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ENERGY DEMAND, ENERGY SUBSTITUTION AND ECONOMIC GROWTH: EVIDENCE FROM DEVELOPED AND DEVELOPING COUNTRIES

Azlina Abd.Aziz

Abstract

This thesis contributes to the literature on energy demand in three ways. Firstly, it examines the major determinants of energy demand using a panel of 23 developed countries and 16 developing countries during 1978 to 2003. Secondly, it examines the demand for energy in the industrial sector and the extent of inter-fuel substitution, as well as substitution between energy and non-energy inputs, using data from 5 advanced countries and 5 energy producer's developing countries. Third, the thesis investigates empirically the relationship between energy consumption and economic growth for these groups of countries over a 26-year period.

The empirical results of this study confirm the majority of the findings in energy demand analysis. Income and price have shown to be important determinants for energy consumption in both developed and developing countries. Moreover, both economic structure and technical progress appear to exert significant impacts on energy consumption. Income has a positive impact on energy demand and the effect is larger in developing countries. In both developed and developing countries, price has a negative impact but these effects are larger in developed countries than in developing countries. The share of industry in GDP is positive and has a greater impact on energy demand in developing countries, whereas technological progress is found to be energy using in developed countries and energy saving in developing countries.

With respect to the analysis of inter-factor and inter-fuel substitution in industrial energy demand, the results provide evidence for substitution possibilities between factor inputs and fuels. Substitutability is observed between capital and energy, capital and labour and labour and energy. These findings confirm previous evidence that production technologies in these countries allow flexibility in the capital-energy, capital-labour and labour-energy mix. In the energy sub-model, the elasticities of substitution show that large substitution took place from petroleum to coal, natural gas and especially to electricity. In addition, the evidence for significant inter-fuel substitution between coal and natural gas implies that there is a possibility of replacing the use of coal with natural gas in the industrial sector. The existence of moderate input substitution suggests that there is some flexibility in energy policy options and energy utilization.

Finally, the empirical evidence presented in this study suggests that the direction of causality between energy consumption and economic growth varies substantially across countries. There is a unidirectional causality running from GDP to energy consumption in 12 developed countries and in 5 developing countries. A unidirectional causality from energy to GDP exists in Netherlands and bidirectional causality exists in Slovak Republic.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Energy has gained a crucial role in the world's economic developments and environmental challenges.[1] Energy resources such as oil and gas are not only important as sources of energy but also as major sources of income to many countries (McPhail, 2000). Energy resources can generate sizeable revenues and creates jobs and business opportunities. Moreover, energy resources have the potential to stimulate economic growth, reduce poverty and raise living standards.[2] In addition, countries which have a rich source of energy benefit from being exposed to best international practices in project planning and implementation and from being forced to build up their administrative and institutional capacity[3].

The relationship between energy and gross domestic product (GDP) can be seen in Figure 1.1, which plots energy consumption per capita versus the GDP per capita (as proxy for economic growth) of several developed and developing

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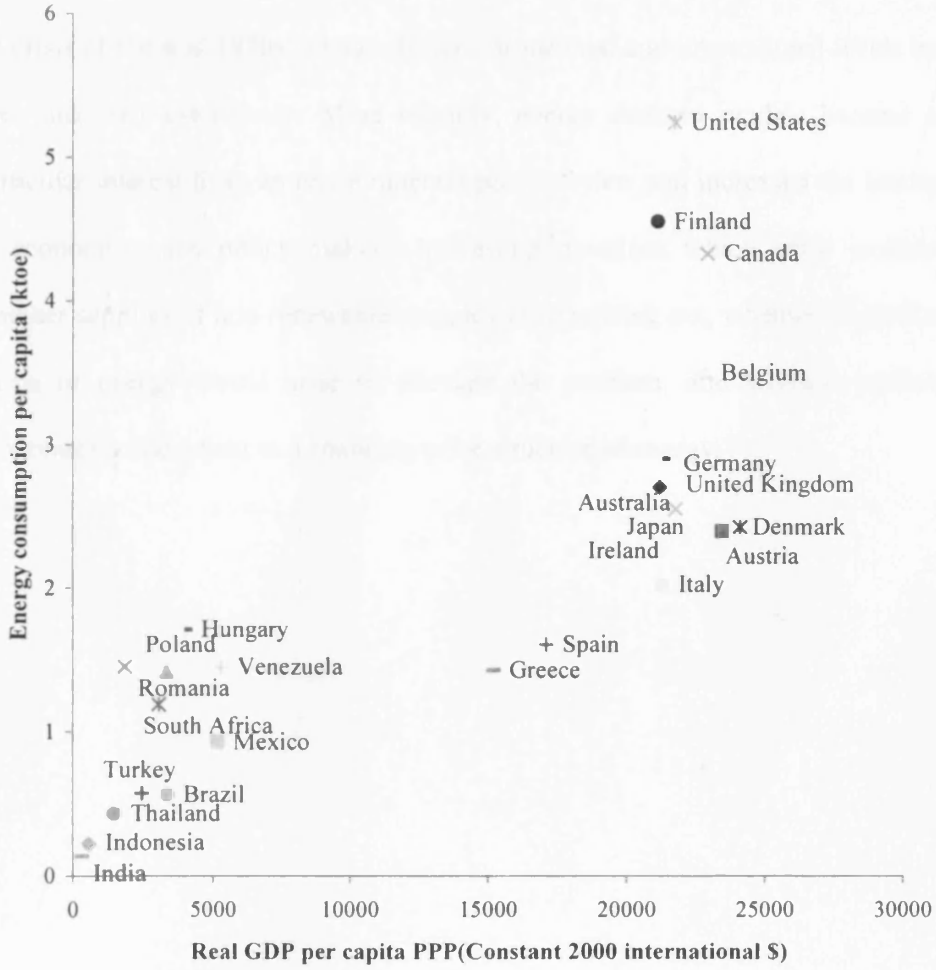
[1] In economic terminology, energy includes all energy commodities and energy resources that embody significant amounts of physical energy and thus offer the ability to perform work (Sweeney, 2002 and IEA, 2004). Energy commodities - e.g., gasoline, diesel fuel, natural gas, propane, coal or electricity - can be used to provide energy services for human activities, such as lighting, space heating, water heating, cooking, motive power and electronic activity. Energy resources - e.g., crude oil, natural gas, coal, biomass, hydro, uranium, wind, sunlight, or geothermal deposits - can be harvested to produce energy commodities.

[2] Robison and Duffy-Deno (1996) show that oil and gas industry in Utah have proved to provide important contributions to income and employment in the region.

[3] See, for example Pollio and Koichi (1999) for the case of Japanese upstream petroleum industry. Although Japan depends substantially on imports to meet its energy needs, it provides a useful example on the linkages between management efficiency, corporate governance and industrial performance.

nations. This figure plots average energy consumption and average GDP in the period 1978 to 2003. As depicted by the scatter plot, GDP is closely related to the energy consumption. There is a clear trend toward higher energy consumption as a nation industrialises and increases its gross national product.

Figure 1.1 Energy Use Per Capita versus GDP Per Capita in 1978-2003



Sources: WDI (2006), IEA (2004)

Figures 1.2 to 1.4 represent the historical behaviour of energy consumption and economic growth in the world, in both high income and low income countries, respectively. It can be seen that energy consumption follows the same pattern as economic growth. The very close relationship of energy consumption and real GDP thus raises an interesting and important question. Does GDP push up energy consumption or is it energy use that causes GDP to increase? Moreover, the relationship between energy consumption and aggregate economic output is related to the economics of energy demand (Medlock and Soligo, 1999). Since the oil crisis of the mid 1970s, energy demand at national and international levels has been analysed extensively. More recently, energy demand models became of particular interest from an environmental point of view and increased the interest of economists and policy makers. Interesting questions which arose included whether supplies of non-renewable energies were running out, whether alternative forms of energy would arise to alleviate the problem, and whether national economies could adjust to a changing price structure of energy.

Figure 1.2: World Energy Use and Real GDP for the period 1971-2003

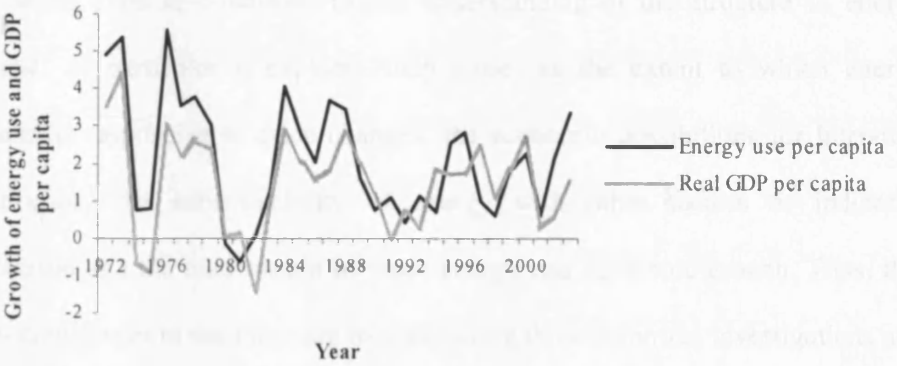


Figure 1.3: High Income Countries Energy Use and Real GDP for the period 1971-2003

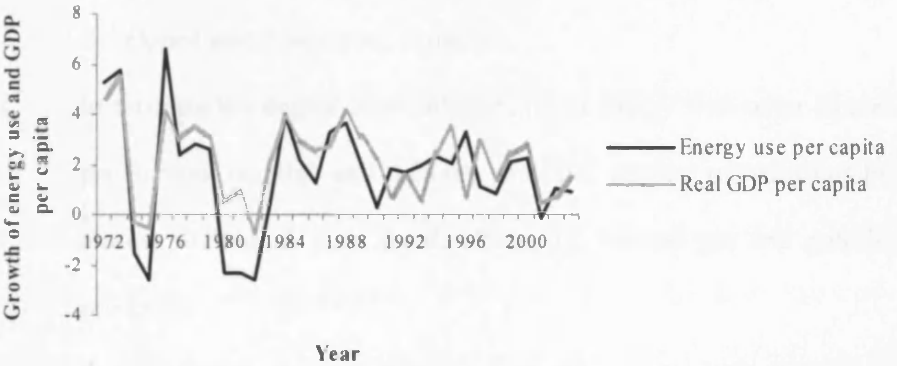
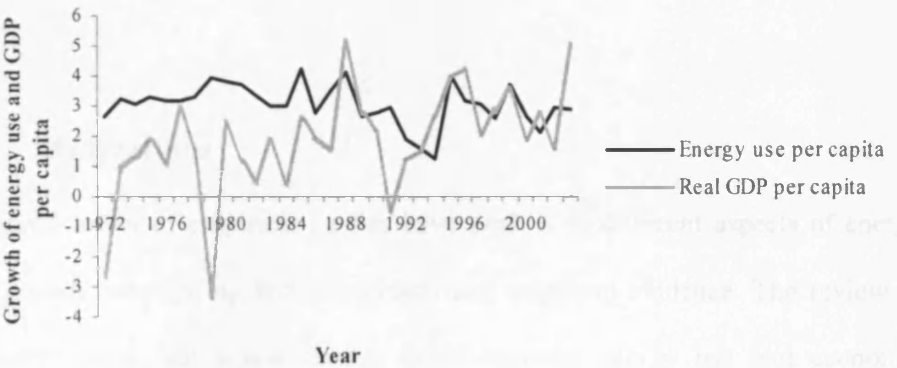


Figure 1.4: Low Income Countries Energy Use and Real GDP for the period 1971-2003



Sources: World Development Indicators (WDI) (2006), Economic and Social Data Service (ESDS) International, website: http://esds.ac.uk/international/

1.2 Objectives of the Study

This study aims to contribute to our understanding of the structure of energy demand. In particular it explores such issues as the extent to which energy demand is responsive to price changes, the economic possibilities for inter-fuel substitution, the substitutability of energy with other factors of industrial production and the relationship between energy and economic growth. Thus, this study contributes to the literature by conducting three empirical investigations and the more specific objectives are as follows:

i. to examine the important determinants of energy demand in both developed and developing countries.

ii. to estimate the degree of substitutability of energy with other factors of production (capital and labour) and the degree of substitutability among individual fuels (coal, electricity, natural gas and petroleum products).

iii. to investigate the relationship between energy consumption and economic growth.

1.3 Motivations

A great number of empirical studies have dealt with different aspects of energy and growth issues using both theoretical and empirical evidence. The review of literature states that a relationship exists between energy use and economic growth. However, when it comes to whether energy use is a result of, or a prerequisite for, economic growth, there are no clear conclusions in the literature. Stern and Cleveland (2004) view energy as an essential factor of production in addition to capital, labour and materials and thus suggested that energy is necessary for growth. In contrast to the above view, Toman and Jemelkova (2003) argued that economic development has an impact on energy use. Empirically, Masih and Masih (1996) find that energy use is a prerequisite for economic growth in India. On the other hand, Ghosh (2002), who also examined the relationship between energy use and economic growth in India, find that energy use is a result of economic growth. Therefore, further research on the link between energy use and economic growth may be needed to address this issue due to the mixed theoretical views and empirical findings in the literature.

