimate the causal relationship for two Asian less-developed countries: Thailand and Sri Lanka. They have discovered that energy consumption, GDP, and price are cointegrated and there is a unidirectional causality from energy consumption to GDP and price. Therefore energy consumption is relatively exogenous variable.

Cheng (1999) uses Granger causality, cointegration, and error correction approach for India during 1952-1995. He detects that energy consumption, GNP, capital, and labor are cointegrated and economic growth unidirectionally Granger causes energy consumption both in the short run and in the long run. Cheng (1999) contradicts with Masih and Masih's (1999) result by finding a unidirectional causality from energy consumption and economic growth for India. Variables and time period are different in these studies.

Asafu-Adjaye (2000) tests the causal relationship between energy consumption and GDP by using a model based on demand functions that includes energy consumption, GDP, and price in four Asian developing countries. A short-run unidirectional causality running from energy consumption to GDP for India and Indonesia and short-run bidirectional causality between energy consumption and

GDP for Thailand and the Philippines are reported. Asafu-Adjaye's results for Indonesia, the Philippines, and India are different from the results of Masih and Masih (1996) and Cheng (1999). However Asafu-Adjaye's result for India is consistent with the finding of earlier study done by Masih and Masih (1996).

Chang *et al.* (2001) focus on the causal relationship between energy consumption and economic growth in a bivariate framework using Taiwanese data on energy consumption and GDP over the period 1982:01 to 1997:11 by using cointegration and VECM. His results indicate that energy consumption causes economic growth. The findings of this paper do not support Masih and Masih's (1997) earlier finding of bidirectional causation in a multivariate framework.

Soytaş *et al.* (2001) study the link between energy consumption and GDP for Turkey based on 1960-1995 series. They draw the conclusion that current as well as past changes in energy consumption have significant impact on a change in income.

Glasure (2002) applies five variable VECM consisting of real money supply a proxy for monetary policy, real government expenditure a proxy for government activity, dummy variable for the two oil price shocks, real oil price, energy consumption, and GDP to investigate the link between energy consumption and GDP for Korea by using VECM. He uses yearly data for the period 1961-1990 to conclude a bidirectional causality running between energy consumption and GDP. This result for Korea is similar to results of the Masih and Masih (1997) and Glasure and Lee (1997) studies which show the bidirectional causality between energy consumption and economic growth.

Hondroyiannis et al. (2002) consider the trivariate system of energy consumption, GDP, and price a measure of economic efficiency in causality studies of different categories of energy consumption: total, industrial, and residential consumption and economic growth for Greece (based on 1960-1996 series) by using VECM. They show a bidirectional causal relationship between energy consumption (total and industrial) and GDP and no causality between residential energy consumption and GDP.

Soytaş and Sarı (2003) examine the causality between energy consumption and GDP for the top 10 emerging markets, excluding China due to lack of information, and G7 countries. Using cointegration and VECM, the estimation results indicate bidirectional causality for Argentina, unidirectional causality running from GDP to energy consumption for Italy and Korea, from energy consumption to GDP for Turkey, France, Germany, and Japan and no evidence of causality for Poland and Indonesia.

Oh and Lee (2004a) employ cointegration and vector error correction modeling techniques to estimate the causal relationship in the Korea for the 1970-1999 period by applying multivariate model of energy consumption, GDP, capital, and labor. They show the presence of the unidirectional causality running from energy consumption to economic growth in the short run and bidirectional causality between energy consumption and GDP in the long run. Oh and Lee (2004b) use quarterly data over the period 1981-2000 for Korea. They apply cointegration and VECM on two multivariate models: one a demand side model and the other a production side model. In their results, VECM shows no causal relationship for energy consumption and GDP in the short run but bidirectional causal relationship between energy consumption and GDP in the long run. When the time period is changed, they find contradictory causality results for Korea.

Shiu and Lam (2004), Jumbe (2004), Yoo (2005), and Mozumder and Marathe (2007) focus on the causal relationship between electricity consumption and GDP. Shiu and Lam (2004) report a unidirectional causality from electricity consumption to GDP for China over the period 1971 to 2000 by using cointegration and error correction models. Jumbe (2004) applies Granger causality, cointegration, and error correction approach for discussing the relationship between various kinds of GDP, including overall GDP, agricultural GDP, and non-agricultural GDP and electricity consumption for Malawi during 1970-1999. The Granger causality results indicate a bidirectional causal relationship between electricity consumption and overall GDP and a unidirectional causal relationship running from non-agricultural GDP to electricity consumption. On the other hand VECM results show a unidirectional causality from overall GDP and non-agricultural GDP to electricity consumption. Yoo (2005) has discovered bidirectional causality between electricity consumption and GDP for Korea in 1970-2002 using cointegration and error correction models.

Mozumder and Marathe (2007) conclude that there exists a unidirectional causal relationship running from GDP to electricity consumption for the period 1971-99 in Bangladesh by utilizing cointegration and vector error correction model in a bivariate framework.

The work of Ghali and El-Sakka (2004) in Canada over the period 1961 to 1997 based on the production side multivariate model finds evidence of bidirectional causality between energy consumption and economic growth.

Paul and Bhattacharya (2004) analyze monthly India data from 1950 to 1996 through various causality tests. Their empirical results identify a short-run unidirectional causality from energy consumption to GDP using standard Granger causality test, a long-run unidirectional causality from GDP to energy consumption using Engle-Granger cointegration approach and a short-run unidirectional causality from energy consumption to GDP and long-run unidirectional causality from GDP to energy consumption using Johansen cointegration approach. The results of standard Granger causality test combine with the Engle-Granger cointegration approach are same as the results of Johansen cointegration approach.

Lee and Chang (2005) report the bidirectional causality between GDP and both total energy and coal consumption and the unidirectional causality from oil, gas and electricity consumption to GDP in Taiwan for the period 1954-2003.

Lise and Montfort (2007) investigate the causality between energy consumption and GDP for Turkey over the period 1970-2003. Using cointegration and error correction method, it is shown that there is an evidence of unidirectional causality running from economic growth to energy consumption with no feedback.

Applying standard Granger approach, Sica (2007) finds the unidirectional causality from energy consumption to GDP for Italy in 1960-2001. On the other hand, in the same study Sica (2007) employing error correction approach shows no evidence of causality for Italy. As a result, the standard Granger causality test has overestimated the causality relationship in this case.

The Granger causality results are very sensitive to the selection of lag length. The omission of the relevant lags can cause biased estimation results and the irrelevant lags in a model can also cause ineffective estimation results. Hsiao (1981) states a way to determine optimal lag length of each variable in a model by combining the Akaike's final prediction error (FPE) criterion with the Granger causality test. This method can be employed regardless of the existence of any cointegration properties of the data.

3.4 Hsiao's Granger Causality Test

Hsiao's procedure consists of two steps. The first step is to estimate equation (3.1) with varying values for m.

$$y_t = \alpha_0 + \sum_{i=1}^{m} \alpha_i y_{t-i} + \varepsilon_t \qquad (3.1)$$

where y_t and x_t are two stationary time series, m is the maximum lag order. Then, FPE is computed for each regression by using following formula:

$$FPE(m) = \left(\frac{T+m+1}{T-m-1}\right)\frac{SSE(m)}{T} \tag{3.2}$$

where T is sample size and SSE is the sum of squared error. The lag order which produces smallest FPE is chosen the optimal lag (m*).

The second step is to estimate equation (3.3) with varying values for n conditional on the optimal lag (m*).

$$y_t = \delta_0 + \sum_{i=1}^{m^*} \delta_i y_{t-i} + \sum_{j=1}^{n} \varphi_j x_{t-j} + u_t \tag{3.3}$$

The following FPE is computed for each value of n.

$$FPE(m^*, n) = \left(\frac{T+m^*+n+1}{T-m^*-n-1}\right)\frac{SSE(m^*, n)}{T} \tag{3.4}$$

Then, the optimum lag order n* which produces smallest FPE is determined. The FPE(m*) and FPE(m*, n*) are compared to show whether there exists Granger causality running from variable x to variable y. If FPE(m*) is less than FPE(m*, n*), this means that variable x does not Granger cause variable y. On the other hand, if FPE(m*) is greater than FPE(m*, n*), this means that variable x Granger cause variable y.

Cheng (1995) studies the temporal causal relationship between energy consumption and economic growth for the USA in 1947-1990 based on both bivariate and multivariate model. Case of non-causality is found in the USA using Hsiao's version of the Granger causality for both bivariate model of energy consumption and GNP and multivariate model of energy consumption, GNP, and capital.

Test of the causal relationship between energy consumption and economic growth in three Latin American countries applying Hsiao's version of the Granger causality is the subject of the study by Cheng (1997). His results indicate no causality in either direction in Mexico for the 1949-1993 period and in Venezuela for the 1952-1993 period in a multivariate model. However, in Brazil, for the 1963-1993 period, Cheng (1997) has revealed a unidirectional causal relationship running from energy consumption to GDP without feedback in a bivariate model.

Cheng and Lai (1997) examine the causality between energy consumption and economic growth in a bivariate model for Taiwan over the period 1955 to 1993. They find that no cointegrating relationship exists between energy consumption and GDP. The results of Hsiao's version of the Granger causality methodology indicate unidirectional causality from GDP to energy consumption. Yang (2000) tests the causal relationship between income and various kind of energy consumption in Taiwan using 1954-1997 data. Using cointegration and Hsiao's version of the Granger causality, the estimation results indicate bidirectional causality between energy consumption (total, coal and electricity) and GDP, unidirectional causality running from GDP to oil consumption and unidirectional causality from gas consumption to GDP. His result for total energy consumption and GDP does not support previous the finding of Cheng and Lai (1997) of unidirectional causal relationship running from GDP to energy consumption.

Cheng (1998) applies Hsiao's version of Granger causality test to investigate the causality between energy consumption and GNP for Japan in 1952-1995 based on production side model of energy consumption, GNP, employment, and capital. This study finds that there is no cointegration among these variables and economic growth Granger causes energy consumption.

Aqeel and Butt (2001) analyze monthly Pakistani data from 1955 to 1996 through cointegration and Hsiao’s version of the Granger causality test. They conclude no cointegration between the variables and unidirectional causality running from GDP to total energy and oil consumption and unidirectional causality running from electricity consumption to GDP.

Altınay and Karagöl (2004) focus on the causal relationship between energy consumption and economic growth for Turkey (based on 1950-2000 series) applying bivariate model. Their study indicates that energy consumption and GDP are stationary series with different structural breaks and there is no evidence of causality relationship between energy consumption and GDP using Hsiao’s version of the Granger causality test.

Yoo (2006) employs cointegration and Hsiao’s version of the Granger causality tests to analyze the causality relationship between electricity consumption and economic growth in the four countries of the Association of South East Asian Nations (ASEAN) by using data for the period 1971 to 2002. Evidence shows that there does not exist a long-run relationship between electricity consumption and GDP for all countries but there is bidirectional causality between electricity consumption and GDP for Malaysia and Singapore and unidirectional causality running from GDP to electricity consumption for Indonesia and Thailand.

Chontanawat *et al.* (2006) use the cointegration and Hsiao’s version of the Granger causality methodology to analyze the causal relationship between energy consumption and output for 30 OECD countries over the period 1960-2000 and 78 non-OECD countries over the period 1971-2000. This is the first study of such a large number of countries. The conclusions indicate that the proportion of the developed OECD countries for causality running from energy to GDP and causality running from GDP to energy is greater than the developing non-OECD countries. However the difference of the causality from energy consumption to GDP is greater than the difference of the causality from GDP to energy consumption. Energy is an important ingredient for economic growth for developed OECD countries (Lee 2005).

According to Sims *et al.* (1990) and Toda and Phillips (1993) a standard F-test for testing Granger non-causality may not be valid in an integrated or cointegrated system. Moreover, according to Mavrotas and Kelly (2001) and Chowdhury and Mavrotas (2003) testing for unit roots and cointegration before Granger causality test may cause an over-rejection of the non-causality. As a consequence, autoregressive distributed lag (ARDL) model, the Toda-Yamamoto, and the Dolado-Lütkepohl approach are used for testing Granger causality, since they do not require pretesting integration and cointegration properties of the data series. Hence these tests eliminate potentially biased pretest for stationarity and cointegration.

3.5 Toda-Yamamoto Test

Toda and Yamamoto have developed a simple procedure that involves testing for Granger non-causality in the following VAR system of whether the variables are integrated, cointegrated or not. In order to apply the Toda and Yamamoto approach, (k+dmax)th order of VAR model is estimated, where k is the optimal order of the model and dmax is the maximal order of integration of the variables. The causality is tested by standard Wald test ignoring last dmax lagged vector of the variables.

$$y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} y_{t-i} + \sum_{j=k+1}^{d_{\max}} \alpha_{2j} y_{t-j} + \sum_{i=1}^{k} \beta_{1i} x_{t-i} + \sum_{j=k+1}^{d_{\max}} \beta_{2j} x_{t-j} + \varepsilon_{1t} \tag{3.5}$$

$$x_t = \delta_0 + \sum_{i=1}^{k} \delta_{1i} x_{t-i} + \sum_{j=k+1}^{d_{\max}} \delta_{2j} x_{t-j} + \sum_{i=1}^{k} \varphi_{1i} y_{t-i} + \sum_{j=k+1}^{d_{\max}} \varphi_{2j} y_{t-j} + \varepsilon_{2t} \tag{3.6}$$

From equation (3.5), Granger causality from x_t to y_t implies $\beta_{1i} \neq 0 \; \forall i$ and in equation (3.6), Granger causality from y_t to x_t implies $\varphi_{1i} \neq 0 \; \forall i$.

Fatai *et al.* (2004) analyze the causal relationship between GDP and various categories of energy consumption in New Zealand and Australia for the period 1960 to 1999. They use the standard Granger causality test and a modified version of Granger causality test proposed by Toda and Yamamoto for New Zealand and the results are similar with both methodology. They find out unidirectional causality running from GDP to industrial and total energy consumption. The standard Granger causality test, the Toda-Yamamoto approach, and ARDL approach are applied for Australia. They have discovered unidirectional causality running from GDP to coal, electricity, and final energy consumption using the standard Granger causality test and Toda-Yamamoto test. On the other hand, the result for coal consumption and GDP is inconclusive for ARDL approach.

Wolde-Rufael (2004) applies Toda-Yamamoto methodology to investigate the causality between GDP and aggregate energy consumption as well as several disaggregate categories for Shanghai in 1952-1999. The study shows that unidirectional causality runs from coal, coke, electricity, and total energy consumption to GDP.

Wolde-Rufael (2005) studies the causal relationship between energy consumption and economic growth for 19 African countries between 1971 and 2001 The Toda-Yamamoto test results indicate a bidirectional causality for energy consumption and GDP for Gabon and Zambia, a unidirectional causality from GDP to energy consumption for Algeria, Democratic Republic of Congo, Egypt, Ghana, and Ivory Coast, unidirectional but reversed causality for Cameroon, Morocco, and Nigeria and neutral relationship for Benin, Republic of Congo, Kenya, Senegal, South Africa, Sudan, Togo, Tunisia, and Zimbabwe.

Altınay and Karagöl (2005) use standard Granger causality test and Dolado-Lütkepohl test to examine the causal relationship between electricity consumption and economic growth for Turkey using the annual data covering the period 1950-2000. Zivot and Andrews's unit root test with endogenous structure break indicate that both series are stationary with different structural breaks. Similar to Toda and Yamamoto test, Dolado and Lütkepohl employ a modified Wald test (MWALD) for testing causality. Dolado and Lütkepohl estimate a $(k+1)^{th}$ order of VAR and test the causality by standard Wald test ignoring last lagged vector of the variables. The results from both tests suggest unidirectional causality running from electricity consumption to GDP.

Hatemi and Irandoust (2005) examine the causality between energy consumption and economic growth for Sweden over the period 1965 to 2000. They consider trivariate system of energy consumption, GDP, and consumer price index as a proxy for price instead of bivariate system of energy consumption and GDP. They test for causality among the variables using Toda-Yamamoto method. However they use the leveraged bootstrap simulation technique to generate critical values. Empirical results have established the existence of causality running from GDP to energy consumption.

Lee (2006) tries to demonstrate the causal relationship between energy consumption and economic growth for G-11 countries. Results using the test based on Toda-Yamamoto procedure reveal bidirectional causality for GDP and energy consumption in the USA, unidirectional causality from energy consumption to GDP in Canada, Belgium, Netherlands, and Switzerland, exactly for reverse in France, Italy, and Japan and neutrality for the UK, Germany, and Sweden.

Ciarreta and Zarraga (2007) focus on the causality between electricity consumption and economic growth proxied by GDP for Spain between 1971 and 2005. Applying both standard Granger causality and Dolado-Lütkepohl methodology, they find unidirectional causality running from GDP to electricity consumption.

Zachariadis (2007) applies different Granger causality test methods such as VEC, ARDL, and Toda-Yamamoto to test causal relationship between GDP and total energy consumption as well as sectoral energy consumption for G-7 countries over the different time periods. The results of these tests are robust for the US. In contrast, the study shows that the results of these tests are not consistent for other countries. Since US data set has the largest sample size and the power of these tests is low in the small data sets.

Previous studies having used time series data may yield inconsistent results because of a short data span. According to Pierse and Shell (1995) the short data span lowers the power of unit root test. Besides, Perron (1991) points out that the power of cointegration test can be distorted with small sample size. To this end many studies use panel unit root and panel cointegration tests combining the time series and cross sectional data in order to provide more powerful test results.

3.6 Panel Cointegration and Error Correction Model

Lee (2005) examines the causality issue between energy consumption and GDP for 18 developing countries over the period 1975 to 2001 using recently developed three different panel unit root tests by Levine and Lin (1993), Im *et al.* (1997), and Hadri (2000), heterogeneous panel cointegration developed by Pedroni (1999) and panel-based error correction model. Empirical results based on trivariate model of energy consumption, GDP, and capital indicate that there exists a long run equilibrium relationship among these variables after adding specific heterogeneous country effect and energy consumption Granger causes GDP in both short and long-run.

As opposed to previous studies that focus on oil importing countries, Al-Iriani (2006) has investigated the causal relationship between energy consumption and economic growth proxied by GDP among Gulf Cooperation Council (GCC) six members, namely Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates that are oil exporting countries for the 1971-2002 period. The results conclude that energy consumption and GDP series have a panel unit root applying panel unit root test proposed by Im *et al*. (1997) and the data series are cointegrated using Pedroni's heterogeneous panel cointegration test. Furthermore, panel causality test proposed by Holtz-Eakin *et al.* (1988, 1989) shows the unidirectional causality running from GDP to energy consumption. This implies that an energy conservation policy may be feasible without causing adverse effect on GDP growth in GCC countries.