As mentioned earlier, the relationship between energy consumption and economic growth is associated with the economics of energy demand. Energy demand estimates have been used by a number of researchers and policy decision makers to investigate demand behaviour and also for forecasting, demand management and design of appropriate energy policies (Halicioglu, 2007). Most of these studies typically analyse the long-term and short-term impact of GDP and energy prices on aggregate consumption of one or more fuels, in individual sectors or over the whole economy. Hunt et al. (2003), Hunt and Ninomiya (2003, 2005) emphasise the importance of correctly specifying the demand function to obtain accurate estimates of price elasticities. They suggested that by capturing other exogeneous factors that potentially will have an important influence on energy demand, the elasticities obtained could be used for formulation of a reliable policy analysis. However, this raises the question of which are the determinants of energy demand that should be included in the regression equation.

According to IEO (2006), the industrial sector is the largest of the end-use sectors, consuming 50% of delivered energy worldwide in 2003. For the industrial sector, energy demand depends on the characteristics of production and the extent to which capital, labour and energy will be substituted for each other as their relative prices change. Energy demand in the industrial sector also depends on the extent to which individual fuels can be substituted for each other in response to changes in the prices of these fuels. According to Pindyck (1979a) and McNown (1991), these substitution patterns not only have an important impact on energy demand for the industrial sector, but also have major implications for growth and economic planning. Therefore, the extent of inter-factor and inter-fuel substitution is important and needs to be addressed because it will contribute to our understanding of the energy demand in the industrial sector and also its relationship with the economic growth.

1.4 The Contributions of this Dissertation

This dissertation attempts to contribute to the existing energy demand, energy substitution and economic growth literature in three ways. First, in the context of estimating the demand for energy, this study attempts to fill the gap in the current literature by incorporating other potential regressors (namely the degree of industrialisation and technological progress) in addition to the traditional economic variables (income and price), at the international aggregate levels. The sample of this study is based on 39 countries over the period 1978 to 2003. Given the substantial differences in economic development among countries within the sample, it is more appropriate to examine energy demand by grouping the countries into two groups of economic development. Thus, the relationship between energy demand, economic growth, energy price, the degree of industrialisation and technological progress is further analysed at two categories, namely developed countries and developing countries. By dividing the sample into different stages of economic development, this study also contributes to fill a gap in the empirical identification of energy demand estimation in developing countries. Moreover, this study uses a panel data technique to empirically estimate the energy demand, which has not been used extensively in this area of research.

Second, numerous studies have been conducted to examine the extent of inter-fuel and inter-factor substitution in the industrial sector. However, most of these studies cover the period before 1990, whereas this study uses recent data, starting from 1978 to 2003. In addition, most of the previous analysis used a static model. Thus, this thesis contributes to the literature by taking into account the dynamic component of the adjustment process of energy demand in the industrial sector.

Third, this study contributes to the debate on the relationship between energy consumption and economic growth by adopting a multivariate approach. This approach allows an additional channel of causality to be investigated on both the supply and the demand side. That is, it considers both the short- and the long-run causality test. The recently developed panel methods to test for unit roots and cointegration are carried out to test for the existence of long-run relationships. This method avoids problems of low power associated with the traditional unit root and cointegration tests in short time series. For each country, the VECM is estimated to identify the direction of causality and this allows country-specific policy implications to be made.

1.5 Chapter Organisation

The rest of this thesis is organised as follows. Chapter 2 provides the literature review on 1) the factors that are important to account for when estimating energy demand, 2) substitution possibilities between energy and non-energy inputs and between fuels and 3) the causal relationship between energy use and economic growth.

Chapter 3 presents an empirical analysis of energy demand. Specifically, this chapter uses modern econometric techniques to estimate energy demand and it carries out tests of significance for the effect of potential exogenous factors on energy demand. The empirical analysis in this chapter uses panel data: 23 developed countries and 16 developing countries over the period 1978 to 2003.

Chapter 4 investigates empirically the substitution possibilities in the industrial sector of five major countries of the OECD area and five major energy producers of the developing world. This chapter presents estimates of the own- and cross-price elasticities, as well as elasticities of substitution, for energy, capital, labour and for individual fuels.

Chapter 5 deals with the relationship between energy use and economic growth in developed and developing countries. In particular, this chapter attempts to examine empirically the existence of the long-run relationship between energy use and economic growth and also to identify the direction of causality for individual countries. Finally, Chapter 6 summarises the empirical results and implications.

CHAPTER TWO

ENERGY DEMAND, ENERGY SUBSTITUTION AND ECONOMIC GROWTH: A REVIEW OF THE LITERATURE

2.1 Introduction

This chapter reviews the related literature on energy demand, energy substitution and economic growth. It is organized into four sections. Section 2.2 describes the conceptual linkages between energy and the economy. Section 2.3 reviews the literature on the determinants of energy demand. Section 2.4 provides an overview of the literature on energy substitution, specifically for the analysis of inter-fuel and inter-factor substitution among energy and non-energy inputs. Finally, section 2.5 surveys empirical studies of the relationships between energy and economic growth.

2.2 Energy and Development: Conceptual Linkages

The literature concerning the linkages between energy and the economy have been addressed in several ways, which largely reflect the theoretical background of each approach and the scope of each analysis. Within the neoclassical theory of economic growth, the focus has been on the interaction between energy, technical progress, productivity as well as examining the substitutability or complementarity between energy and other factors of production. In the traditional literature, Berndt and Wood (1975), Griffin and Gregory (1976), Fuss (1977) and Pindyck (1979a) view energy as an important input in the production process of the industrial sector since energy commodities are used to support various of its activities.

In the same context, but from a different perspective, Toman and Jemelkova (2003) examine the relationship of energy development with economic development, that is, how energy usage is driven by economic development. They claimed that the linkages among energy and economic growth vary with the stages of the development process and conclude that energy development is an important component of economic development. For instance, at the lowest level of development, energy mainly comes from biological sources (wood, dung, sunshine for drying) and human effort. In the intermediate stages, more processed biofuels (charcoal/fuel wood), animal power and some commercial fossil energy become more important. In the most advanced stages of development, commercial fuels like electricity become prevalent.

In contrast to the above study, Stern and Cleveland (2004) adopt a different point of view on the relationship between energy and economic development. Building on a strand of ecological economics, they emphasize that there are limits to both technical progress and substitution possibilities between inputs (i.e. energy, capital, labour, etc.) in the production process (Stern, 1997). Therefore, they suggest that all economic processes require energy as an essential factor of production and conclude that energy is necessary for growth.

Empirical findings, on the other hand, are not unanimous in their results and this leads to a commonly accepted conclusion that the discussion on the interactions of energy with the economy remains open to different interpretations. Therefore, in this context, the structure of each economy and its stage of development may also be crucial for determining the interaction between energy and economic growth. For example, in comparison to causality findings in industrialised countries, the interpretation of causal relationships may be very different in the developing world, often characterised by low energy use per capita and per unit of GDP, poor infrastructure, energy supply shortages and the use of fuels (such as biomass).

2.3 The Determinants of Energy Demand

The economic and public policy literatures have long been concerned with the determinants of demand for non-renewable resources, as well as long-term trends and cycles in the prices of primary commodities and resource-based products (Cuddington, 2001). In terms of energy demand, various authors have examined its main determinants. Examples are Pindyck (1979b), Field and Grebenstein (1980), Fiebig et al. (1987), Bentzen and Engsted (1993), Chan and Lee (1997), Pesaran et al. (1999) and Cooper (2003). The majority of these studies concluded that income and price have considerable influence on energy demand.

In an early study, Pindyck (1979a) focused on the demand for energy on a pooled time-series cross-section data for a group of OECD countries and a few less developed countries. He reports that for both developed and developing countries, the price of energy and income has a significant effect on demand in the long run for residential, industrial and transport sectors. Similar evidence was provided by Beenstock and Willcocks (1981). Using international data of OECD countries over the period 1950 to 1978, they found that income and price were the main variables to determine energy demand. In addition, it was also found that a time trend, as a proxy for technical progress, had considerable influence on energy demand. Moreover, Chan and Lee (1996) claimed that instead of income and price, the share of heavy industry in the national income does have an important impact on energy demand. Their analysis shows that the degree of industrialisation increases the demand for energy in China. The importance of the economic structure as an important determinant on energy demand has also been supported by Adams and Shachmurove (2000). They revealed that there is a positive relationship between the degree of industrialisation and energy demand in the East Asian countries.

In addition to income, price and the structure of economy, technical progress or improvements in energy efficiency has been argued to have a potential important impact on energy demand. Beenstock and Willcocks (1981), Kouris (1983) and Mountain et al. (1989) have argued that technological progress plays a crucial role in the demand of energy. Similar evidence was provided by Sterner (1990), Berndt et al. (1993) and Popp (2001), who found that improved efficiency leads to a reduction in energy demand.

2.3.1 Determinants of Demand – Income

According to previous research, energy demand is affected by economic performance in such a way that high energy consumption is associated with higher income. As shown in Fouquet et al. (1996), Hunt and Ninomiya (2005) and Rapanos and Polemis (2006), at an aggregate level, energy demand is related to economic activity since the growth rates of GDP and energy consumption reflect similar trends. Medlock and Soligo (2001) have expressed a similar view, arguing that as per capita income rises, consumer activity accounts for an increasing proportion of total energy demand. Accordingly, as consumer wealth rises, there will be an increasing share of the consumer's budget spent on consumer durables that use energy intensively, such as air conditioners, refrigerators and automobiles (World Bank Development Indicators, 2004). As a result, the utilisation of these items increases energy demand not only in residential but also in commercial and transportation sectors.

In an early study of the relationship between income and energy consumption, Brookes (1972) analyses cross-section data for 22 countries from 1950 to 1965. He first based his estimation on the entire set of nations and found that the income elasticity for the less developed countries was consistently higher than for the developed countries. He attributed his finding to structural differences across the stage of development, arguing that "post-industrial" development could lead to significant reductions in the income elasticity of energy demand. Nevertheless, the empirical study by Zilberfarb and Adams (1981) drew the opposite conclusion. They estimated the relationship between energy and GDP in developing countries by incorporating a dummy variable to capture the effects of differences among countries at different levels of development. They found that differences in degree of development among countries are not significant in explaining energy demand. However, they agreed that an increase in GDP is an important contribution to higher energy demand.

With regard to the value of the income elasticities, Zilberfarb (1983) found that the income elasticity in developing countries is above unity, with a tendency to decline over time. He suggests that the high income elasticity implies that economic growth of developing countries is energy-intensive and therefore, any changes in oil price are likely to affect the growth of these countries more than in developed countries. Similarly, the view of Kouris (1983) is that in the future, the income elasticity of energy demand for industrialised countries could decline from a present value of about one to a value of less than one. He stated that "as industrialised countries move toward more efficient processes or less energy intensive techniques and that appliance in the household become both more efficient and plentiful, it should be reasonable to expect that in the future every percentage increase in GDP will be associated with a less than equal percentage increase in energy." In this circumstance, given the above scenario, income elasticity in developed countries will decrease.

Samoulidis and Mitropoulos (1984) also claimed that developed economies tend to have income elasticities less or equal to unity, which means that changes in the national product have attenuated effects on the demand for energy. They explained that as the economy heads towards maturity with the transition from the agricultural to the industrial mode of production, the impact of energy saving technology and an expansion of the service sector imply falling income elasticity. On the other hand, they suggest that income elasticities measured in developing economies are considerably higher than one.

The long run relationship between energy demand and income has been studied by Gately and Huntington (2002). Using data for 96 countries, they examine the asymmetric effects on energy demand of increases and decreases in income. They claimed that the income effect on demand may be asymmetric in such a way that the impact of a decrease in income might be different from the impact of an increase in income. Based on data from 1971 to 1997, they found that income is the most important determinant for energy demand and that the long-run income elasticity of energy for the OECD countries is about 0.5 and ranges from about 0.5 to 1.0 for the non-OECD countries. They drew the conclusion that demand has responded more to increases in income than to decreases in income for the non-OECD Oil Exporters.

2.3.2 Determinants of Demand – Price

In addition to income, energy price is another important factor affecting energy demand. Pindyck (1979a) claimed that higher energy prices have contributed to reduce economic growth in many countries and may result in changes in lifestyles in the long run. A variety of research has been undertaken from both theoretical and empirical perspective after the changes in the price of energy of 1973 and 1980, and the consequent impact to energy policy. This is because the price elasticities of energy demand are crucial parameters in some price-based models that project the effects of pollution abatement, energy conservation or environmental improvement policies (Barker, 1995).

In the literature, different types of energy price has been used to examine the relationship between energy demand and the price of energy, such as the world price of crude oil and the international prices (see, for example, Beenstock and Willcocks, 1981 and Gately and Huntington, 2002). Kouris (1983) expressed a view that the use of price of Saudi Arabian crude oil in industrialised countries may lead to misleading results in the study performed by Beenstock and Willcocks (1981). The use of this price proxy disregards 1) the differences between the price of Saudi Arabian crude and the cost of average imported crude and oil products landed in the OECD countries and 2) the relationship between the cost of landed oil prices and the prices of final oil products in the market. In addition it also disregards the final prices of gas, coal and electricity. Griffin and Schulman (2005) have also expressed a similar view, since due to local import duties, consumer taxation, subsidy schemes, inter- and intra-country tax structures and exchange rates, most consumers may not experience the level of, or changes in, world market prices.