Lee and Chang (2007) employ data on 22 developed from 1965 to 2002 and 18 developing countries from 1971 to 2002 to test the causal relationship between energy consumption and GDP. They use panel data stationarity test with multiple structural break proposed by Carrion-i-Silvestre *et al.* (2005) and find that both energy consumption and GDP series are stationary series for both developed and developing countries. Applying panel VARs, this study reveals bidirectional causal relationship between energy consumption and economic growth for developed countries and unidirectional causal relationship running from economic growth to energy consumption for developing countries. Their result for developing countries is inconsistent with the result of an earlier study done by Lee (2005).

Table 2: *Empirical Results from Causality Studies between Energy Consumption and Economic Growth*

Study	Empirical method	Period	Countries	Results
Kraft and Kraft (1978)	Sims' technique	1947-1974	United States	GNP→E
Akarca and Long (1980)	Sims' technique	1947-1972	United States	no causality
Yu and Hwang (1984)	Sims' technique Standard Granger test	1947-1979	United States	no causality
Yu and Choi (1985)	Sims' technique Standard Granger test	1950-1976	The Philippines	E→GNP
			South Korea	GNP→E
			United States	no causality
			United Kingdom	no causality
			Poland	no causality
Erol and Yu (1987)	Sims' technique Standard Granger test	1950-1982	Canada	E→GNP
			West Germany	GNP→E
			Italy	GNP→E
			France	no causality
			United Kingdom	no causality
			Japan	GNP↔E
Stern (1993)	Standard Granger test	1974-1990	United States	E→GDP
Ebohon (1996)	Standard Granger test	1960-1984	Tanzania	GNP and GDP↔E
		1960-1981	Nigeria	GNP and GDP↔E
Nachane (1988)	Sims' technique Standard Granger test Cointegration	1950-1985	16 countries	GNP↔E (except Colombia and Venezuela)
Yu and Jin (1992)	Cointegration	1974-1990 (monthly)	United States	no causality
Stern (2000)	Cointegration	1948-1994	United States	E→GDP
Ghosh (2002)	Cointegration	1950-1997	India	GDP→Elec.
Masih and Masih (1996)	Cointegration & Error correction model	1955-1990	India	E→GDP
		1960-1990	Indonesia	GDP→E
		1955-1990	Pakistan	GDP↔E
		1955-1990	Malaysia	no causality
		1960-1990	Singapore	no causality
		1955-1991	The Philippines	no causality
Glasure and Lee (1997)	Cointegration & Error correction model	1961-1990	South Korea	GDP↔E
			Singapore	GDP↔E
	Standard Granger test		South Korea	no causality
			Singapore	E→GDP
Masih and Masih (1997)	Cointegration & Error correction model	1955-1991	South Korea	GDP↔E
		1952-1992	Taiwan	GDP↔E
Masih and Masih (1998)	Cointegration & Error correction model	1955-1991	Thailand	E→GDP
			Sri Lanka	E→GDP
Cheng (1999)	Cointegration & Error correction model	1952-1995	India	GNP→E
Asafu-Adjaye (2000)	Cointegration & Error correction model	1973-1995	India	E→GDP
		1973-1995	Indonesia	E→GDP
		1971-1995	Thailand	GDP↔E
		1971-1995	The Philippines	GDP↔E

Table 2 continued

Chang et al. (2001)	Cointegration & Error correction model	1982-1997 (monthly)	Taiwan	E→GDP
Soytaş et al. (2001)	Cointegration & Error correction model	1960-1995	Turkey	E→GDP
Glasure (2002)	Cointegration & Error correction model	1961-1990	Korea	GDP↔E
Hondroyiannis et al. (2002)	Cointegration & Error correction model	1960-1996	Greece	GDP↔E
Soytaş and Sarı (2003)	Cointegration & Error correction model	1950-1990	Argentina	GDP↔E
		1950-1992	Italy	GDP→E
		1953-1991	Korea	GDP→E
		1950-1992	Turkey	E→GDP
		1950-1992	France	E→GDP
		1950-1992	Germany	E→GDP
		1950-1992	Japan	E→GDP
		1965-1994	Poland	no causality
		1960-1992	Indonesia	no causality
Oh and Lee (2004a)	Cointegration & Error correction model	1970-1999	Korea	GDP↔E(LR) E→GDP(SR)
Oh and Lee (2004b)	Cointegration & Error correction model	1981-2000 (quarterly)	Korea	GDP↔E(LR) no causality(SR)
Jumbe (2004)	Standard Granger test	1970-1999	Malawi	GDP↔Elec.
	Cointegration & Error correction model			GDP→Elec.
Yoo (2005)	Cointegration & Error correction model	1970-2002	Korea	GDP↔Elec.
Mozumder and Marathe (2007)	Cointegration & Error correction model	1971-1999	Bangladesh	GDP→Elec.
Ghali and El-Sakka (2004)	Cointegration & Error correction model	1961-1997	Canada	GDP↔E
Paul and Bhattacharya (2004)	Standard Granger test	1950-1996	India	E→GDP(SR)
	Engle-Granger cointegration			GDP→E(LR)
	Johansen cointegration			GDP↔E
Lee and Chang (2005)	Error correction model Cointegration &	1954-2003	Taiwan	GDP↔E
Lise and Montfort (2007)	Error correction model Cointegration &	1970-2003	Turkey	GDP→E
Sica (2007)	Standard Granger test	1960-2001	Italy	E→GDP
	Error correction model Cointegration &			no causality
Cheng (1995)	Hsiao's Granger test	1947-1990	United States	no causality
Cheng (1997)	Hsiao's Granger test	1949-1993	Mexico	no causality
		1952-1993	Venezuela	no causality
		1963-1993	Brazil	E→GDP
Cheng and Lai (1997)	Hsiao's Granger test	1955-1993	Taiwan	GDP→E
Yang (2000)	Hsiao's Granger test	1954-1997	Taiwan	GDP↔E
Cheng (1998)	Hsiao's Granger test	1952-1995	Japan	GNP→E

Table 2 continued

Aqeel and Butt (2001)	Hsiao's Granger test	1955-1996	Pakistan	GDP→E
Altınay and Karagöl (2004)	Hsiao's Granger test	1950-2000	Turkey	no causality
Yoo (2006)	Hsiao's Granger test	1971-2002	Malaysia	GDP↔Elec.
			Singapore	GDP↔Elec.
			Indonesia	GDP→Elec.
			Thailand	GDP→Elec.
Fatai et al. (2004)	Standard Granger test and Toda-Yamamoto	1960-1999	New Zealand	GDP→E
	Standard Granger test, Toda-Yamamoto test and ARDL	1960-1999	Australia	GDP→E
Wolde-Rufael (2004)	Toda-Yamamoto test	1952-1999	Shanghai	E→GDP
Wolde-Rufael (2005)	Toda-Yamamoto test	1971-2001	Gabon, Zambia	GDP↔E
			Ivory Coast, Congo DR Egypt, Ghana, Algeria	GDP→E
			Morocco, Nigeria, Cameroon	E→GDP
			Benin, Congo RP, Togo Kenya, Senegal Sudan, South Africa Tunisia, Zimbabwe	no causality
Altınay and Karagöl (2005)	Standard Granger test and Dolado-Lütkepohl test	1950-2000	Turkey	Elec.→GDP
Hatemi and Irandoust (2005)	Toda-Yamamoto test	1965-2000	Sweden	GDP→E
Lee (2006)	Toda-Yamamoto test	1960-2001	United States	GDP↔E
		1960-2001	Belgium, Switzerland Netherlands	E→GDP
		1965-2001	Canada	E→GDP
		1960-2001	France, Italy, Japan	GDP→E
		1960-2001	United Kingdom, Sweden	no causality
		1971-2001	Germany	no causality
Ciarreta and Zarraga (2007)	Standard Granger test and Dolado-Lütkepohl test	1971-2005	Spain	GDP→Elec.
Lee (2005)	Panel cointegration and error correction model	1975-2001	18 Developing Countries	E→GDP
Al-Iriani (2006)	Panel cointegration and error correction model	1971-2002	6 GCC Countries	GDP→E
Lee and Chang (2007)	Panel cointegration and error correction model	1965-2002	22 Developed Countries	GDP↔E
		1971-2002	18 Developing Countries	GDP→E

CHAPTER 4

METHODOLOGY

Granger (1969) causality tests in panel data models are generally classified in two different types according to the autoregressive coefficients and regression coefficients. In the first type proposed by Holtz-Eakin *et al.* (1985), Hsiao (1986), Holtz-Eakin *et al.* (1988), Hsiao (1989), Weinhold (1996), Weinhold (1999), Nair-Reichart and Weinhold (2001) and Choe (2003), it is assumed that the autoregressive coefficients and regression coefficients are variable. On the contrary, in the second type proposed by Hurlin and Venet (2001), Hurlin (2004a), Hurlin (2004b), Hansen and Rand (2004), they consider that the autoregressive coefficients and regression coefficients are constant. In this thesis, the second type is used since there are a large number of cross-section units (N) over a short time period (T) in the data set, limiting sample size to estimate a model with changing coefficients.