With regard to the price elasticity, most of the empirical results reported that the price elasticity for developed countries is higher than in the developing countries (see, for example, Zilberfarb, 1983). As Zilberfarb (1983) cited, Pindyck (1979a) explains this difference as '...at low levels of income most energy is consumed as a necessity, while as income grows, the additional use of energy becomes more discretionary, allowing for greater substitution away from energy if prices rise'. The low value of the price elasticity of energy demand in developing countries may give an indication that energy conservation measures based on the price mechanism are less effective in developing countries than in developed countries (Zilberfarb, 1983).

Theoretically, the short-run price elasticity is smaller than the long run price elasticity. In one of the earliest comprehensive overviews of price elasticity of energy demand estimation, Dahl (1993) summarizes estimates of crude oil own price elasticity for developing countries. These estimates vary between -0.05 and -0.09 for short run price elasticity and between -0.05 to -0.09 for long run elasticity. Pesaran et al. (1998) present results in a panel data framework for the Asian developing countries. They report average price elasticity of -0.03 for short run and -0.48 for long run. Gately and Huntington (2002) estimated the price elasticity for OECD and non-OECD countries in a pooled cross section time series framework. For OECD countries, the short run price elasticity was -0.03 and the long run price elasticity were between -0.59 to -0.64. For non-OECD countries, these estimates were -0.03 and between -0.16 to -0.27, for short and long run, respectively.

2.3.3 Determinants of Demand - Structure of Economy

The structural change in the economy (from agriculture to industry and then to services), may be considered to be one of the important factors to determine energy demand, since it may causes similar sector shifts in final energy use (Schäfer, 2005). According to previous research, the growth of energy demand might result from the industrialisation process in the economy. For instance, Samoulidis and Mitropoulos (1984) claimed that the gradual increase of industry's value share in the domestic product describes the industrialisation process and might influence energy demand. They use the proportion of value added in industry as a proxy for the industrialisation process, and their empirical results indicate that there is a positive relation between the value share of industry and energy demand. Moreover, they indicate that the corresponding elasticity is very high which shows that energy demand is very sensitive to the composition of GDP.

The importance of the structure of the economy in explaining energy demand has also been studied by Chan and Lee (1996). In their model, the structure of the economy is represented by the share of heavy industry in the national income. This is due to the fact that heavy industry has long been one of the major energy consumers of China. They argued that the increase of the share of the heavy industry output in the national income has significantly increased energy demand. The empirical test by Adams and Shachmurove (2000) also support the positive relation between the structure of the economy and energy demand. Using the share of industry in GDP, they provide evidence of the positive effect of the degree of industrialisation on energy demand in the East Asian countries.

In the same context, but different point of view, Schäfer (2005) discusses the importance of the structural change in energy use for 11 world regions at various stages of economic development from 1971 to 1998. She claimed that the structural change in GDP must cause a similar sector shift in the energy system. She pointed out that in a post-industrial economy, the energy consumption by the industry sector decreases due to a continuous decline in industrial energy intensity and a rapid growth of the service sector. Therefore, she suggests that the change in sector shares in energy consumption, caused by structural change in the economy, follows regular patterns, i.e., from residential to industry and then to services, especially in most of developed countries.

2.3.4 Determinants of Demand - Technical Progress

A majority of previous energy demand studies have focused mainly on the contribution of technical progress or efficiency improvements which typically lead, ceteris paribus, to a reduction in energy demand through improved efficiency. They have modelled it in a very simple way, either using as a proxy a simple deterministic time trend (see, for example, Beenstock and Willcocks,1981, 1983; Mountain et al., 1989; Sterner,1990 and Berndt et al.,1993) or ignoring it completely (see, for example, Prosser, 1985 and Liu, 2004).

The importance of technical progress in aggregate energy demand has been explained by Kouris (1983) and Jones (1994). According to Kouris (1983), the relationship between energy demand and technical progress is related to many different factors, such as energy price and non-energy price. He argues that a great part of technical progress is related to price in the sense that a price increase can provide an incentive for energy consumers to find and efficient ways to increase energy's productivity. Thereby the speeding up of technical progress should be expected when the price of energy is increasing. Moreover, he also argues that there are many factors that will contribute to greater technical progress in energy consumption. Example of these are: environmental regulations, energy efficiency standard, energy policies, the substitution of labour, capital or materials inputs for energy inputs and the decline of energy intensive industries. In addition, as Jones (1994) noted, an increase in the price of energy will lead to reduction in energy demand, both in the short run and in the long run. He claimed that in the long term, the technical progress will reduce future energy consumption by shifting the energy demand curve to the left over time.

According to Jones (1994), the standard approach to accounting for technical progress is to include a time trend. For example, Mountain et al. (1989) simply modelled technological change by including a time trend in the regressions and find that technological change is energy using in Canada. That is, energy use per unit of output increased over time. Their paper, however, used data from the period 1962 to 1984, which includes the energy crises of the 1970s that led to much innovation designed to save energy. Thus, it is reasonable to expect that the results are sensitive to the time period studied.

On the other hand, Berndt et al. (1993), Popp (2001), Lin (2003) and Welsch and Ochsen (2005) found that technological change was energy saving. One feature common in the work of Berndt et al. (1993) and Welsch and Ochsen (2005) is that they introduced a time trend to capture the impact of technological change in energy demand. In contrast, Popp (2001) constructed stocks of energy-efficient knowledge as an indicator of technological change to estimate the effect of new technologies on energy demand. In doing so, he used data on energy patents granted in the United States. However, as he claimed, the patent data contained only the average value of patents, and did not reflect therefore the variation in the quality of patents, which in practice varies widely. In contrast to the above studies, Lin (2003) defines an efficiency improvement as the value added by industry divided by electricity consumed, and uses it as an indicator of technological progress. Using data for China from 1952 to 2001, the introduction of the new technologies is found to have a negative relationship with electricity demand, implying that technological change is energy saving.

2.4 Energy Input and Substitution

According to Thompson (2006), energy input involves work that moves or transforms matter, and includes a range of fuels based on some natural resource. On the other hand, Caloghirou et al. (1997) define energy substitution as the ability of industry to adjust energy input when the prices of energy and other factors change. As noted by Saicheau (1987), Solow (1987), Caloghirou et al. (1997), Frondel (2004) and Roy et al. (2006), reliable measures of energy substitution can be used to asses important issues, including the effect of energy price changes on energy use and total output and also the impacts of carbon taxes to reduce climate change. Therefore, the study of energy substitution, which has its roots in microeconomic production theory, has been the subject of extensive empirical research in both developed and developing countries.

In the literature, most of the previous studies belong to three categories. The first category focuses on substitution between energy and other factors like labour, capital and materials (see Berndt and Wood, 1975; Fuss, 1977; for early empirical studies, and Caloghirou et al., 1997; Christopoulos, 2000, Christopolus and Tsionas, 2002 and Roy et al., 2006 for more recent ones). In the second category, the study focuses on inter-fuel substitution between various types of energy (for example, Hall, 1986; Vlachou and Samouilidis, 1986; Taheri, 1994 and Jones, 1996). The third category focuses on both factors and fuels, which is referred to the two-stage approach. These three approaches lead to the estimation of individual factor or fuel share equations and their corresponding partial own- and cross-price elasticities.

2.4.1 Econometric Studies of Energy Substitution

Many econometric studies of energy substitution have been published, where the crucial point for such studies was to examine the extent to which energy was substitute or complement to the other inputs. The methodology developed in these studies was later extended to disaggregating between the different fuels so that it became possible to examine the degree to which one fuel can be substitutes for another as well as the degree to which aggregate energy were substituted against other factors of production.

Field and Grebenstein (1980), Hunt (1984), Siddayao et al. (1987), McNown et al. (1991) and Al-Mutairi and Burney (2002) treated energy as a single fuel and concentrated on its relation to other types of production inputs (capital and labour). Most of these studies followed the framework of a translog cost function developed by Christensen et al. (1973) and the standard econometric approach provided by Berndt and Wood (1975), Griffin and Gregory (1976) and William and Laumas (1981), who assume Hicks neutral technological change, constant return to scale, and factor price symmetry. Based on the production function, the output (Q) is assumed to be twice differentiable function of the capital (K), labour (L) and energy (E) inputs. As in Pindyck (1979a, 1979b), materials (M) can also be included as one of the production inputs, by assuming that it is weakly separable from the other inputs as a group. This assumption is crucial because it allows materials, for which there is no data, to be ignored at an aggregate level.

The production function describes the output which will be obtained from the various combinations of inputs. This function can also be described by a cost function (C), which explains the cheapest total cost of producing a given output with the given prices of the various factors of production. The general form of the cost function can be written as:

$$C = C(P_K, P_L, P_E, P_M, Q) \tag{2.1}$$

where P_i denotes the price of input i. In other instances, the studies such as Griffin (1977), Hall (1986), Vlachou and Samouilidis (1986), Taheri (1994) disaggregated energy by different types of fuels (coal (C), electricity (E), natural gas (G) and oil (O) or petroleum products (P)). Thus, the cost function is written as:

$$C = C(P_K, P_L, P_M, P_C, P_E, P_G, P_O, Q) \tag{2.2}$$

In some cases, it is highly desirable to analyse fuel choice separately from the choice of labour and capital. This is crucial when data are scarce. As Pindyck (1979a) noted, although price series for individual fuels are available, a price index that reflects the unit cost of energy will not be the same as a simple weighted average of fuel prices because fuels are not perfect substitutes. For this reason, it is important to assume that energy fuels are weakly separable from all other inputs of production. This assumption allows the cost function to be written as:

$$C = C(P_K, P_L, H(P_C, P_E, P_G, P_O), Q) \tag{2.3}$$

$$C = C(P_K, P_L, P_E, Q) \tag{2.4}$$

$$P_E = H(P_C, P_E, P_G, P_O) \tag{2.5}$$

in which P_E is referred as the price of the energy aggregate. This assumption suggests that there are two sub-models, 1) in which fuel inputs are determined and 2) in which capital, labour and energy are determined. The cost function (2.3) can explain the use of fuels within total energy and provides an estimate of the extent to which a higher price of a fuel would lead to a lower demand for other type of fuels. In addition, it can assess whether there would be further feedback effects, through macro-economic effects linked to the rise in fuel prices (Cho et al., 2004). Other studies related to this approach are for example, Pindyck (1979a, 1979b), Iqbal (1986), Kim and Labys (1988), Andrikoupolos et al. (1989), Cho et al. (2004) and Floros and Vlachou (2005).

The cost function (2.3) can be represented by the translog cost function. The advantage of using translog specification is that it imposes no prior restriction on the production structure, that is, it does not impose neutrality, homotheticity[4], homogeneity, constant return to scale, or unitary elasticities of substitution. Furthermore, the translog cost function allows the elasticities of substitution to differ between pair of factors. That is, it has elasticities which vary depending on the fuel shares and thus allows a more flexible description of the relation between the various inputs. In contrast, Cobb-Douglas type functions have all elasticities equal to unity while a Constant Elasticity of Substitution (CES) function has all elasticities constant. For this reason, therefore the translog cost function is often used in the empirical literature on energy substitution because of its flexibility. The basic form of the translog cost function can be written as:

[4] Homotheticity means that the cost function can be written as a separable function in output and factor prices. With homothetic functions relative input demands are independent of the level of output. By contrast, with non-homothetic cost functions their ratios of cost minimising input demands are allowed to depend on the level of output.

$$\ln C = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln P_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln P_i \ln P_j + \alpha_Y \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 + \sum_{i=1}^{n} \gamma_{iY} \ln P_i \ln Y \tag{2.6}$$

where i, j = 1,..., N index the N different inputs considered and $\gamma_{ij} = \gamma_{ji}$, C is total cost, Y is output and the P_i's are the prices of the factor inputs. For a cost function to be well behaved it must be homogeneous of degree one in prices, implying that, for a fixed level of output, total cost must increase proportionately when all prices increase proportionately (e.g. if every price is doubled total costs must double). Therefore, the following restrictions on equation (2.6) apply

$$\sum_{i}^{n} \alpha_i = 1; \quad \sum_{i}^{n} \gamma_{ij} = 0; \quad \sum_{i}^{n} \gamma_{iY} = 0; \quad \gamma_{ij} = \gamma_{ji} \tag{2.7}$$

Direct estimation of equation (2.6) can be carried out. However, gains in efficiency can be obtained if the optimal cost-minimising input demand equations, cost-share equations, are estimated jointly with equation (2.6). Equations for cost shares can be obtained:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i}{C}\frac{\partial C}{\partial P_i} = \frac{P_i X_i}{C} = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln P_j + \gamma_{iY} \ln Y, \tag{2.8}$$

where $\sum_{i=1} P_i X_i = C$. If $S_i \equiv \frac{P_i X_i}{C}$, then $\sum_{i=1} S_i = 1$.

Once the coefficients of equations (share equations) have been estimated, the Allen elasticities of substitution (σ_{ij}), own price elasticities (η_{ii}) and cross price elasticities (η_{ij}) can be calculated from the parameter estimates and the cost shares as follows:

$$\sigma_{ii} = (\gamma_{ii} + S_i^2 - S_i)/S_i^2 \qquad \text{for all i, i =j:} \qquad (2.9)$$

$$\sigma_{ij} = (\gamma_{ij} + S_i S_j)/S_i S_j \qquad \text{for i, i} \neq \text{j} \qquad (2.10)$$

$$\eta_{ii} = \partial \ln X_i / \partial \ln P_i = \sigma_{ii} S_i \qquad \text{for all i, i =j;} \qquad (2.11)$$

$$\eta_{ij} = \partial \ln X_i / \partial \ln P_j = \sigma_{ij} S_j \qquad \text{for i, i} \neq \text{j} \qquad (2.12)$$

where S_i and S_j are the cost share of the ith and the jth factor relative to the total factor cost and with i and j equal to different inputs considered.

These elasticities are crucial to describe the pattern and degree of substitutability and complementarity amongst the factors of production. Basically, they measure the percentage change in factor proportions due to a one-percent change in their relative prices. Based on Saicheau (1987), the cross price elasticity is a more useful measure for policy purpose because the cross-price elasticity measures the proportionate change in amount of factor use induced by a proportionate change in the price of the other factor. On the contrary, the Allen elasticity is a share-weighted cross-price elasticity which measures the proportionate change in relative factor shares induced by proportionate changes in relative price of factors.

Most of these previous studies that have been mentioned so far dealt with the static model, which holds only in long-run equilibrium (an exception are Taheri, 1994 and Cho et al., 2004). In the static model, which is referred to as the long-run model, it is assumed that there is no difference between consumers or producers short-run and long-run behaviour. That is, the behaviour of consumers and producers is always in equilibrium. However, in reality, habit persistence, adjustment cost, imperfect information, incorrect expectations, and misinterpreted real price changes often prevent consumers from adjusting their expenditure instantly to price and income changes (Anderson and Blundell, 1983). According to Hogan (1989) and Cho et al. (2004), a slow adjustment process might occur during and after a period of rapid and large changes in relative prices among inputs. Furthermore, in the short-run, there is uncertainty about the future cost of capital, energy, labour prices and output. Thus, ignoring the dynamic element would lead to inadequate knowledge of the adjustment process and of the long-run structure.

2.4.2 Empirical Evidence on the Energy Substitution Possibilities

2.4.2.1 Inter-factor Substitution

Previous empirical studies found considerable potential for factor substitution, with the consensus being that labour is substitute for both capital and energy in the developed countries (McNown, 1991). However, the most controversial issue that has been discussed is the substitution possibilites between energy and capital, where the results have been mixed. For example, earlier works of Berndt and Wood (1975) for the United States and Fuss (1977) for Canada, all find evidence of complementarity between energy and capital. Recent studies by Caloghirou et al. (1997), Christopoulos (2000) and Christopoulos and Tsionas (2002) also provide evidence of energy-capital complementarity for the Greek manufacturing.

On the other hand, Griffin and Gregory (1976) and Pindyck (1979b) for a sample of 10 developed countries report that substitution possibilities exist between energy and capital.

Input substitutability also has become controversial in the developing countries where generally, capital and labour are found to be substitutes. Labour and energy and are as likely to be substitutes as complements, and the same happens with energy and capital. Siddayao et al. (1987) investigates energy substitution for the manufacturing sector in Bangladesh, the Philippines and Thailand. The results obtained varied according to the industries studied and across countries. For example, labour and energy are substitutes in most manufacturing industries in Thailand. In the Philippines, energy, labour and capital are substitutes in the food processing and in the manufactured exports group while a complementary relationship is found between energy and labour in the textile industry. In general, they provide evidence that substitutability among inputs is greater in the manufacturing sectors of the developing countries than in those of developed countries.

McNown et al. (1991) examine the input substitution in the industrial sector for three labour abundant countries: India, Pakistan and Bangladesh. Using aggregate data at the manufacturing level, they found evidence of high degree of substitutability among capital, labour and energy. Their finding confirms previous evidence that production technologies in these developing countries allow flexibility in the capital-labour mix. For example, higher energy prices can be partially compensated by greater use of capital in Bangladesh and both capital and labour in India and Pakistan.

Roy et al. (2006) use pooled data from several developing countries and the U.S to examine the substitution possibilities for the paper, iron & steel, and aggregate manufacturing industries. They find that own-price elasticities for capital are greater than or close to one. In addition, they also find that the demands for energy and material are inelastic relative to capital and labour. They suggest that these inelastic demand functions show the relative vulnerability of the sectors (paper and aggregate manufacturing) to fluctuations in the prices of energy and materials.

2.4.2.2 Inter-fuel Substitution

According to Hall (1986) inter-fuel substitution involves the process whereby shifts in relative fuel prices lead to changes in the degree of utilisation of individual fuels. Using annual observations from the period 1960 to 1979, he estimates own-price and cross-price elasticities of demand for petroleum, gas, coal and electricity in the seven major countries of the OECD area, i.e. the United States, Japan, Germany, France, the United Kingdom, Italy and Canada. He has found that on average the demands for both coal and gas have been elastic (-1.9 and -1.4, respectively) and for both petroleum products and electricity have been inelastic (-0.8 and -0.2, respectively). With regard to the cross-price elasticity, he found evidence of substitution possibilities between gas and coal in the United Kingdom and France. In the United States, Japan, Italy and Canada, he reports a very inelastic response of electricity to any change in the price of petroleum products.

Vlachou and Samouilidis (1986) examined interfuel substitution in three major sectors (agriculture, industry and transport) of the Greece economy over the period 1960 to 1980. They report low own-price elasticities for liquid fuels, electricity and solid fuels in all sectors, with the exception of agriculture. Thus, they conclude that there is limited scope for policies that try to reduce the consumption of energy by changing its price. In addition, they also found that the relationship between the fuels appears to be predominantly of substitution rather than complementarily. For instance, the relationships between liquid fuels and electricity and between solid fuels and electricity are of substitution. The only exception relates to solid fuels and liquid fuels, which are found to be complements in the Greek industry. However, this study did not investigate the substitutability of natural gas with other types of energy and therefore, this study fails to give a complete answer to the question of inter-fuel substitution in the Greek economy.

Taheri (1994) suggested that the dramatic rise in the price of oil during the decade of 1970s is expected to result in inter-fuel substitution from oil to other types of fuels where the substitution response is expected to be significant in the long run. He also suggested that the substitution effect will be greater in the long-run. He claimed that subsequent adjustments to even higher oil prices will occur only gradually, rather than instantaneously. Thus, he incorporated the partial adjustment mechanism in the translog cost function and claimed that the dynamic structure is less restrictive than the static specification. He pooled observations for the period 1974 to 1981 to investigate the substitution among fuels: coal, oil, natural gas and electricity in the United States manufacturing. He found that the results support the incorporation of the lagged adjustment responses in the translog model, since 75% of the lagged dependent variables are statistically significant. For the own price elasticity, his results confirmed the principle hypothesis of the cost minimization, finding that both short and long run own price elasticities are all negative. For the cross price elasticity, he found that there is a greater potential for inter-fuel substitution from oil to coal and electricity whilst oil and natural gas are found to be complement.

Jones (1996) examined the inter-fuel substitution possibilities in the industrial sector of the Group of Seven (G-7).[5] He pooled data from 1960 to 1991 and estimates two models. In Model 1, the coefficients are assumed to have a common value for all countries, so that fuel price elasticities would only differ between countries because of differences in their fuel cost shares. Model 2 allowed for the intercept terms to differ across countries in order to account for regional heterogeneity. The results show that the dynamic versions of Model 1 and Model 2 perform better than the corresponding static versions. He found that both dynamic models satisfied, for all four fuels and all seven countries, the concavity conditions of negative own price elasticities. With respect to elasticity estimates, he found that oil and coal are the most price elastic and there was evidence that oil and natural gas are substitutes. Jones (1996) suggested that in the G-7 countries, since the elasticity for oil is very elastic, higher tax rates on oil prices, levied for

[5] G7 countries is the world's seven largest industrialized countries consist of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States.

environmental or security reasons, would be highly effective in reducing oil consumption and effecting switches to natural gas, coal or electricity.

2.4.2 Two-stage Approach: Inter-fuel and Inter-factor Substitution

The earliest study to propose the two-stage approach is the classic paper on Canadian energy by Fuss (1977). Using the data for Canadian total manufacturing over the period 1961 to 1971, he found that the inter-fuel substitution indicate that the own price elasticity estimates are negative and, apart from motor gasoline, significant at the 1 per cent level. Furthermore, there is considerable inter-fuel substitution among fuels, except for electricity and motor gasoline. The cross price elasticities are found to be positive and this indicates that there is a possible substitution among the fuels. With regards to the share equations of the inter-factor substitution model, it was found that for all factor inputs, the own price elasticities of demand are negative and significant at 1 per cent level and all factors have a price inelastic demand. In general, factors are found to be substituted, although there is a slight complementarity between energy and materials and between energy and capital. It was also found that the own price elasticities of demand for the aggregate factor are in the inelastic range (for instance, the own price elasticity of demand for aggregate energy is -0.5). However, the cross price elasticities are low in all cases. Comparing to the inter-fuel substitution, only slight substitution exists between aggregate energy and other aggregate inputs in the Canadian manufacturing sector.

An early example of estimation of inter-factor and inter-fuel substitution potential in developing countries is the work of Uri (1979). Based on a pooled annual dataset for the period over 1960 to 1971, he examined the extent to which shifts in the composition of energy consumption in the commercial sector can be explained by changes in relative prices during the decade of the 1960s and the early 1970s in the commercial sector in India. He divided the commercial sector into five sub-sectors: (1) mining and manufacture, (2) transportation, (3) domestic, (4) agriculture and (5) government and commercial. He used a static translog cost function model for capital, labour and energy inputs (coal, oil and electrical energy). In general, he found that energy price across the commercial sector has significant effects on energy consumption. He also found that coal and electrical energy are significantly more price responsive than what has been found by other similar studies in other countries. However, for oil the responsiveness is about the same. He also explained that the effect of higher oil prices will trigger a significant stimulus to the consumption of coal and less to the consumption of electrical energy. Thus, he concluded that coal will be the primary alternative to the consumption of oil, when the oil prices increase. In addition, he also claimed that since this study dealt with cross-section data, the interpretation of the estimated elasticities reflect the long-run effects of prices on energy demand. Nevertheless, these results can be questioned since the standard errors of these estimates are not reported.

The analysis of inter-fuel substitution and the industrial demand for energy was also considered by Pindyck (1979a). Using an international data set, he applied a two-stage approach similar to that of Fuss (1977). Because of data deficiencies (a lack of material price data), he assumed that capital, labour and energy are weakly separable from materials. He used pooled time-series data for a cross-section of ten countries; Canada, France, Italy, Japan, the Netherlands, Norway, Sweden, the United States, the United Kingdom and Germany. The results for the share equations of the inter-fuel model show that thirteen of the sixteen coefficients are statistically significant. The fuel price elasticities are substantial, except for electricity where he stated that electricity is the most expensive fuel on a thermal basis and so it is only used when necessary. The own price elasticities for coal range from -1.04 in France to about -2.00 in Canada, Norway and the United States. Natural gas own price elasticities are large for Europe and Japan where the range between -1.3 and -2.3. In Canada and the United States, it was found that the own price elasticity for oil is substantial, even though they had relatively low prices. Pindyck (1979a) explained this on the basis of a greater availability of alternative fuels at low prices, for instance natural gas. Thus, producers can choose technologies that allow for greater possibilities in inter-fuel substitution. For the share equations of inter-factor substitution, the parameters are also found to be significant. The elasticities of substitution indicate that all factors are substitutes for energy (i.e. elasticity of substitution for energy and capital and for energy and labour are positive).

The two-stage translog model was also used by Andrikopoulos et al. (1989) to study the inter-fuel and inter-factor substitution in Ontario manufacturing. Although their approach is similar to that adopted by Fuss (1977) and Pindyck (1979a, 1979b), this work deviates in two ways: first, the level of disaggregation of the manufacturing sector and second, the time period considered in this study. Using yearly data from 1962 to 1982, the manufacturing sector is disaggregated for seven two-digit manufacturing industries: food and beverages, paper and allied products, non-metallic minerals, primary metals, chemical products, transport equipment, and other manufacturing. The energy inputs considered were coal, electricity, fuel oil and natural gas. With respect to other factor inputs, they analysed only capital and labour. The result for the inter-fuel model shows that the there are substitution possibilities between fuel oil and electricity, between fuel oil and natural gas and between coal and natural gas. With regard to the inter-factor model, there was substitutability between capital and labour for all industries (except in the transportation equipment industry), between capital and energy (except in food and beverages and other manufacturing) and between labour and energy in all four sectors. However, compared to other similar studies, the elasticity estimates are high. As explained by Andrikopoulos et al. (1989), the high estimates of the elasticity suggest an increased flexibility both in energy policy options and energy utilization. Consequently, the empirical finding from this work revealed that the two-stage translog model is consistent with the principles of cost-minimizing factor demand theory, since it was found that all own-price elasticities were negative and statistically significant, both in the inter-fuel model and the inter-factor model.

A recent study by Cho et al. (2004) is an example of the more innovative recent work that investigates the inter-factor and inter-fuel substitution via the impact of increases in oil consumption and changes in wage rates. Even though the two-stage estimation method used in this study is similar to the approach taken by Fuss (1979), Pindyck (1979a) and Andrikopoulos et al. (1989), it deviates in the sense that they considered the feedback effect of fuel price changes between the inter-factor and the inter-fuel substitution models. As Cho et al. (2004) explained, ignoring the feedback effect will only yields partial elasticities rather than total elasticities. This is because any changes in fuel price will not only have a substitution effect among individual fuels but also among factors of production. The latter substitution effect takes place through changes in total energy consumption.[6] They further explained that the effect from inter-factor substitution will be transmitted into inter-fuel substitution due to the changes in aggregate energy demand.