According to Hurlin and Venet (2001), there are two covariance stationary variables, denoted by x and y, observed on T time periods and on N cross-section units. Given the standard Granger (1969) causality procedure, for each individual $i \in [1, N]$, the variable $x_{i,t}$ is causing $y_{i,t}$ if the prediction error of current $y_{i,t}$ declines when past values of $x_{i,t}$ and past values of $y_{i,t}$ are used. In practice, it will not usually be possible to use completely optimum predictors, so only linear ones are considered. Therefore, this concept can be examined in the panel data context of a time-stationary VAR representation. For each cross-section unit i and time period t:

$$y_{i,t} = \sum_{k=1}^{p} \alpha^{(k)} y_{i,t-k} + \sum_{k=0}^{p} \beta_i^{(k)} x_{i,t-k} + u_{i,t} \qquad i = 1,...,N \tag{4.1}$$

with $u_{i,t} = \mu_i + \varepsilon_{i,t}$ where $\varepsilon_{i,t}$ are i.i.d. $(0, \sigma_\varepsilon^2)$ and μ_i are the individual effects. Hurlin and Venet (2001) assume that the autoregressive coefficients $\alpha^{(k)}$ and regression coefficients $\beta_i^{(k)}$ are constant for all $k \in [1, p]$. In addition, they assume that autoregressive coefficients $\alpha^{(k)}$ are identical for all cross-section units, while the regression coefficients $\beta_i^{(k)}$ can be different. It is further assumed that following assumptions about the individual residuals are satisfied $\forall i \in [1, N]$, $\forall t \in [1, T]$:

(i) $E(\mu_i) = E(\varepsilon_{i,t}) = E(\mu_i \varepsilon_{i,t}) = 0$

(ii) $E(\mu_i \mu_j) = 0$ for all $i \neq j$ and $E(\mu_i^2) = \sigma_\mu^2$ for all i

(iii) $E(\varepsilon_{i,t} \varepsilon_{j,s}) = 0$ for all $i \neq j$ and $t \neq s$ and $E(\varepsilon_{i,t}^2) = \sigma_\varepsilon^2$ for all i and t

(iv) $E(\mu_i x_{i,s}) = E(\varepsilon_{i,t} x_{i,s}) = 0$ for all s and t

And both processes are covariance stationary. Therefore, these variables are assumed to satisfy the following properties:

(i) $E(x_{i,t}^2) < \infty$ and $E(y_{i,t}^2) < \infty$

(ii) $E(x_{i,t} x_{j,s})$, $E(y_{i,t} y_{j,s})$ and $E(y_{i,t} x_{j,s})$ are functions of the difference $t - s$

(iii) $E(x_{i,t})$ and $E(y_{i,t})$ are independent of t

Both cross-section and time series information are used to test Granger causality in panel data model. This approach allows us to increase the degrees of freedom compared to cross-sectional approach and reduce the collinearity among explanatory variables. Therefore, this procedure improves the efficiency of Granger causality tests. When the Granger causality test in panel data model is used, heterogeneity between cross-section units is taken into account. The first source of heterogeneity comes from permanent cross sectional disparities between cross-section units. A pooled regression without heterogeneous intercepts causes biased autoregressive coefficients $\alpha^{(k)}$ and regression coefficients $\beta_i^{(k)}$. If individual effects, μ_i, are used, the first source of heterogeneity is controlled. The second source is caused by heterogeneous regression coefficients $\beta_i^{(k)}$. This source of heterogeneity may lead to wrong causality conclusions about different subgroups. Therefore, the analysis of causality in panel data sets should take into consideration the different sources of heterogeneity of the data generating process (Hurlin and Venet, 2001). There are three different types of causality hypothesis in the panel data model with fixed coefficients.

4.1 Homogenous Non Causality (HNC) Hypothesis

Under HNC hypothesis, there do not exist any individual causality relationships and the hypothesis can be showed by:

$$E(y_{i,t} \mid \overline{y}_{i,t}, \mu_i) = E(y_{i,t} \mid \overline{y}_{i,t}, \overline{x}_{i,t}, \mu_i) \text{ for all } i$$

where the set of past values of $y_{i,t}$, denoted by $\overline{y}_{i,t} = (y_{i,-p}, ..., y_{i,0}, ..., y_{i,t-1})'$, the set of past values of $x_{i,t}$, denoted by $\overline{x}_{i,t} = (x_{i,-p}, ..., x_{i,0}, ..., x_{i,t-1})'$, the best linear predictor of $y_{i,t}$ given the set of past values of $y_{i,t}$, denoted by $E(y_{i,t} \mid \overline{y}_{i,t}, \mu_i)$ and the best linear predictor of $y_{i,t}$ given the set of past values of $y_{i,t}$ and set of past values of $x_{i,t}$, denoted by $E(y_{i,t} \mid \overline{y}_{i,t}, \overline{x}_{i,t}, \mu_i)$.

Firstly, HNC is testing whether or not regression coefficients $\beta_i^{(k)}$ are null for all cross-section unit i and for all lag k and this test may be formulated as:

$$H_0 : \beta_i^{(k)} = 0 \quad \forall i \in [1, N], \forall k \in [1, p] \qquad (4.2)$$

$$H_1 : \beta_i^{(k)} \neq 0 \quad \exists (i, k)$$

The resultant Wald statistic based on Np linear restrictions in (4.2) may be expressed as:

$$F_{HNC} = \frac{(SSR_R - SSR_U)/(Np)}{SSR_U / [NT - N(1+p) - p]}$$

where the unrestricted sum of squared residuals, denoted by SSR_U, is obtained from the unrestricted model (4.1) and the restricted sum of squared residual, denoted by SSR_R, is obtained from the model under H_0. If the null hypothesis is not rejected, this means that there is no causal relationship from the variable x to the variable y for all cross-section units. If the null hypothesis is rejected, this means that the variable x is causing the variable y in at least one cross-section unit.

The maximum likelihood estimator corresponds to the fixed effects (FE) estimator when the individual effects, μ_i are assumed to be fixed. Then, model (4.1) can be written as:

$$y_{i,t} = \sum_{k=1}^{p} \alpha^{(k)} y_{i,t-k} + \sum_{k=0}^{p} \beta_i^{(k)} x_{i,t-k} + \mu_i + \varepsilon_{i,t} \qquad (4.3)$$

Then, model (4.3) may be expressed in stacked form as:

$$y = W\alpha + X\beta + D_\mu \mu + \varepsilon \qquad (4.4)$$

where, $D_\mu = I_N \otimes e_T$ is an $NT \times N$ matrix of dummy variables and vector of individual effect, vector of autoregressive coefficients, vector of regression coefficients are respectively defined by:

$$\underset{(N,1)}{\mu} = (\mu_{1,}\mu_2,...,\mu_N)'$$

$$\underset{(p,1)}{\alpha} = \left[\alpha^{(1)},\alpha^{(2)},...,\alpha^{(p)}\right]'$$

$$\underset{(Np+N,1)}{\beta} = \left[\beta_1^{(0)},\beta_1^{(1)},...\beta_1^{(p)},\beta_2^{(0)},\beta_2^{(1)},...,\beta_2^{(p)},.......,\beta_N^{(0)},\beta_N^{(1)},...,\beta_N^{(p)}\right]'$$

The vector y, the matrix of W, X and the vector of error terms are respectively defined by:

$$\underset{(TN,1)}{y} = \begin{bmatrix} y_1^{(0)} \\ y_2^{(0)} \\ . \\ y_N^{(0)} \end{bmatrix} \text{ where, } \underset{(T,1)}{y_i^{(-k)}} = \begin{bmatrix} y_{i,-k+1} \\ y_{i,-k+2} \\ . \\ y_{i,T-k} \end{bmatrix}$$

$$\underset{(TN,p)}{W} = \begin{bmatrix} W_1 \\ W_2 \\ . \\ W_N \end{bmatrix} \text{ where, } \underset{(T,p)}{W_i} = \left[y_i^{(1)} : y_i^{(2)} : ... : y_i^{(p)}\right]$$

$$\underset{(TN,Np+N)}{X} = \begin{bmatrix} X_1 & 0 & . & 0 \\ 0 & X_2 & . & . \\ . & . & . & 0 \\ 0 & . & 0 & X_N \end{bmatrix} \text{ where, } \underset{(T,p+1)}{X_i} = \left[x_i^{(0)} : x_i^{(1)} : ... : x_i^{(p)}\right] \ \underset{(T,1)}{x_i^{(-k)}} = \begin{bmatrix} x_{i,-k+1} \\ x_{i,-k+2} \\ . \\ x_{i,T-k} \end{bmatrix}$$

$$\underset{(TN,1)}{\varepsilon} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ . \\ \varepsilon_N \end{bmatrix} \text{ where, } \underset{(T,1)}{\varepsilon_i} = \begin{bmatrix} \varepsilon_{i,1} \\ y_{i,2} \\ . \\ y_{i,T} \end{bmatrix}$$

$N_\mu = (I_N \otimes I_T) - M_\mu$ where $M_\mu = D_\mu (D_\mu' D_\mu)^{-1} D_\mu' = I_N \otimes M_T$ so that $N_\mu = (I_N \otimes N_T)$ with $N_T = I_T - (e_T' e_T)/T$.