Using Korea as a representative developing country, a static and dynamic translog cost function is examined by employing quarterly aggregate data over the period 1981 to 1997. In the static model, fuels were assumed to be weakly separable from labour and capital. This assumption permits to construct an aggregate energy price index of coal, oil and electricity. The cost function is expressed as

$$C = C\left[P_K, P_L, P_E\left(P_{CO}, P_{OI}, P_{EL}\right); Y\right] \tag{2.13}$$

where P_E is a homothetic aggregate energy price index function of the three fuel prices: coal (CO), oil (OI) and electricity (EL).

Cho et al. (2004) argued that the substitution effect might be characterized by a slow adjustment process since fuel and factor demands are relatively fixed in the short-run. Thus, they applied a partial adjustment process to the translog model specification to reflect the dynamic structure of the inter-factor and inter-fuel substitution.

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[6] The details of the model to account for this feedback effect are explained further in Chapter 4, Section 4.3.1.2.

The parameter estimates of the translog factor cost share equations indicate that for the static model, the own price elasticity for capital and labour is found to be negative whilst it is positive for energy. Cho et al. (2004) explained that the positive own-price elasticity of energy could be indicative of the administrative control on energy prices and market imperfections, which tend to prevent the energy prices from functioning within the market system. In addition, it was also found that there is substitutability between capital and labour, and between capital and energy whereas, labour and energy are found to be complements. For the dynamic model, it was found that labour and energy are complementary. According to Cho et al. (2004), this result reflects the impact of the sharp increase in wages in Korea after 1989. For the dynamic adjustment model, it was found that there is substitutability between coal and oil and complementarity between coal and electricity and between oil and electricity. Cho et al. (2004) concluded that the sudden increase in oil consumption and the upward shift in wage rate since 1989 have had an important impact on the inter-factor and inter-fuel substitution, reflected in the clear differences in elasticity estimates for both periods.

2.5 The Relationship Between Energy and Economic Growth

The need to determine the relationship between energy and economic growth has been the subject of intense research over the past three decades. To date, the empirical findings have been remained empirically elusive. The central issue concerns the question of which variable takes precedence over the other: Is energy consumption a stimulus for economic growth (or alternatively, does energy 'cause' GDP?) or does economic growth lead to energy consumption? (or alternatively does GDP 'cause' energy?) (Masih and Masih, 1996, 1998; Toman and Jemelkova, 2003; Fatai, 2004).

The bulk of the literature has so far based upon the 'Granger-causality' principle (Granger, 1969) in investigating energy-GDP causality. The concept of Granger causality is based on the idea that while the past can cause/predict the future, the future cannot cause/predict the past. More precisely, variable X is said to Granger-cause another variable, Y, if the current value of Y (y_t) is conditional on the past value of X ($x_{t-1}, x_{t-2}, \ldots, x_0$). Thus, the history of X is likely to help predict Y.

Granger causality test can be described by applying a Vector Autoregressive (VAR) models. In the case of two variables, y_t and x_t, the VAR model can be written as:

$$y_t = \alpha_1 + \sum_{i=1}^{p} \beta_i x_{t-i} + \sum_{i=1}^{p} \delta_j y_{t-j} + u_{1t} \tag{2.14}$$

$$x_t = \alpha_2 + \sum_{i=1}^{p} \phi_i x_{t-i} + \sum_{i=1}^{p} \gamma_j y_{t-j} + u_{2t} \tag{2.15}$$

where u_t is the residual term. There are four types of outcome that can be derived from this type of model. First, x_t is said to cause y_t when the lagged x terms in (2.14) are statistically different from zero, and the lagged y terms in (2.15) are not statistically different from zero. Second, y_t causes x_t when the lagged y terms in (2.15) are statistically different from zero, and the lagged x terms in (2.14) are not statistically different from zero. Third, bi-directional causality occurs when both sets of x and y terms are statistically different from zero in both (2.14) and (2.15). Finally, when both sets of x and y terms are not statistically different from zero in both equations, then x_t is independent of y_t.

The majority of works that applied this technique can be found mostly in the study undertaken in the United States, other developed countries and for few developing countries. For instance, Yu and Choi (1985) and Erol and Yu (1988), all of whom who found different results in their study. Yu and Choi (1985) examined the causality between energy and income in five countries in various stages of economic development: the United States, South Korea, the Philippines, Poland and the United Kingdom. They confirmed the absence of causality between income and energy for the United States, the United Kingdom and Poland. However, they detected unidirectional causality from income to energy for South Korea and the opposite for Philippines. In addition, Erol and Yu (1988) studied the causality relationship for six developed countries: Japan, West Germany, Italy, Canada, France and the United Kingdom, and they also revealed mixed results for the causality relationship between energy and income. Ebohon (1996) also applied the same method and found that energy plays an important role in economic development for Nigeria and Tanzania.

2.5.1 The Bivariate Model Studies

The use of the standard Granger causality test in the above studies is subject to a criticism because it does not account for the error correction mechanism (ECM). The application of the standard Granger test requires that the variables, y and x, be stationary. Since most economic variables are non-stationary in level forms, the standard Granger causality test is conducted using regressions based on appropriately differenced stationary variables. This differencing process removes useful long-run information about causal relationships among the variables. Therefore, the standard Granger causality test may be invalid and a more comprehensive test of causality based on ECM should be adopted.

The methodology developed by Granger (1983, 1986) and Engle and Granger (1987) provides a more comprehensive test of causality which is applied within the cointegration and ECM. This framework considers the possibility that the long-run information in the data represented by the lagged level of a variable, x, may help to explain the current changes in another variable, y, even if the short-run information in the data given by the past changes in x, do not.

The intuition in this methodology is that if y and x have a common trend, then the current change in y is partly the result of y moving into alignment with the trend value of x. Such causality may not be detected by the standard Granger test, which examines only short-run information given by the past changes in a variable, x, which help explain current changes in another variable, y.

In such a case, the model in equation (2.14) can be written in the ECM form as follows:

$$\Delta y_t = \alpha_0 + \alpha_{1i} \sum_{i}^{p} \Delta x_{t-i} + \alpha_2 v_{t-1} + u_t \qquad (2.16)$$

where $v_{t-1} = y_{t-1} - \alpha_1 x_{t-1}$ is the residual of the cointegration equation. In this procedure, X Granger cause Y, if either the estimated coefficients on lagged values of X or the estimated coefficient on lagged value of error term from cointegrated regression is statistically significant (where the null hypothesis is $H_0 : \alpha_1 = \alpha_2 = 0$). Similarly, Y Granger cause X, if either the estimated coefficients on lagged values of Y or the estimated coefficient on lagged value of error term from cointegrated regression is statistically significant. Therefore, there are two sources of causation, either through the lagged terms Δx or through the lagged cointegrating vector. This means that the inclusion of lagged value of error term from cointegrated regression in the error correction model gives an additional channel, which is not detected by a standard Granger causality test.

In summary, therefore if any linear combination of the non-stationary variables is non-stationary, then the Standard Granger causality test should be adopted, that is a VAR on first differences data. If there exists a linear combination of the non-stationary variables that is stationary, then error-correction model (ECM) should be adopted. Since the use of the ECM requires the series to be cointegrated with the same order, it is essential to first test the series for stationarity and cointegration. A series is said to be non-stationary (or stationary) if it has non-constant (constant) mean, variance, and auto-covariance (at various lags) over time. If a non-stationary series has to be differenced d times to become stationary, then it is said to be integrated of order d: i.e. I(d).

The techniques of cointegration analysis have been employed in the recent studies. For example, Masih and Masih (1996) study the causality between energy consumption and real income for six Asian countries (India, Pakistan, Malaysia, Singapore, Indonesia and the Philippines). By utilising the ECM framework, they found evidence of a long-run relationship for India, Pakistan and Indonesia, with unidirectional causality from energy to income in India, from income to energy in Indonesia and bidirectional causality in Pakistan. Yang (2000), on the other hand uses different types of energy consumption (i.e. oil, gas, coal and power) to study the causal relation with income in Taiwan. He concludes that different directions of causality exist between income and various kinds of energy consumption.

Ghosh (2002) also uses the ECM framework to study the causality between income and energy consumption (electricity) in India using annual data for the period 1950-51 to 1996-97. He revealed that both the series are non-stationary and individually integrated of order one. However, they find that there is no cointegration relationship between the series and therefore, they modelled the bivariate system of income and energy as an unrestricted VAR. Applying the Standard Granger causality test, he concluded that there exists unidirectional Granger causality running from economic growth to energy.

Soytas and Sari (2003) examine the causality relationships between energy consumption and GDP in the top 10 emerging markets and the G-7 countries. Their results of the unit root tests show that these two variables are I(1) in 16 countries. They also found that there is evidence of cointegration for only seven countries (Argentina, Turkey, Korea, France, Italy, West Germany and Japan). They indicate that the causality runs from energy to GDP in Turkey, France, Germany and Japan, whereas a bi-directional causality is detected in Argentina. In

Italy and Korea, the found that the causality runs from GDP to energy consumption.

Employing the same framework, Jumbe (2004) study the link between electricity consumption and GDP for Malawi. He considers annual data over the period 1970 to 1999. However, his approach was slightly differs with Ghosh (2002), such that he uses different types of GDP, i.e. aggregate GDP (GDP), agricultural-GDP (AGDP) and non-agricultural GDP (NGDP). He finds that there was a long-run relationship between electricity and GDP, as well as with NGDP, but not with AGDP. He employed both the standard Granger causality test and ECM techniques to examine the causality between electricity and GDP, and with NGDP. He finds bi-directional causality between electricity and GDP, but a unidirectional causality from NGDP to electricity, for the standard Granger causality test. On the other hand, the ECM results show that there is unidirectional causality from GDP to electricity, as well as from NGDP to electricity. He concludes that the ECM results give a better indication of the Malawi economy that of being less dependent on electricity.

Shiu and Lam (2004), on the other hand, estimates the causal relationships in China during 1971 to 2000. His results indicate that GDP and electricity consumption are cointegrated. They, in contrary to the conclusion derive by Jumbe (2004) draw the conclusion that there is unidirectional Granger causality running from electricity to real GDP.

Lee and Chang (2005) also use different types of energy consumption (i.e. coal, oil, gas and electricity) to study data on Taiwan for the period 1954 to 2003.

However, differ with Yang (2000) they also considered aggregate data for energy consumption. They find different directions of causes that exist between income and various kinds of energy consumption. They concluded that energy is an important source of economic growth in Taiwan.

More recently, attention has increased to studying the causality between energy consumption and GDP, in the panel data framework. The panel data set is used as an attempt to deal with the disadvantages of the short data span in the time series data. The recently developed techniques in panel unit root test and panel cointegration test are being increasingly applied. For example, Al-Iriani (2006), Mehrara (2007), and Chen et al. (2007), all of whom utilised these two tests, in order to rid of the problems with low power tests in time series approach.

Al-Iriani (2006) applies the panel unit root tests and cointegration to verify whether there is a long-run relationship between energy and GDP in the six countries of the Gulf Cooperation Council (GCC). He tested a hypothesis that is since oil-exporting countries of the GCC experience cheap energy sources, therefore energy consumption acts as important source of their economic growth. However, his results show that the hypothesis is rejected. He finds a unidirectional causality running from GDP to energy consumption. Therefore, he concludes that energy conservation policies in these countries may be adopted without much concern about negative effects on their economic growth.

Mehrara (2007) also study the link between energy and GDP in the case of oil exporting countries. He uses annual data over the period 1971 to 2002 on real

GDP and energy use for a panel of 11 countries. They find that causality is running from economic growth to energy use, which is similar with the result by Al-Iriani (2006). Therefore, they summarise that economic growth is important in explaining energy use in the oil exporting countries.

Chen et al. (2007) estimate the causal relationship between electricity consumption and economic growth in 10 Asian countries using both single and panel data sets. The results for the single data set show the causality directions are mixed in these countries. However, in the panel data approach, the causality is found to be running from economic growth to electricity consumption in the short-run and there is a bi-directional causality between the variables in the long-run.

2.5.2 The Multivariate Model Studies

The above studies that have been discussed so far dealt with the link between energy and income in the bivariate model. Studies that focus only on two variables may be biased due to the omission of relevant variables (Lütkepohl, 1982, Chang et al., 2001; Stern, 2000 and Glasure, 2002). In addition, as noted by Stern (2000), "The multivariate methodology is important because changes in energy use are frequently countered by the substitution of other factors of production, resulting in an insignificant overall impact on output." Therefore, the most common approach in recent studies is to employ Granger causality tests in the multivariate framework.

In addition to energy and output variables, previous studies normally include one or more other variables. For example: Cheng (1997) and Lee (2005) both have included a variable for capital; Masih and Masih (1997, 1998), Asafu-Adjaye (2000, 2002) and Mahadevan and Asafu-Adjaye (2007), all of whom have included a variable for price; Chang et al. (2001), Narayan and Smith (2005), all of whom have included a variable for labour and Stern (1993, 2000), Oh and Lee (2004), Paul and Bhattacharya (2004) and Sari and Soytas (2007), all of whom have included variables for both labour and capital. Glasure (2002), on the other hand, included three variables (real money, real government expenditure and the real oil price) in addition to energy consumption and GDP.

In an attempt to investigate this issue using a multivariate framework, Stern (1993) uses a vector autoregression (VAR) model of GDP, energy use, capital and labour inputs to test for Granger causality on the United States data over the period 1947 to 1970. He provided evidence that changes in gross energy use do not cause economic growth, but economic growth causes changes in gross energy use.

Masih and Masih (1997), on the other hand, examined the causal relationship between energy consumption and economic growth for South Korea and Taiwan. In order to examine the causality between income and energy consumption in a multivariate context, they also included the third variable, i.e. price in the model. They used a Vector Error Correction Model (VECM) to test the causality and this model can be shown as:

$$\Delta x_t = \alpha_1 + \sum_{i=1}^{l} \beta_{1i} \Delta x_{t-i} + \sum_{i=1}^{m} \gamma_{1i} \Delta y_{t-i} \sum_{i=1}^{n} \delta_{1i} \Delta z_{t-i} + \sum_{i=1}^{r} \xi_{1i} ECT_{r,t-1} + u_{1t} \quad (2.17)$$

$$\Delta y_t = \alpha_2 + \sum_{i=1}^{l} \beta_{2i} \Delta x_{t-i} + \sum_{i=1}^{m} \gamma_{2i} \Delta y_{t-i} \sum_{i=1}^{n} \delta_{2i} \Delta z_{t-i} + \sum_{i=1}^{r} \xi_{2i} ECT_{r,t-1} + u_{2t} \quad (2.18)$$

$$\Delta z_t = \alpha_3 + \sum_{i=1}^{l} \beta_{3i} \Delta x_{t-i} + \sum_{i=1}^{m} \gamma_{3i} \Delta y_{t-i} \sum_{i=1}^{n} \delta_{3i} \Delta z_{t-i} + \sum_{i=1}^{r} \xi_{3i} ECT_{r,t-1} + u_{3t} \quad (2.19)$$

where x_t, y_t and z_t are income, prices and energy consumption respectively, Δ denotes a difference operator, ECT refers to the error correction term derived from the long-run cointegrating relationships and $u_{i,t}$'s are error term.

Masih and Masih (1997) noted that equation (2.17) was used to test causation from prices and energy consumption to income. Equation (2.18), on the other hand was used to test causation from income and energy consumption to prices, whereas equation (2.19) was used to test causation from income and prices to energy consumption. They also claimed that in addition of the direction of causality, the VECM approach also allows the distinction between the short-run and the long-run causality. The significance of the explanatory variables give an indication of the short-run causality whereas the significance of the lagged error-correction terms shows the long-run causal relationship (the ECT contains the long-run information because it is derived from the long-run cointegrating relationships). They found that there exists a long-run relationship among energy consumption, real income and prices and bi-directional causality between energy consumption and real income for both South Korea and Taiwan.

Following the same approach, Masih and Masih (1998) tested the causal relationship between energy use and income in Thailand and Sri Lanka over the period 1955 to 1991. Using a time-series techniques such as unit root testing, they found that all the variables are I(1). Then, using the Johansen and Juselius's (1990) multivariate procedure, they found that there is evidence of at most one cointegrating relationship for both countries. This means that there exists only one ECT for each of the countries. The result for Thailand shows that there is short-run causality from energy consumption to price. However, in the long-run, causality was detected to run from prices and energy consumption to income. This is because the ECT is only significant in the income equation of the VECM in Thailand. On the other hand, in the case of Sri Lanka, the short-run causality was detected to run from energy consumption to income, whereas the long-run causality is running from energy consumption and price to income.

Applying the same procedure, Asafu-Adjaye (2000) estimated the causal relationships between energy consumption and income for four energy dependent Asian developing countries: India, Indonesia, Philippines and Thailand. Using the Granger causality testing procedure, they report that unidirectional Granger causality runs from energy to income for India and Indonesia, while there is bidirectional Granger causality in Thailand and the Philippines.

Chang et al. (2001) examined the causal relationships among energy consumption, employment and output for Taiwan over the period January 1982 to November 1997. Johansen (1988) and Johansen and Juselius (1990) cointegration test results indicate these three variables are cointegrated with one cointegrating vector. The results from Granger causality tests based on vector error-correction models (VECM) suggest bidirectional Granger causality for employment-output and employment-energy consumption, but only unidirectional causality running from energy consumption to output. Although their results are not consistent with those of Masih and Masih (1997) (feedback exists between energy consumption and GNP) and Cheng and Lai (1997) (GDP Granger causes energy consumption) in the Taiwanese case, they however claimed that their results are more reliable due to the use of a larger sample size.

Another similar study is by Ghali and El-Sakka (2004), whom study the link between energy consumption and income for Canada. They follow an approach that is based on the neo-classical production. Besides energy (E), labour (L) and capital (K), were treated as important factors for generating GDP. This production function can be shown as follows:

$$Y_t = f(K_t, L_t, E_t) \quad (2.20)$$

where Y is aggregate output or real GDP and the subscript t denotes the time period. Using the Johansen cointegration technique, they found that the long-run movements of output, labour, capital and energy consumption are related by two cointegrating vectors. They found evidence of short-run causality running in both directions between output growth and energy use.

Contrary to the above studies, Lee (2005) and Mahadevan and Asafu-Adjaye (2007), all of whom employ the panel methods to test for unit roots, cointegration and causality, in the multivariate framework. They utilised panel tests of Hadri (2000), Levin et al. (2002) and Im et al. (2003) to test for the unit roots of the series (energy, income, capital and labour). They also utilised a panel cointegration of Pedroni (1999) to examine whether there exists a long-run relationships between them.

Lee (2005) studies the link between energy consumption and economic growth in 18 developing countries, covering the period 1975 to 2001. In order to identify the direction of causality, he uses a dynamic panel-based error correction model, which is written as follows:

$$\Delta GDP_{it} = \theta_{1j} + \lambda_{1i}\varepsilon_{it-1} + \sum_k \theta_{11ik}\Delta GDP_{it-k} + \sum_k \theta_{12ik}\Delta EC_{it-k} + \sum_k \theta_{13ik}\Delta K_{it-k} + u_{1it} \quad (2.21)$$

$$\Delta EC_{it} = \theta_{2j} + \lambda_{2i}\varepsilon_{it-1} + \sum_k \theta_{21ik}\Delta GDP_{it-k} + \sum_k \theta_{22ik}\Delta EC_{it-k} + \sum_k \theta_{23ik}\Delta K_{it-k} + u_{2it} \quad (2.22)$$

where GDP_{it}, EC_{it} and K_{it} denote income, energy consumption and capital, respectively, i denotes country and t is year, Δ denotes first differencing, k is the lag length and u_{it} is the error term. The capital stock equation is omitted because he claimed that it is not relevant for the purpose of his study.

Lee (2005)'s results supported the findings of Masih and Masih (1998) and Asafu-Adjaye (2000), namely that there are long-run and short-run causal relationship running from energy to economic growth. He therefore concluded that energy is an important ingredient for economic development because energy consumption leads to economic growth. This implies that high energy consumption tends to have high economic growth.

Mahadevan and Asafu-Adjaye (2007), on the other hand, include price (p) as a third variable in explaining the link between energy consumption (en) and economic growth (gdp). They use annual data over the period 1971 to 2002 for 20 energy importers and exporters, in both developed and developing countries. The results of the panel unit root tests indicate that energy consumption, GDP and prices are I(1). They therefore proceed to the next step, to establish the long-run relationship between the variables. Using the Pedroni' test, they find that the null hypothesis of no cointegration is rejected for both the energy exporters and energy importers countries. Having established the cointegration between the variables, they then estimate a panel-based VECM to identify the direction of causality.

With this analysis they find that in the short-run, there is a bidirectional relationship between energy consumption and GDP for both energy exporters and energy importers developed countries. On the other hand, bidirectional causality is found only in developing countries that are energy exporters. In energy importers developing countries, they find that there is causality running from energy to GDP. In the long-run, bidirectional causality is detected in energy exporters developed countries. In the case of developed countries energy importers, the causality is detected from price to energy consumption. With respect to developing countries, unidirectional causality from GDP to energy consumption is found in energy exporters, while bidirectional causality between energy and GDP is found in energy importers.

CHAPTER THREE

ENERGY DEMAND IN DEVELOPED AND DEVELOPING COUNTRIES: EVIDENCE FROM PANEL DATA ANALYSIS

3.1 Introduction

Spurred by the oil price shocks in late 1973, during the period 1979 to 1980 and in the recent oil prices increased in 1999 and 2000, energy demand analysis has received a great deal of attention.[7] In particular, the estimation of energy demand has been a cornerstone for the identification of the future evolution of energy consumption, its implications for the global environment and the impact of policies response (Brenton, 1997 and Galindo, 2005). Hunt et al. (2003) emphasised the importance of estimating the demand function correctly to obtain accurate estimate of the price elasticity. This is especially important at a time when energy policy is focussed on reducing emissions. For instance, if the price elasticity is relatively small, then energy taxes may not succeed. Hence, other restrictions and regulations may also be needed to achieve the desired aim.

As a consequence, great effort has been made to identify the main forces behind energy consumption.[8] The purpose of most of these studies has been to measure the impact of economic activity and energy prices and thereby obtain estimates of price and income elasticities of energy demand. More recently, it has been argued

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[7] Barker *et al.*, (1995), Brenton (1997) and Pesaran *et al.*, (1998) were among the many studies who discussed the importance of the empirical investigation of energy demand.
[8] See Pindyck (1979a, 1979b); Field and Grebenstein (1980); Fiebig *et al.* (1987); Bentzen and Engsted (1993) and Chan and Lee (1996) for early empirical studies, and Pesaran *et al.* (1998); Cooper (2003); Liu (2004) and Welsch and Ochsen (2005) for more recent ones.

that in addition to the normal economic variables (income and price) there are a range of other exogenous factors that potentially will have an important influence on energy demand.[9]

It is standard in these previous studies to investigate the relationship between energy demand and its determinants using data from a single country. Consequently, there is comparatively little research on the issue using aggregate international data.[10] Moreover, most of them only consider the traditional economic variables (such as income and price) in the analysis of energy demand. Therefore, a serious impediment to the design of appropriate energy policies is a scarcity of studies which provide a rigorous analysis of the determinants of energy demand at the international aggregate level. Besides, most of the estimations of energy demand are obtained using information from developed countries with, arguably, different economic circumstances than those of a developing country (Galindo, 2005).[11]

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[9] Early empirical studies such as Beenstock and Willcocks (1981); Kouris (1983); Mountain *et al.* (1989); Sterner (1990); Berndt *et al.* (1993) and recently Popp (2001) show that technological progress plays a crucial role in the demand of energy. In addition, the degree of industrialisation also has been identified to have an important influence on energy demand (Chan and Lee, 1996; Adams and Shachmurove, 2000 and Schäfer, 2005). More recently, Hunt *et al.* (2003); Hunt and Ninomiya (2003, 2005) and Dimitropoulos *et al.* (2004) explained that other factors that can have an impact on energy demand are: environmental pressures and regulations, energy efficiency standards, substitutability of labour, capital or raw materials for energy inputs, general changes in tastes that could lead to a more or less energy intensive situation and the change in the economic structure.

[10] Among the few studies, Pindyck (1979a) focused on the demand for energy on a pooled time-series cross-section data for a group of OECD countries and a few less developed countries. He showed that income and price have a significant effect on energy demand. Beenstock and Willcocks (1981) have estimated a positive income effect and a negative price effect on energy demand using international data of OECD countries. Brenton (1997) and Pesaran *et al.* (1998) provide similar evidence using data from 60 countries and a panel of Asian developing economies, respectively.

[11] Developed countries differ substantially from developing countries in their economic structure, consumption patterns, technology levels, transportation patterns, the structure of urbanisation and life style.

Attempting to partially fill this gap, this study therefore demonstrates the importance of identifying the major determinants of energy demand using a panel of 23 developed countries and 16 developing countries over a 26-year period. By grouping the countries into two groups of economic development, the possibilities and limitations of alternative energy control policies can be identified (Galindo, 2005). As such, the objectives of this study are (1) to reliably estimate price and income elasticities of energy demand (2) to examine the impact of additional determinants of aggregate energy demand (3) to compare the different patterns of energy consumption in developed and developing countries.

In this study, the Pooled Mean Group (PMG) estimator is used to assess the short- and long-run relationship between energy demand and its determinants. This method developed by Pesaran et al. (1999) takes account of homogenous long-run relationships in heterogeneous panels. In particular, it allows short-term adjustments and convergence speeds to vary across countries, and impose the long-run relationship to be identical across groups. There are indeed good reasons to believe in common long-run coefficients across countries, given that they have access to common technologies and will be experiencing a similar budget constraint. Conversely, there is no reason to assume short-run responses to be homogeneous across countries because they depend much on patterns of energy use, equipment and supply constraints which tend to be different in each country.

This study differs from earlier works in the subject in three distinct ways. First, the approach used in this study takes into account the impact of economic structure and technological progress on energy demand. Secondly, the application of the PMG estimation has not been used extensively in energy demand studies, compared to other techniques.[12] To date, only Pesaran et al. (1999) have applied PMG estimation to study energy demand in developing countries. However, this study differs from theirs in two important respects. First, with regards to the choice of countries used in the analysis and second, they only account for income and price as determinants of energy demand.

The structure of this chapter is organised as follows. Section 3.2 explains the general framework that usually underlies the empirical formulation of the demand for energy and it also explains the econometric methodology. Section 3.3 describes the data used in this study. Section 3.4 reports and interprets the results. Finally, section 3.5 provides a summary of the key results of this study and policy implications.