If Z is defined by $Z = [W : X]$ and γ is defined by $\gamma' = (\alpha' : \beta')$, then the model (4.4) can be written as:

$$y = Z\gamma + D_\mu \mu + \varepsilon \tag{4.5}$$

Then, the unrestricted sum of squared residuals, denoted by SSR_U, is obtained from the model (4.5) and the restricted sum of squared residuals, denoted by SSR_R, is obtained from the model (4.5) under H_0. SSR_U and SSR_R are calculated as:

$$SSR_U = y'N_\mu y - (y'N_\mu Z)(Z'N_\mu Z)^{-1}(Z'N_\mu y) \tag{4.6}$$

$$SSR_R = y'N_\mu y - (y'N_\mu W)(W'N_\mu W)^{-1}(W'N_\mu y)$$

4.2 Homogenous Causality (HC) Hypothesis

HC implies that there exists N causality relationships and the hypothesis can be showed by:

$$E(y_{i,t} \mid \overline{y}_{i,t}, \mu_i) \neq E(y_{i,t} \mid \overline{y}_{i,t}, \overline{x}_{i,t}, \mu_i) \text{ for all } i$$
$$E(y_{i,t} \mid \overline{y}_{i,t}, \overline{x}_{i,t}, \mu_i) = E(y_{j,t} \mid \overline{y}_{j,t}, \overline{x}_{j,t}, \mu_j) \text{ for all } i \text{ and } j$$

The HC hypothesis is testing whether or not all the regression coefficients $\beta_i^{(k)}$ are identical for all lag k. If the HNC hypothesis is rejected, the HC hypothesis is tested. This test may be formulated as:

$$\begin{aligned} H_0' &: \beta_i^{(k)} = \beta^{(k)} \quad \forall i \in [1, N], \forall k \in [1, p] \\ H_1' &: \beta_i^{(k)} \neq \beta_j^{(k)} \quad \exists (i, j) \in [1, N],\ \exists k \in [1, p] \end{aligned} \tag{4.7}$$

The resultant Wald statistic based on $p(N-1)$ linear restrictions in (4.7) may be expressed as:

$$F_{HC} = \frac{(SSR_R' - SSR_U) / [p(N-1)]}{SSR_U / [NT - N(1+p) - p]}$$

where the restricted sum of squared residuals, denoted by SSR_R', is obtained from the model under H_0'. If the null hypothesis is not rejected, this means that there is a causal relationship from the variable x to the variable y for all cross-section units and this causality is homogeneous. If the null hypothesis is rejected, this means that there is no homogenous causality relationship from the variable x to the variable y for all cross-section units but this does not mean that there is no causal relationship from the variable x to the variable y. This implies that the variable x is causing the variable y in at least one cross-section unit.

The maximum likelihood estimator corresponds to the fixed effects (FE) estimator when the individual effects, μ_i are assumed to be fixed. Then, the unrestricted sum of squared residuals, denoted by SSR_U, is obtained from the equation (4.6) and the restricted sum of squared residuals, denoted by SSR'_R, is obtained from the model (4.5) under H'_0. SSR'_R is calculated as:

$$SSR'_R = y'N_\mu y - (y'N_\mu \widehat{X})(\widehat{X}'N_\mu \widehat{X})^{-1}(\widehat{X}'N_\mu y)$$

where $\widehat{X}'$ is defined by:

$$\underset{(p+1,TN)}{\widehat{X}'} = \begin{bmatrix} X_1' & X_2' & \dots & X_N' \end{bmatrix}'$$

4.3 Heterogeneous Non Causality (HENC) Hypothesis

The last hypothesis is HENC, in which there exist at least one and at most $N-1$ non causality relationships. The hypothesis can be showed by:

$$E(y_{i,t} \mid \overline{y}_{i,t}, \mu_i) = E(y_{i,t} \mid \overline{y}_{i,t}, \overline{x}_{i,t}, \mu_i) \text{ for some } i$$

The HENC hypothesis is testing for each cross-section unit whether or not all the regression coefficients $\beta_i^{(k)}$ are null for all lag k. If the HC hypothesis is rejected, the HENC hypothesis is tested. This test may be formulated as:

$$\begin{aligned} &H''_0 : \beta_i^{(k)} = 0 \quad \forall i \in [1, N], \forall k \in [1, p] \\ &H''_1 : \beta_i^{(k)} \neq 0 \quad \forall i \in [1, N], \exists k \in [1, p] \end{aligned} \tag{4.8}$$

The resultant Wald statistic for each cross-section unit based on p linear restrictions in (4.8) may be expressed as:

$$F^{i}_{HENC} = \frac{(SSR''_{R,i} - SSR_U)/p}{SSR_U / [NT - N(1+2p) + p]}$$

where the restricted sum of squared residuals for each cross-section unit, denoted by $SSR''_{R,i}$, is obtained from the model under H''_0. If the null hypothesis is not rejected, this means that there exists a cross-section unit for which there is no causal relationship from the variable x to the variable y. If the null hypothesis is rejected, this means that there is a causal relationship from the variable x to the variable y for this cross-section unit.

The maximum likelihood estimator corresponds to the fixed effects (FE) estimator when the individual effects, μ_i are assumed to be fixed. Then, the unrestricted sum of squared residuals, denoted by SSR_U, is obtained from the equation (4.6) and the restricted sum of squared residuals, denoted by $SSR''_{R,i}$, is obtained from the model (4.5) under H''_0. $SSR''_{R,i}$ is calculated as:

$$SSR''_R = y'N_\mu y - (y'N_\mu Z_i)(Z_i'N_\mu Z_i)^{-1}(Z_i'N_\mu y)$$

where Z_i is defined by $Z_i = [W : \widehat{X}_i]$ and matrix $\widehat{X}_i$ is defined by:

$$\underset{(T(N-1),(N-1)(p+1))}{\widehat{X}_i} = \begin{bmatrix} X_1 & 0 & . & . & 0 \\ 0 & X_2 & . & . & . \\ . & . & X_{i-1} & . & 0 \\ . & . & . & . & . \\ . & . & . & X_{i+1} & . \\ 0 & . & . & 0 & X_N \end{bmatrix}$$

In one-way panels, in general there are a large number of cross-section units (N) over a short time period (T). According to Nickell (1981), the fixed effects estimator of the autoregressive coefficients is inconsistent. To simplify the equation (4.4), it is assumed that there are only one lagged dependent variable, denoted by y_{-1} and one explanatory variable, denoted by X

$$y = y_{-1}\alpha^{(1)} + X\beta^{(1)} + u \tag{4.9}$$

To see why this occurs, equation (4.9) can be expressed in the transformed equation as:

$$N_{\mu}y = (N_{\mu}y_{-1})\alpha^{(1)} + (N_{\mu}X)\beta^{(1)} + N_{\mu}\varepsilon \tag{4.10}$$

In order the fixed effects estimator of coefficients to be consistent, $N_{\mu}y_{-1}$ and $N_{\mu}X$ should be uncorrelated with $N_{\mu}\varepsilon$ as $N \to \infty$ in equation (4.10). Since X represent exogenous variables, $N_{\mu}X$ satisfies this requirement. On the contrary, the asymptotic covariance expression for $N_{\mu}y_{-1}$ and $N_{\mu}\varepsilon$ may be expressed as:

$$\begin{aligned} &\underset{N\to\infty}{p\lim}\frac{1}{NT}y_{-1}{}' N_{\mu}\varepsilon = \underset{N\to\infty}{p\lim}\frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}(Y_{i,t-1} - \overline{Y}_{i,-1})(\varepsilon_{i,t} - \overline{\varepsilon}_{i}) \\ &= E_i\left[\frac{1}{T}\sum_{t=1}^{T}(Y_{i,t-1} - \overline{Y}_{i,-1})(\varepsilon_{i,t} - \overline{\varepsilon}_{i})\right] \\ &= \frac{1}{T}\left[\sum_{t=1}^{T}E_i(Y_{i,t-1}\varepsilon_{i,t}) - \sum_{t=1}^{T}E_i(\overline{Y}_{i,-1}\varepsilon_{i,t}) - \sum_{t=1}^{T}E_i(Y_{i,t-1}\overline{\varepsilon}_{i}) + TE_i(\overline{Y}_{i,-1}\overline{\varepsilon}_{i})\right] \end{aligned} \tag{4.11}$$

Since it is assumed that the $\varepsilon_{i,t}$ are independent and identically distributed, $\underset{N\to\infty}{p\lim}\frac{1}{N}[.] = E_i[.]$. In equation (4.11) $E_i(Y_{i,t-1}\varepsilon_{i,t}) = 0$ but $E_i(\overline{Y}_{i,-1}\varepsilon_{i,t})$, $E_i(Y_{i,t-1}\overline{\varepsilon}_{i})$ and $E_i(\overline{Y}_{i,-1}\overline{\varepsilon}_{i})$ are not equal to zero. Therefore, $N_{\mu}y_{-1}$ and $N_{\mu}\varepsilon$ are asymptotically correlated. This correlation will tend to zero not only when N tends to infinity but also T tends to infinity.

On the other hand, the MLE for dynamic fixed effects models is still biased with the introduction of exogenous variables when T is small (Hurlin and Venet, 2001). However, Nickell (1981) pointed out that the size of bias on the coefficients of lagged endogenous variables falls with the presence of exogenous regressors. Moreover, Judson and Owen (1999) found that this inconsistency decreases as T become larger in their Monte Carlo experiments. However, this asymptotic bias could be as much as 20% of the true value of the coefficient in first order autoregressive process (Judson and Owen, 1999). In this case, FE estimator is used since its bias may not be large.

CHAPTER 5

DATA AND ESTIMATE RESULTS

5.1 Data

Data used in the analysis are real GDP and energy use during the period 1990–2004. The use of GDP is better than the GNP, since the country's total energy consumption depends on goods and services produced within the country. The variables are as follows.

E : Energy use in kg of oil equivalent per capita
GDP: Gross Domestic Product per capita (constant 2000 US$)

GDP per capita and energy use per capita in a panel data setting are taken from World Bank's World Development Indicators, 2007. World Bank classifies all member countries (185) and all other economies with populations of more than 30,000 (209 total) according to 2006 gross national income (GNI) per capita. Each economy is classified as low income, lower middle income, upper middle income or high income according to GNI per capita. The groups are: low income (LIC), $905 or less; lower middle income (LMIC), $906–3,595; upper middle income (UMIC), $3,596–11,115; and high income (HIC), $11,116 or more. After eliminating the countries with missing observations, 21 LIC, 18 LMIC, 17 UMIC, and 26 HIC have been included in data set. These 82 countries are selected on the basis of their data availability for the 1990-2004 period. Since the number of lower middle-income countries and upper middle-income countries are low compared to other country groups, lower middle-income and upper middle-income are combined as a one group named as middle-income (MIC) group with 35 countries.

The list of countries is reported in appendix A. All data are annual and span the years 1990–2004. Therefore, we have a balanced panel data set for real GDP per capita (GDP) and energy use per capita (E) on 82 countries between 1990 and 2004. The list of countries included is presented at appendix. The data are transformed into natural logarithms denoted as LE and LGDP, respectively.

5.2 Estimate Results

Macroeconomic series generally contain unit roots, and causality tests are sensitive to unit roots in the series (Stock and Watson, 1989). Therefore, before estimating the models, it is necessary to verify the order of integration of GDP and energy consumption for each country group. It is well known that unit root tests based on individual time series such as Augmented Dickey Fuller (ADF) have low power in rejecting the null of stationarity of the series when sample period is short. In addition, recent literature have showed that panel unit root tests have higher power than individual unit root tests. Recently developed panel unit root tests are Levin et al. (LLC) (2002), Im et al. (IPS) (2003), Choi (2001) and Hardi (2000). The most popular panel unit root tests are LLC and IPS in the literature. In this study IPS is used to determine the presence unit root for both variables in each country group since recent literature suggest that it is more powerful than other panel unit root tests (Barbieri, 2006). Furthermore, this test allows for heterogeneity in choosing the lag length in ADF tests (Al-Iriani, 2006). The results of panel unit root test indicate that for level variables the null hypothesis that each variable has a unit root cannot be rejected. However, the null hypothesis can be rejected when first-differences of these series are used. It means that first differences of these series lead to stationarity and the integration of GDP and energy consumption for each country group is of order one, i.e. I(1). Appendix B reports the results of panel unit root test in the level variables as well as in their first difference. Then, the equation (5.1) and (5.2) are estimated with first-differenced data.

$$\Delta LGDP_{i,t} = \sum_{k=1}^{p} \alpha^{(k)} \Delta LGDP_{i,t-k} + \sum_{k=0}^{p} \beta_i^{(k)} \Delta LE_{i,t-k} + u_{i,t} \tag{5.1}$$

$$\Delta LE_{i,t} = \sum_{k=1}^{p} \alpha^{(k)} \Delta LE_{i,t-k} + \sum_{k=0}^{p} \beta_i^{(k)} \Delta LGDP_{i,t-k} + u_{i,t} \tag{5.2}$$

Before estimating equations (5.1) and (5.2), the appropriate lag lengths are selected for both variables in each country. There are several model selection criteria to determine the optimal lag length for variables. The most popular model selection criteria are Akaike Information Criteria (AIC) and Schwartz Bayesian Criterion (SBC). It is likely that, these criteria may choose the same lag length. These criteria are defined as

$$\begin{aligned} AIC &= n\ln(SSR) + 2k \\ SBC &= n\ln(SSR) + k\ln(n) \end{aligned}$$

where,

$k =$ number of parameters to be estimated $(p+q+1)$

$n =$ number of usable observations

SBC has more superior large sample properties. It is asymptotically consistent while AIC becomes biased. However, in small samples AIC can work better than SBC (Enders, 2004). Therefore, in this case AIC is used to determine the optimum lag lengths for both variables in each country group. First of all, a maximum lag length of 3 is chosen. However, there does not exist a general rule of choice of the maximum lag length. According to Enders (2004), one should start with a relatively long lag length. Some researchers choose a maximum lag length equal to the cube root of the number of observations (Al Mamun and Nath, 2005). In this case, this is equal to 2,5 ($\cong \sqrt[3]{15}$). Then, AIC is computed for the lag length of 3 and continue with the lag length of 2 and lag length of 1. The optimum lag length at which AIC reaches its minimum is chosen.

Table 3 shows AIC for each country group. For LIC, three lags on GDP and one lag on E are chosen. For MIC, three lags on each variable are chosen. Finally, for HIC, two lags on GDP and one lag on E are chosen.

Table 3: *Number of Lags for GDP and Energy Consumption*

Country Group	Variable	LAG1	LAG2	LAG3	# of Lags
Low-income countries	GDP	-3.305	-3.482	-3.674	**3**
	E	-3.305	-3.279	-3.224	**1**
Middle-income countries	GDP	-3.518	-3.702	-3.732	**3**
	E	-3.108	-3.182	-3.196	**3**
High-income countries	GDP	-4.494	-4.742	-4.695	**2**
	E	-3.515	-3.514	-3.569	**3**

After choosing the lag lengths, in order to test HNC and HC hypothesis equations (5.1) and (5.2) are estimated for each country group. The results of the estimation are reported in appendix C. For low-income countries, the HNC hypothesis which restricts the homogeneity of the non-causality relationship from energy consumption to GDP per capita can not be rejected. This means that energy consumption does not Granger cause GDP for the whole sample of low-income countries. On the contrary, the result of HNC which imposes the homogeneity of the non-causality relationship from GDP to energy consumption per capita allows rejecting the null hypothesis. These results conclude that GDP Granger causes energy consumption in at least one cross-section unit. Then the HC hypothesis is tested and this test result causes us to reject the null hypothesis which means that there is no homogenous causality relationship from GDP to energy consumption. For middle-income and high-income countries, two types of homogeneous causality hypotheses, namely HNC and HC which impose the homogeneous non-causality and homogeneous causality relationship between GDP and energy consumption respectively are rejected. The HNC test results show that the non-causality relationship between GDP and energy consumption does not seem homogeneous. In addition, the HC test results confirm the causality relationship between GDP and energy is not homogeneous for the whole middle-income and high-income countries. The results of HNC and HC tests for each country group are reported in Table 4.

Table 4: *Test results for Homogenous Causality Hypotheses*

Country Group	Test	Causality from E to GDP	Causality from GDP to E
Low Income Countries	HNC HC	0,86	1,88*** 14,76***
Middle Income Countries	HNC HC	2,27*** 10,46***	1,93*** 22,95***
High Income Countries	HNC HC	3,01*** 9,56***	1,89*** 10,97***

****Reject H0 at 1% level of significance.*

Given the rejection of HC hypothesis, then HENC hypothesis is tested to find the individual causality relationship for each low-income countries. The test results show that GDP Granger causes energy consumption in nine low-income countries: Cote d'Ivoire, Haiti, India, Mozambique, Nepal, Sudan, Tanzania, Togo, and Vietnam. This means that past values of GDP have a predictive ability in determining present values of energy consumption in these countries. In addition, HENC hypotheses are tested for each middle-income and high income countries to show the direction of causality relationship. The unidirectional Granger causality from energy consumption to GDP can be observed for only four middle-income countries: Brazil, Guatemala, Islamic Republic of Iran, and Jordan and for seven high-income countries: Finland, France, Republic of Korea, Netherlands, New Zealand, United Arab Emirates, and United States. These results reveal that past values of energy consumption have a predictive ability in determining present values of GDP in these countries. The HENC test results indicate that unidirectional causality running from GDP to energy consumption for seven middle-income countries, namely Algeria, China, Mexico, Morocco, Romania, Turkey and Bolivarian Republic of Venezuela and six high-income countries, namely Greece, Hong Kong, Ireland, Japan, Saudi Arabia, and Switzerland.

Estimate results of HENC test have established the existence of bidirectional causality for GDP and energy consumption in eight middle-income countries: Chile, Colombia, Hungary, Indonesia, Paraguay, Philippines, South Africa, and Thailand and two high-income countries: Portugal, and Spain. This means that there was feedback between energy consumption and GDP in these countries. Appendix D presents the values of F statistics of HENC test and table 5 reports the direction of causality for each country group.