3.2 The Framework: Empirical Model and Methodology

3.2.1 The Empirical Model

There is an extensive literature examining energy demand in the context of developing and developed countries. In most of these studies the aim has been to measure the impact of economic growth and real energy prices on the demand for

[12] So far the PMG test has been adopted in the area of money demand (Slok, 2002), economic growth issues (Bassanini and Scarpetta, 2002), trade unions and productivity growth (Asteriou and Monastiriotis, 2004) and investment (Fedderke, 2004).

energy, by estimating income and price elasticities.[13] Following Kouris (1983), Bentzen and Engsted (1993), and Galindo (2005) among others, energy demand is basically a positive function of income or per capita income and a negative function of its own relative prices, which can be modelled as:

$$E_{it} = f(Y_{it}, P_{it}) \tag{3.1}$$

The dependent variable E_{it} is per capita energy consumption by country i at time t; Y_{it} denotes the real per capita income and P_{it} represents the real price of energy.

In the literature, the function is specified in linear double-log form so that the elasticities are given by the slope coefficients:

$$\ln E_{it} = \alpha_0 + \alpha_1 \ln Y_{it} + \alpha_2 \ln P_{it} + \varepsilon_{it} \tag{3.2}$$

where ε_{it} is an error term and is assumed to be identically and independently distributed with zero mean and constant variance, i.e., $\varepsilon_{it} \sim IID\,(0, \sigma^2)$.

The adopted log-linear functional form as shown in equation (3.2) has been employed by the majority of energy demand studies because of its simplicity in the model structure, the ease in interpretation of the estimated parameters and less costly data requirements compared to other more complex theoretical models (Hunt and Ninomiya, 2005). Furthermore, Pesaran et al. (1998) have shown that

[13] See for example, Beenstock and Willcocks (1981), Samouilidis and Mitropoulos (1984), Fiebig (1987), Bentzen and Engsted (1993), Pesaran *et al.* (1998), Gately and Huntington (2002), Cooper (2003) and Galindo (2005).

the log-linear specification fits actual energy data better than models which have a stronger connection to the utility maximisation theory. In addition, they also argued that this specification is a convenient forecasting tool.

Recently, it has been argued that in addition to the normal economic variables such as income and price, there are a range of other exogenous factors that potentially will have an important impact on energy demand (see for instance, Chan and Lee, 1996; Popp, 2001; Hunt et al., 2003 and Schäfer, 2005). Therefore, this study extends equation (3.2) to include the structure of the economy and technical progress in order to examine their influence on energy demand. Thus, the energy demand equation is extended as follows:

$$\ln E_{it} = \alpha_0 + \alpha_1 \ln Y_{it} + \alpha_2 \ln P_{it} + \alpha_3 \ln I_{it} + \alpha_4 \ln T_{it} + \varepsilon_{it} \qquad (3.3)$$

where I represents the structure of the economy, which is proxied by the share of industry in GDP and T is the technical progress or efficiency improvement which is proxied by a deterministic time trend. As for the expected signs in equation (3.3), it is expected that $\alpha_1 > 0$ because higher real per capita income should result in greater economic activity and accelerate the use of energy. The coefficient of price level is expected to be less than zero, that is $\alpha_2 < 0$. The degree of industrialisation, as a measure of the economic structure, is expected to increase the consumption of energy, therefore, $\alpha_3 > 0$. Technological progress could have either a positive or negative effect on energy consumption (Hogan and Jorgenson, 1991 and Hunt et al., 2003). As discussed in Mountain et al. (1989), technology is energy using if $\alpha_4 > 0$ and energy saving if $\alpha_4 < 0$.

3.2.2 The Econometric Approach

Energy demand has been estimated from cross-section models across countries, from dynamic time-series models for individual countries, and from pooled models on panel data. The results obtained from the various methods have tended to differ substantially, and it is often argued that cross-section estimates produce more sensible long-run relationship than time-series do (Pesaran and Smith, 1995).[14] However, cross-sectional estimation methods do not take advantage of the time-series variation in the data, which could produce inefficiency of parameter estimation. Hence, this study uses panel data techniques to estimate variants of equation (3.3), thereby exploiting the cross-section (N) and time-series (T) dimensions of the data.

Equation (3.3) can be examined empirically in different ways. In this study, two approaches of panel data analysis are applied; firstly using the traditional panel data techniques (pooled ordinary least square (OLS), fixed effects (FE) and random effects (RE)) and secondly using a dynamic heterogeneous panel model. In the latter approach, the mean group (MG) and pooled mean group (PMG) estimators suggested by Pesaran, et al. (1999) are employed. The panel data regressions are estimated based on the sample period from 1978 to 2003 and uses two groups of countries: (1) 23 developed countries and (2) 16 developing countries.

[14] For instance, Baltagi and Griffin (1984) provide an empirical result of the tendency for cross sections data to yield long run responses and time series to yield short run responses. Through the use of Monte Carlo simulations, they show that for estimated energy demand equation, the cross-section estimates provide sensible long-run estimates compared to the time-series estimates.

3.2.2.1 Traditional Panel Data Analysis

The basic framework for this analysis is provided in equation (3.3). The procedure commonly used imposes common slopes but allows for a heterogeneous fixed or random intercept. Therefore, these estimators, known as fixed and random effects estimators, allow the intercepts to differ across groups while all other coefficients and error variance are constrained to be the same. In general, equation (3.3) could be written as

$$y_{it} = \alpha_i + x_{it}'\beta + \varepsilon_{it}, \qquad \varepsilon_{it} \sim IID(0, \sigma_\varepsilon^2) \tag{3.4}$$

where α_i contains a constant term and a set of individual or group specific variables, y_{it} is a vector of dependent variables and x_{it} is a vector of explanatory variables. If the individual effects α_i are treated as N fixed unknown parameters, the model in (3.4) is referred to as the FE model. The FE model is a linear regression model in which the intercept terms vary over the individual units *i*, allowing the unobserved individual effects to be correlated with the included variables. Alternatively, when α_i are treated as random, the model is referred to as the RE model. The RE model assumes that the unobserved individual heterogeneity is uncorrelated with the regressors. Under this assumption the RE estimator will be consistent and also efficient. This RE model specifies that the error term consists of two independent components, one being time-variant (α_i) and the other time-invariant (ε_{it}). It can be written as

$$y_{it} = \mu + x_{it}'\beta + \alpha_i + \varepsilon_{it},$$

$$\varepsilon_{it} \sim IID(0, \sigma_\varepsilon^2); \quad \alpha_i \sim IID(0, \sigma_\alpha^2) \tag{3.5}$$

where μ denotes the intercept term.

In this study, the static energy demand model in equation (3.3) is first estimated by using pooled ordinary least square (OLS), which ignores the panel nature of the data and assumes that ε_{it} has no serial correlation. A test is then carried out on whether the data can be pooled. In particular, the Breusch-Pagan test is used (Breusch and Pagan, 1980) to test for the random effects model based on the OLS residuals. This test has the pooled model as the null hypothesis, and a random effects model as the alternative. In particular, if we let σ_{α}^{2} denote the variance of α_{i} (individual- specific term), the null hypothesis can be expressed as $H_{o}:\sigma_{\alpha}^{2}=0$ and the alternative hypothesis as $H_{1}:\sigma_{\alpha}^{2}\neq 0$. The Lagrange multiplier (LM) test statistic is given by

$$LM=\frac{NT}{2(T-1)}\left[\frac{\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{\varepsilon}_{it}\right)^{2}}{\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{\varepsilon}_{it}^{2}}-1\right]^{2} \tag{3.6}$$

where $\hat{\varepsilon}_{it}$ is the OLS residual from regressing y_{it} on a constant and x_{it}. If the null hypothesis is true, this statistic is distributed as a chi-squared with one degree of freedom. If the null hypothesis is rejected (the calculated value exceeds the tabulated chi-squared value), this shows that the OLS regression model (pooled model) is inappropriate and the random effects model is favoured by the data.

In order to determine whether a fixed or random effect model is more appropriate (that is whether to treat the individual effects α_i as fixed or random), the Hausman test is employed. Under the null hypothesis, the two estimates should not differ systematically, and a test can be based on the difference. Specifically, under the null hypothesis that x_{it} and α_i are uncorrelated, both RE and FE models are consistent, but FE is inefficient, whereas under the alternative, FE is consistent, but RE is not (Greene, 2003 and Verbeek, 2004). In this analysis, the Hausman specification test is used to choose between the two estimators, one which is efficient and consistent under the null, but inconsistent under the alternative and another one which is consistent under both.

The Hausman test statistic is given as the following:

$$Haus = \left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right)'\left[V_{FE} - V_{RE}\right]^{-1}\left(\hat{\beta}_{FE} - \hat{\beta}_{RE}\right) \qquad (3.7)$$

where $\hat{\beta}_{FE}$ is the fixed effects estimator of slope parameters, $\hat{\beta}_{RE}$ is the random effects estimator of slope parameters for the time-variant regressors, the variance-covariance matrix of $\hat{\beta}_{FE}$ and $\hat{\beta}_{RE}$ are denoted by V_{FE} and V_{RE} respectively and the Hausman statistic will have an asymptotic chi-squared distribution with K degrees of freedom under the null, where K is the number of elements in β. Thus, the Hausman test tests whether the FE and RE estimators are significantly different (($\hat{\beta}_{FE} - \hat{\beta}_{RE}$) = 0). Under the null hypothesis the random effect is appropriate. Alternatively, a significant difference between the two estimators indicates that the null hypothesis is unlikely to hold (that is, the rejection of the null favours the FE model).

3.2.2.2 Dynamic Heterogeneous Panel Model

In the presence of dynamics, the use of standard panel techniques leads to inconsistent estimates and potentially misleading inferences even for large N and T panels (Pesaran et al., 1996). Moreover, these approaches generally impose homogeneity of all slope coefficients, allowing only the intercept to vary across countries. Pesaran et al., (1999) suggest that while it is implausible that the dynamic specification is common to all countries, it is at least conceivable that the long-run parameters of the model may be common.

In view of these considerations, the long-run demand model expressed in equation (3.3) was estimated using two recently developed methods for the statistical analysis of dynamic panel models: the Mean Group (MG) and the Pooled Mean Group (MG) estimation. The MG estimator introduced by Pesaran and Smith (1995) consists of estimating separate regressions for each country and computing averages of the country-specific coefficients, which imposes no restrictions. By contrast, the PMG estimator proposed by Pesaran et al. (1999) restricts the long-run coefficients to be the same across countries but allows the short-run coefficients to be heterogenous.[15] Imposing equality restrictions, if they are valid,

[15] The restriction of long-run slope homogeneity can be justified by appealing to the existence of a similar budget or solvency constraints, arbitrage, common technologies and uniform preferences across individual units. On the other hand, heterogeneous short-run responses will be the consequence of state-specific institutional factors such as laws, customs and market structure (Pesaran *et al.*, 1998 and Freeman, 2000). Particularly, in the energy sector, the long-run responses of energy demand to income and relative energy prices are likely to be similar across countries. On the other hand, the short-run responses are unlikely to be homogenous across countries because they depend much on patterns of energy using, equipment and supply constraints which tend to be different at any particular period.

will increase the efficiency and reduce the standard errors of the estimates (Pesaran et al., 1998). These estimations, unlike traditional procedures, are able to estimate long-run relationships while allowing for the possibly heterogeneous dynamic adjustment process.

Following Pesaran et al. (1999), the panel analysis on the unrestricted error correction ARDL (p,q) model is represented as the following:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \beta_i' x_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}' \Delta x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{3.8}$$

where $i = 1,2,...N;\ \ t = 1,2,...,T$, denote the cross-section units and time periods, respectively. Here, y_{it} is a scalar dependent variable, x_{it} is the k x 1 vector of explanatory variables for group i, μ_i represents the fixed effects, ϕ_i is a scalar coefficient on the lagged dependent variable, β_i is the k x 1 vector of coefficients on explanatory variables, λ_{ij} 's are scalar coefficients on lagged first-differences of dependent variables, δ_{ij} 's are k x 1 coefficient vectors on first difference of explanatory variables and their lagged values. It is assumed that the disturbances ε_{it} 's are independently distributed across i and t, with zero means and variances $\sigma_i^2 > 0$. A further assumption is that $\phi_i < 0$ for all i and there exists a long-run relationship between y_{it} and x_{it} which is defined by

$$y_{it} = -\left(\beta_i' / \phi_i\right) x_{it} + \eta_{it} \tag{3.9}$$

for each i = 1, 2, ..., N. Equation (3.8) can be written as

$$y_{it} = \theta_i' x_{it} + \eta_{it} \qquad i = 1,2,...N; \quad t = 1,2,...,T \tag{3.10}$$

where $\theta_i' = -\beta_i'/\phi_i$ is the k x 1 vector of the long-run coefficients and η_{it}'s are stationary with possibly non-zero means because they include fixed effects. Given the above assumptions, this allows equation (3.8) to be written as:

$$\Delta y_{it} = \phi_i \eta_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}' \Delta x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{3.11}$$

where $\eta_{i,t-1}$ is the error correction term given by (3.10). Therefore, the error correction coefficient measuring the speed of adjustment towards the long-run equilibrium is represented by ϕ_i.