Table 5: *Test results for Heterogeneous Causality Hypotheses*

Low Income Countries	**Direction**	**Middle Income Countries**	**Direction**	**High Income Countries**	**Direction**
Bangladesh	No causality	Algeria	GDP to E	Australia	No causality
Benin	No causality	Argentina	No causality	Austria	No causality
Congo	No causality	Bolivia	No causality	Belgium	No causality
Cote d'Ivoire	GDP to E	Botswana	No causality	Canada	No causality
Ethiopia	No causality	Brazil	E to GDP	Denmark	No causality
Ghana	No causality	Bulgaria	No causality	Finland	E to GDP
Haiti	GDP to E	Chile	Bidirectional	France	E to GDP
India	GDP to E	China	GDP to E	Germany	No causality
Kenya	No causality	Colombia	Bidirectional	Greece	GDP to E
Mozambique	GDP to E	Costa Rica	No causality	Hong Kong	GDP to E
Nepal	GDP to E	Ecuador	No causality	Ireland	GDP to E
Nigeria	No causality	Egypt	No causality	Israel	No causality
Pakistan	No causality	El Salvador	No causality	Italy	No causality
Senegal	No causality	Guatemala	E to GDP	Japan	GDP to E
Sudan	GDP to E	Honduras	No causality	Korea	E to GDP
Tanzania	GDP to E	Hungary	Bidirectional	Netherlands	E to GDP
Togo	GDP to E	Indonesia	Bidirectional	New Zealand	E to GDP
Vietnam	GDP to E	Iran	E to GDP	Norway	No causality
Yemen	No causality	Jamaica	No causality	Portugal	Bidirectional
Zambia	No causality	Jordan	E to GDP	Saudi Arabia	GDP to E
Zimbabwe	No causality	Malaysia	No causality	Spain	Bidirectional
		Mexico	GDP to E	Sweden	No causality
		Morocco	GDP to E	Switzerland	GDP to E
		Panama	No causality	United Arab Emirates	E to GDP
		Paraguay	Bidirectional	United Kingdom	No causality
		Peru	No causality	United States	E to GDP
		Philippines	Bidirectional		
		Poland	No causality		
		Romania	GDP to E		
		South Africa	Bidirectional		
		Syrian	No causality		
		Thailand	Bidirectional		
		Turkey	GDP to E		
		Uruguay	No causality		
		Venezuela	GDP to E		

To sum up, the proportion of low-income and middle-income countries for causality running from economic growth to energy consumption is greater than high-income countries. This implies that, energy consumption is driven by economic growth. The energy conservation policies may be implemented without affecting the economic growth negatively in the countries where unidirectional Granger causality running from economic growth to energy consumption exists. On the other hand, the proportion of high-income countries for causality running from energy consumption to economic growth is greater than low-income and middle-income countries. The estimate results indicate that growth in HIC economies is caused by growth in energy consumption. This means that, the cuts in energy consumption will harm the economic growth in the countries where this type of causality exists.

CHAPTER 6

CONCLUSION

This thesis attempted to investigate the causal relationship between energy consumption and GDP for 82 countries over the period 1990–2004. Granger causality tests in panel data models were performed using recently developed techniques. The results show that there exists a heterogeneous causality from GDP to energy consumption for each country group. In addition, the causality from energy consumption to GDP is found heterogeneous for middle-income and high-income countries. On the other hand, this relationship is homogeneous for low-income countries.

The causality from GDP to energy consumption is dominant for low-income and middle-income countries. This result can be interpreted as follows. Energy is an important input of economic growth. Economic growth causes expansion in the industrial sector. Production in industries such as manufacturing, construction and transportation demands a huge amount of energy. In addition, because of higher disposal income related to economic growth households begin to use highly energy-consuming goods and services such as plasma television and wireless Internet connection. Thus these products stimulate further energy consumption. Therefore, an increase in GDP causes an increase in energy consumption in low-income and middle-income countries.

The unidirectional causality running from GDP to energy is found 22 out of 82 countries. This implies that, these counties are less energy-dependent that energy conservation policies may be designed without affecting economic growth negatively. In these countries, decision-makers may implement many energy policies such as, new tariff structure, renewing electricity infrastructure and reducing excess energy demand which decrease energy consumption without affecting final benefit. For example, in Turkey the electricity sector reform which has been defined as reducing loss and theft in electricity may be performed by means of renewing electricity infrastructure. Due to this reform, the wastage of electricity consumption can be diminished without adversely affecting economic growth. Then, energy efficiency can be achieved by imposing such conservation policy.

GDP is an explanatory variable to estimate demand function of energy consumption for these countries. In fact income is always a necessary explanatory variable to estimate the demand equation for energy consumption. However, if GDP is used as an explanatory variable to estimate demand function of energy consumption for countries in which the unidirectional causality from GDP to energy does not exist, the demand equation produces a misleading relationship between GDP and energy consumption.

On the other hand, no Granger causality from energy to GDP is found for low-income countries. This result may arise because a lot of low-income countries have economies based on agriculture and are less energy-dependent. Energy used per unit of output is small as agriculture can not require large amount of energy. For this reason, we can not find any causal relationship running from energy to economic growth for each low-income country. In addition, the number of countries in which the causality runs from energy to GDP is lower in middle-income countries than high-income countries. This means that, energy consumption does not have a significant effect on economic growth in low-income and middle-income countries. This is because these countries have lower possibility to access to advanced technologies which need more energy. Therefore, in lower income countries low technologies limit economic growth. Hence, energy does not Granger cause GDP. Energy sources such as electricity and gasoline are real drivers of growth. In high-income countries energy sources such as electricity and gasoline are used whereas in low- income countries more primitive energy sources are used. The conclusion is that energy serves as an engine of economic growth for high-income countries. This suggests that earlier changes in energy consumption had a significant impact on income.

The causality running from energy to GDP signifies energy-dependent economy implying that energy conservation policies may negatively affect economic growth in energy dependent economies. Therefore, in order to enhance economic growth, energy policies for increasing energy supply investment must be made to encourage government and private sector. Moreover, government must overcome the constraints on energy consumption and give some energy subsidies since high energy consumption leads high economic growth.

Energy is one of the production factors. Increased GDP requires enormous energy consumption for countries in which there is unidirectional causality from energy to GDP, even though there are many other factors of production such as capital, labor. On the other hand, a decrease in energy does not necessarily cause a decrease in output, given the other production factors for countries in which there is unidirectional causality from GDP to energy. Therefore, the relationship between energy and output depends on substitution between energy and other inputs.

The number of countries in which bidirectional Granger causality is found is higher in middle- income countries than high-income countries. The established bi-directional causality between variables reveals two policy implications. First, by stimulating economic growth, countries can encourage further energy consumption. Second, a high level of energy consumption leads to high level of economic growth. This means that energy consumption and economic growth are endogenous and therefore single equation forecast could produce spurious econometric results for ten countries out 82.

I suggest two extensions of this study in the future research. First of all, due to the limited time series data for each low-income and middle-income country, it may be better to model only high-income countries over a long time period without assuming that the autoregressive coefficients are same for each individual country in the same country group. This assumption is unrealistic because there exist different energy consumption and economic growth structures for countries under consideration in each county group. Secondly, this study based on bivariate system can be extended to multivariate system in future study. Since other economic factors such as prices, capital stock, employment, etc. may affect both energy consumption and real income. Due to this multivariate system, causal relationship mechanisms between energy consumption and economic growth may be understood completely.

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APPENDICES

Appendix A: *Countries in the Data Set*

1990-2004 ANNUAL		
Low Income Countries	**Middle Income Countries**	**High Income Countries**
Bangladesh	Algeria	Australia
Benin	Argentina	Austria
Congo, Dem. Rep.	Bolivia	Belgium
Cote d'Ivoire	Botswana	Canada
Ethiopia	Brazil	Denmark
Ghana	Bulgaria	Finland
Haiti	Chile	France
India	China	Germany
Kenya	Colombia	Greece
Mozambique	Costa Rica	Hong Kong, China
Nepal	Ecuador	Ireland
Nigeria	Egypt, Arab Rep.	Israel
Pakistan	El Salvador	Italy
Senegal	Guatemala	Japan
Sudan	Honduras	Korea, Rep.
Tanzania	Hungary	Netherlands
Togo	Indonesia	New Zealand
Vietnam	Iran, Islamic Rep.	Norway
Yemen, Rep.	Jamaica	Portugal
Zambia	Jordan	Saudi Arabia
Zimbabwe	Malaysia	Spain
	Mexico	Sweden
	Morocco	Switzerland
	Panama	United Arab Emirates
	Paraguay	United Kingdom
	Peru	United States
	Philippines	
	Poland	
	Romania	
	South Africa	
	Syrian Arab Republic	
	Thailand	
	Turkey	
	Uruguay	
	Venezuela, RB	

Appendix B: *Results of Panel Unit Root Tests*

Im, Pesaran and Shin Test

	Energy		GDP	
	Level	First Difference	Level	First Difference
Low Income Countries	2,5473	-8,1637***	3,8517	-4,8903***
Middle Income Countries	0,5191	-13,5769***	2,1698	-11,0264***
High Income Countries	0,4469	-14,1720***	4,4111	-8,5654***

**Reject H0 at 10% level of significance, **Reject H0 at 5% level of significance, ***Reject H0 at 1% level of significance.*

Appendix C1: *Estimation Results of VAR Equation from Energy to GDP*

Low Income Countries			**Middle Income Countries**			**High Income Countries**		
Variable	Coefficient	HC. Std. Error	Variable	Coefficient	HC. Std. Error	Variable	Coefficient	HC. Std. Error
C	0.047444	0.110281	C	0.583725	0.226492	C	0.097172	0.293434
DLGDP(-1)	1.006.137	0.122735	DLGDP(-1)	1.034.425	0.069797	DLGDP(-1)	1.034.028	0.130830
DLGDP(-2)	-0.110415	0.150403	DLGDP(-2)	-0.148151	0.074906	DLGDP(-2)	-0.110983	0.109220
DLGDP(-3)	-0.000314	0.064420	DLGDP(-3)	0.037882	0.048093	DLE	0.146423	0.057702
DLE	0.195707	0.049925	DLE	0.299596	0.063412	DLE(-1)	-0.036973	0.068118
DLE(-1)	-0.100370	0.045317	DLE(-1)	-0.279967	0.065284	DLE(-2)	-0.026907	0.069873
			DLE(-2)	-0.001490	0.036903	DLE(-3)	-0.001306	0.031882
			DLE(-3)	-0.016212	0.030572			
Fixed Effects			Fixed Effects			Fixed Effects		
BEN	0.013531		ARG	0.081292		ARE	-0.089290	
BGD	0.111894		BGR	-0.020425		AUS	-0.015642	
CIV	0.052104		BOL	-0.068252		AUT	0.020650	
ETH	-0.064603		BRA	0.025510		BEL	-0.016133	
GHA	-0.024681		BWA	0.052864		CAN	-0.040526	
HTI	0.052309		CHL	0.061092		CHE	0.042020	
IND	0.028615		CHN	-0.025630		DEU	0.004294	
KEN	-0.003856		COL	-0.008644		DNK	0.036362	
MOZ	-0.028172		CRI	0.044066		ESP	0.004001	
NGA	-0.048321		DZA	-0.019677		FIN	-0.020322	
NPL	-0.023131		ECU	-0.047098		FRA	0.000951	
PAK	0.030817		EGY	-0.035945		GBR	0.026152	
SDN	0.009659		GTM	-0.028805		GRC	-0.001047	
SEN	0.076490		HND	-0.074650		HKG	0.067372	
TGO	-0.041816		HUN	0.064616		IRL	0.053923	
TZA	-0.020520		IDN	-0.076780		ISR	0.013493	
VNM	0.025739		IRN	-0.034544		ITA	0.018658	
YEM	0.083703		JAM	0.015973		JPN	0.041450	

ZAR	-0.143833	JOR	-0.021481	KOR	-0.023395
ZMB	-0.054529	MAR	-0.049232	NLD	-0.000390
ZWE	-0.031400	MEX	0.065601	NOR	0.026063
		MYS	0.043287	NZL	-0.027729
		PAN	0.041402	PRT	-0.003024
		PER	0.000934	SAU	-0.098590
		PHL	-0.064538	SWE	-0.002097
		POL	0.070324	USA	-0.009783
		PRY	-0.049826		
		ROM	-0.001938		
		SLV	-0.011170		
		SYR	-0.056597		
		THA	-0.009000		
		TUR	0.016197		
		URY	0.068715		
		VEN	0.038331		
		ZAF	0.014029		

Appendix C2: *Estimation Results of VAR Equation from GDP to Energy*

Low Income Countries			**Middle Income Countries**			**High Income Countries**		
Variable	Coefficient	HC. Std. Error	Variable	Coefficient	HC.Std. Error	Variable	Coefficient	HC.Std. Error
C	0.837064	0.416056	C	0.375916	0.227738	C	1.522.575	0.282413
DLE(-1)	0.732880	0.082390	DLE(-1)	0.740072	0.059966	DLE(-1)	0.628919	0.124982
DLGDP	0.312228	0.067635	DLE(-2)	0.029098	0.063430	DLE(-2)	0.028717	0.092467
DLGDP(-1)	-0.106531	0.069344	DLE(-3)	0.021096	0.054973	DLE(-3)	0.071887	0.070752
DLGDP(-2)	-0.022542	0.043256	DLGDP	0.486612	0.057848	DLGDP	0.450339	0.149022
DLGDP(-3)	-0.053021	0.063691	DLGDP(-1)	-0.307673	0.060861	DLGDP(-1)	-0.311399	0.189621
			DLGDP(-2)	-0.029516	0.075982	DLGDP(-2)	-0.063613	0.129133
			DLGDP(-3)	-0.008957	0.085123			
Fixed Effects			Fixed Effects			Fixed Effects		
BEN	-0.053990		ARG	-0.076008		ARE	0.240607	
BGD	-0.263140		BGR	0.221964		AUS	0.061842	
CIV	-0.076493		BOL	-0.014275		AUT	-0.052200	
ETH	0.057205		BRA	-0.053155		BEL	0.053620	
GHA	0.037315		BWA	-0.075106		CAN	0.154387	
HTI	-0.143419		CHL	-0.011198		CHE	-0.090214	
IND	0.027007		CHN	0.106970		DEU	-0.024799	
KEN	0.027282		COL	-0.085776		DNK	-0.070816	
MOZ	0.067690		CRI	-0.139950		ESP	-0.073141	
NGA	0.155674		DZA	0.008331		FIN	0.105874	
NPL	0.008053		ECU	-0.012550		FRA	-0.007624	
PAK	-0.010574		EGY	-0.018082		GBR	-0.052439	
SDN	0.029112		GTM	-0.073458		GRC	-0.102882	
SEN	-0.183161		HND	-0.027903		HKG	-0.181912	
TGO	0.054067		HUN	0.081282		IRL	-0.074086	
TZA	0.046549		IDN	0.067801		ISR	-0.088771	
VNM	0.048719		IRN	0.182729		ITA	-0.096666	
YEM	-0.160318		JAM	0.026758		JPN	-0.060768	

ZAR	0.099543	JOR	0.039602	KOR	0.028820
ZMB	0.121394	MAR	-0.132674	NLD	0.013175
ZWE	0.111487	MEX	-0.049169	NOR	0.025517
		MYS	0.077200	NZL	0.024765
		PAN	-0.124370	PRT	-0.114316
		PER	-0.158117	SAU	0.137569
		PHL	-0.020177	SWE	0.052464
		POL	0.075618	USA	0.115471
		PRY	-0.000974		
		ROM	0.127683		
		SLV	-0.087505		
		SYR	0.081384		
		THA	0.067057		
		TUR	-0.023032		
		URY	-0.190435		
		VEN	0.054993		
		ZAF	0.154542		

Appendix D1: *Test results for Heterogeneous Causality from Energy to GDP*

Middle Income Countries		**High Income Countries**	
Algeria	2,04	Australia	2,08
Argentina	1,86	Austria	2,31
Bolivia	2,78	Belgium	2,69
Botswana	2,02	Canada	0,23
Brazil	21,39***	Denmark	2,89
Bulgaria	1,48	Finland	3,54*
Chile	4,87**	France	4,22*
China	1,83	Germany	0,04
Colombia	25,75***	Greece	0,86
Costa Rica	2,55	Hong Kong, China	2,46
Ecuador	0,17	Ireland	2,12
Egypt, Arab Rep.	0,65	Israel	1,48
El Salvador	1,68	Italy	1,39
Guatemala	8,14**	Japan	1,92
Honduras	0,1	Korea, Rep.	10,78***
Hungary	73,12***	Netherlands	3,64*
Indonesia	5,69**	New Zealand	5,98**
Iran, Islamic Rep.	3,73*	Norway	0,69
Jamaica	0,51	Portugal	5,66**
Jordan	6,46**	Saudi Arabia	3,12
Malaysia	0,66	Spain	25,03***
Mexico	2,95	Sweden	0,83
Morocco	3,15	Switzerland	0,14
Panama	0,15	United Arab Emirates	7,02**
Paraguay	10,95**	United Kingdom	0,43
Peru	0,3	United States	4,40*
Philippines	10,88**		
Poland	0,35		
Romania	1,92		
South Africa	6,72**		
Syrian Arab Republic	1,69		
Thailand	16,10***		
Turkey	1,89		
Uruguay	0,66		
Venezuela, RB	0,99		

**Reject H0 at 10% level of significance, **Reject H0 at 5% level of significance, ***Reject H0 at 1% level of significance.*

Appendix D2: *Test results for Heterogeneous Causality from GDP to Energy*

Low Income Countries		**Middle Income Countries**		**High Income Countries**	
Bangladesh	0,25	Algeria	11,33**	Australia	2,00
Benin	0,42	Argentina	2,84	Austria	0,81
Congo	2,27	Bolivia	3,20	Belgium	0,61
Cote d'Ivoire	3,64*	Botswana	3,09	Canada	1,04
Ethiopia	1,77	Brazil	0,38	Denmark	0,24
Ghana	1,00	Bulgaria	1,48	Finland	1,75
Haiti	3,48*	Chile	6,56**	France	1,90
India	4,92**	China	4,87*	Germany	0,58
Kenya	1,27	Colombia	52,60***	Greece	8,27**
Mozambique	5,60**	Costa Rica	1,74	Hong Kong	13,97***
Nepal	3,29*	Ecuador	0,83	Ireland	10,93***
Nigeria	1,39	Egypt	2,15	Israel	0,51
Pakistan	0,45	El Salvador	1,44	Italy	0,19
Senegal	1,65	Guatemala	2,12	Japan	4,65*
Sudan	18,15***	Honduras	0,56	Korea, Rep.	2,64
Tanzania	21,56***	Hungary	63,19***	Netherlands	1,50
Togo	3,17*	Indonesia	11,12**	New Zealand	0,51
Vietnam	5,44**	Iran	1,34	Norway	0,08
Yemen	1,25	Jamaica	2,15	Portugal	11,56***
Zambia	1,47	Jordan	0,66	Saudi Arabia	6,53**
Zimbabwe	1,47	Malaysia	3,26	Spain	99,84***
		Mexico	7,10**	Sweden	0,09
		Morocco	5,98**	Switzerland	5,22**
		Panama	0,86	United Arab Emirates	0,51
		Paraguay	6,74**	United Kingdom	0,13
		Peru	0,91	United States	5,18
		Philippines	4,95**		
		Poland	2,39		
		Romania	6,07**		
		South Africa	4,14*		
		Syrian	0,36		
		Thailand	10,06**		
		Turkey	4,90*		
		Uruguay	0,59		
		Venezuela	4,26*		

**Reject H0 at 10% level of significance, **Reject H0 at 5% level of significance, ***Reject H0 at 1% level of significance.*