Under this general framework, there are three approaches that will be considered. First, the dynamic fixed effects (DFE) model which imposes the homogeneity assumption for all the parameters except for the fixed effects. For each i = 1,..., N, this restriction can be shown as:

$$\begin{aligned} &\phi_i = \phi; \ \beta_i = \beta; \ \lambda_{ij} = \lambda_j, && j = 1,...,p-1; \\ &\delta_{ij} = \delta_j, && j = 1,...,q-1; \\ &\sigma_i^2 = \sigma^2. && \end{aligned} \tag{3.12}$$

The fixed effects estimates of all the short-run parameters are obtained by pooling and denoted by $\hat{\phi}_{DFE}$, $\hat{\beta}_{DFE}$, $\hat{\lambda}_{jDFE}$, $\hat{\delta}_{jDFE}$ and $\hat{\sigma}^2{}_{DFE}$. The estimate of the long-run coefficient is then obtained by

$$\hat{\theta}_{DFE} = -\left(\frac{\hat{\beta}_{DFE}}{\hat{\phi}_{DFE}}\right) \tag{3.13}$$

Secondly, the MG estimates, which allows for heterogeneity of all the parameters, yields the following estimates of short-run parameters:

$$\begin{aligned}
\hat{\phi}_{MG} &= N^{-1}\sum_{i=1}^{N}\hat{\phi}_i; \\
\hat{\beta}_{MG} &= N^{-1}\sum_{i=1}^{N}\hat{\beta}_i; \\
\hat{\lambda}_{jMG} &= N^{-1}\sum_{i=1}^{N}\hat{\lambda}_{ij}; \quad j = 1,\ldots,p-1, \\
\hat{\delta}_{jMG} &= N^{-1}\sum_{i=1}^{N}\hat{\delta}_{ij}, \quad j = 1,\ldots,q-1,
\end{aligned} \tag{3.14}$$

where $\hat{\phi}_i, \hat{\beta}_i, \hat{\lambda}_{ij}$ and $\hat{\delta}_{ij}$ are the OLS estimates obtained individually from equation (3.8). The mean of the long-run parameters can be estimated as follows:

$$\hat{\theta}_{MG} = N^{-1}\sum_{i=1}^{N} -(\hat{\beta}_i / \hat{\phi}_i) \tag{3.15}$$

Finally, this chapter also uses the PMG estimator, which allows the intercepts, short-run coefficients and error variances to differ freely across groups, but constraints the long-run coefficients to be homogeneous. That is,

$$\theta_i = \theta, \quad i = 1,2,...,N \tag{3.16}$$

Under this procedure, the group-specific short-run coefficients and the common long-run coefficients are computed by the pooled maximum likelihood (PML) estimation. These estimators are obtained as follows:

$$\begin{aligned}
\hat{\phi}_{PMG} &= N^{-1}\sum_{i=1}^{N}\tilde{\phi}_i; \\
\hat{\beta}_{PMG} &= N^{-1}\sum_{i=1}^{N}\tilde{\beta}_i; \\
\hat{\lambda}_{jPMG} &= N^{-1}\sum_{i=1}^{N}\tilde{\lambda}_{ij}; \qquad j = 1,...,p-1, \\
\hat{\delta}_{jPMG} &= N^{-1}\sum_{i=1}^{N}\hat{\delta}_{ij}; \qquad j = 0,...,q-1, \\
\hat{\theta}_{PMG} &= \tilde{\theta}
\end{aligned} \tag{3.17}$$

PMG estimation provides an intermediate case between the dynamic fixed effects (DFE) estimator, which imposes the homogeneity assumption for all parameters except for the fixed effects, and the mean group (MG) estimator proposed by Pesaran and Smith (1995), which allows all parameters to be heterogeneous.

The test to choose between PMG and MG is an application of the testing principle proposed by Hausman (1978). Thus, a Hausman-type test can be used to test the hypothesis of the long-run slope homogeneity. Under this hypothesis, PMG estimators are consistent and more efficient than MG estimators, which impose no constraint on the regression (Pesaran et al., 1999). Specifically, the test can be computed as follows (Pesaran et al., 1997)

$$h = (\hat{\theta}_{MG} - \hat{\theta}_{PMG})'\hat{\psi}^{-1}(\hat{\theta}_{MG} - \hat{\theta}_{PMG}) \quad (3.18)$$

where $\hat{\psi} = \hat{V}(\hat{\theta}_{MG}) - \hat{V}(\hat{\theta}_{PMG})$ is the difference between the variances of MG and PMG estimators and is a consistent estimator of the variance of $(\hat{\theta}_{MG} - \hat{\theta}_{PMG})$. Under the null hypothesis of no misspecification, the long-run parameters are identical for each group and thus, restricted estimation (PMG) is efficient. The Hausman's statistic is asymptotically χ^2 distributed with k degrees of freedom, where k is the dimension of θ.

3.3 Data

The data set used in this study refers to 39 countries, which are listed in Appendix 3.1 and has annual time series data for the period 1978 to 2003. The sample countries are divided into developed countries and developing countries based on the World Bank classification.[16] The selection of these countries has been determined predominantly by data reliability and availability considerations. A brief description of the variables used in this study is given in Table 3.1. A more detailed description is given in the following.

Energy consumption refers to total final consumption, which is the sum of coal, electricity, natural gas and petroleum products consumption by the different end-

[16] The World Bank divided economies among income groups according to 2002 gross national income (GNI) per capita. It classifies economies as high income if GNI per capita is more than US$9076, middle income if the GNI per capita is between US$736 until US$9075 and low income if the GNI per capita is less than US$735. For developing countries, the classifications for the countries included are low-income economies, lower-middle income and upper-middle income.

use sectors. The unit of measurements is in thousand tonnes of oil equivalent (ktoe) and then divided by population to give a per capita series. By combining demographics data with energy consumption, the trends in energy use per capita and differences in per capita energy use between countries can be analyzed. The annual data of energy consumption is collected from Energy Balances of OECD Countries and Energy Balances of Non-OECD Countries, International Energy Agency (IEA) database.

Data on real gross domestic product (GDP) per capita is taken from the World Development Indicators, 2005 ESDS International database. It is used as the measure of income, and is based on purchasing power parity (PPP) denominated in constant 2000 international dollars.

An annual energy price is collected from the Energy End-Use Prices, IEA database. The basic price data is the nominal price in international currency for a tonne of oil equivalent of a particular fuel. The prices are provided at a detailed level of disaggregation by fuels. For products with more than one price is available, a representative series is created for each country.[17] This representative series of price is constructed as the weighted average of energy price of the particular fuel. For instance, the representative petroleum products price is a combination of high sulphur fuel oil, low sulphur fuel oil, light fuel oil and automotive diesel. The representative coal price is a combination of steam coal and coking coal. Thus, the basic prices used in this study are those for the four fuels, i.e. coal, electricity, natural gas and petroleum products.

[17] The list of products is presented in Appendix 3.II.

In order to calculate the price of energy appropriately, a weighted average price was used as to reflect the relative importance of each fuel. The weighted average price is calculated by multiplying the prices of fuels by the corresponding quantities, and the weights used were the quantities consumed. This can be shown as follows:

$$\overline{P}_{it} = \frac{\sum_{i=1}^{4} P_{it} Q_{it}}{\sum_{i=1}^{4} Q_{it}} \tag{3.19}$$

where $\overline{P}_{it}$, P_{it} and Q_{it} is the weighted average price of energy, the price of fuels and the quantities of fuels consumed, respectively of country i at time t . Thus, energy price is the weighted average of the prices for four fuels (coal, electricity, natural gas and petroleum products), with the weights being the quantities of the four fuels consumed. The resulting weighted average price is deflated by a GDP deflator to give a constant price series. The prices are normalized to a value of 100 in the base year (1995).

The structural changes in the economy, proxied by the share of industry in GDP, attempts to measure the importance of economic structure in explaining energy use. As argued in Chan and Lee (1996), the share of industry in the national income can be used to represent the economic structure. This is due to the fact that the industry sector is a major energy-using sector of many countries. Moreover, Samouilidis and Mitropoulos (1984) and Adams and Shachmurove (2000) employed this variable as a proxy of the maturity of the economy. This variable is expected to have a positive relationship with energy demand. Thus, a higher degree of industrialization tends to be associated with a larger energy demand. This measure comprises value added in mining, manufacturing, construction, electricity, water and gas. The data are obtained from the World Development Indicators, 2005, ESDS International database.

Technical progress is considered to be another important variable that determines energy consumption. In this study, a deterministic time trend is used as a way of capturing improvements in energy efficiency. Although there has been a debate in the energy economics literature about the use of a time trend, (see, for example, Beenstock and Willcocks, 1981; Kouris, 1983; Hunt et al., 2003 and Dimitropoulos et al., 2004), technical progress is an important factor that has always been very difficult to quantify unless a satisfactory way of measuring it can be found. Therefore, following the standard approach to accounting for technical progress, a time trend is used as a proxy of efficiency improvement. This variable is expected to have either a positive or negative effect on energy consumption.

Other variables used in this study are population and gross domestic product (GDP) deflator, which are taken from the World Bank, World Development Indicators (WDI), Economic and Social Data Service (ESDS) International Database.

Table 3.1: Description and Units of the Data

Variable	Unit of measurement	Data Description
E	Kt of oil equivalent (ktoe) per capita	Energy use per capita consist of the sum of four types of fuels; coal, electricity, natural gas and petroleum products.
Y	Constant 2000 international $	Real GDP per capita, based on purchasing power parity (PPP)
P	US$/toe	Real energy price
I	Value added (% of GDP)	The share of industry in GDP
T		Technical progress
$\mathbf{GDP_d}$		Gross Domestic Product deflator

3.3.1 Descriptive Statistics and Correlations

Table 3.2 and 3.3 report summary statistics and correlations of the variables used in the analysis for 23 and 16 developed and developing countries respectively. There is a considerable variation among these variables across countries. In developed countries, energy consumption per capita ranges from 1.20 ktoe in Portugal to a high of 7.63 ktoe in Luxembourg. Real GDP per capita ranges from US$10528.46 in Korea to US$35640.06 in Luxembourg. Greece has the highest energy price of US$241.16 per toe, and Germany has the lowest energy price of US$39.49 per toe. In addition, the degree of industrialisation ranges from 27.15% in Greece to 37.70% in Norway.

With respect to developing countries, energy consumption per capita ranges from 0.14 ktoe in India to 3.76 ktoe in Czech Republic. With regards to the real GDP per capita, the range is from US$329.85 in India to a high of US$5319.87 in Venezuela. Energy price and the share of industry also show significant variation. India experiences the highest energy price and has the lowest degree of industrialisation, with US$255.55 per toe and 20.64%, respectively. Venezuela has the lowest level of energy price whereas Slovak Republic has the highest degree of industrialisation.

On the other hand, the correlation results indicate that energy demand has a positive relationship with income and technological progress, whereas price and degree of industrialisation are negatively correlated with energy consumption per capita. With regards to developing countries, income and economic structure have a positive correlation with energy consumption, whereas price and technology are negatively correlated.

Table 3.2: Descriptive Statistics of Different Groups

(i) Developed Countries

N=26	E	Y	P	I	T
Mean	2.94	21451.23	110.83	32.62	13.5
Std Dev	1.56	6094.91	39.49	3.65	7.51
Max	7.63	35640.06	241.16	37.70	26
Min	1.20	10528.46	72.85	27.15	1

(ii) Developing Countries

N=16	E	Y	P	I	T
Mean	1.34	2736.81	131.42	39.41	13.5
Std Dev	0.97	1611.39	46.86	6.46	7.51
Max	3.76	5319.87	255.55	47.70	26
Min	0.14	329.85	67.94	26.34	1

Note: E = Energy consumption per capita; Y = Real GDP per capita; P = Real energy price; I = Share of industry in GDP; T = Technical progress

Table 3.3: Correlation Results of Different Groups

(i) Developed Countries

N = 26	E	Y	P	I	T
E	1.00				
Y	0.59	1.00			
P	-0.37	-0.48	1.00		
I	-0.11	-0.42	0.12	1.00	
T	0.12	0.48	-0.38	-0.49	1.00

(ii) Developing Countries

N = 16	E	Y	P	I	T
E	1.00				
Y	0.73	1.00			
P	-0.25	-0.30	1.00		
I	0.48	0.14	-0.10	1.00	
T	-0.01	0.09	-0.29	-0.27	1.00

Note: E = Energy consumption per capita; Y = Real GDP per capita; P = Real energy price; I = Share of industry in GDP; T = Technical progress

3.4 Empirical results

This section presents the results of the panel data analysis for two alternative econometric specifications, allowing firstly for static models of energy demand with fixed effects and random effects and secondly for dynamic heterogeneous panel data models. The sample consists of 23 developed countries and 16 developing countries. The dependent variable is energy consumption per capita (E) and the control variables are the real GDP per capita (Y), energy price (P), the degree of industrialisation (I) and technological progress (T).

3.4.1 Traditional Panel Data Analysis Results

Tables 3.4 and 3.5 present the estimation results on the sample of developed and developing countries, respectively, using OLS and GLS estimations of the energy demand models in (3.4) and (3.5). In the case of pooled (no country effects) OLS regression with developed countries, only income enters significantly, and it has, as found in many pure cross-country regressions, a positive sign. In the case of developing countries, in addition to income, the degree of industrialisation (the structure of the economy) also shows a significant result. The price of energy, which is another important determinant for energy demand, does not enter the pooled OLS regressions significantly. However, in the random effects and fixed effects models, not only the income coefficient is significant in developed countries, but also energy price and the technological progress. However, in developing countries, only income and the economic structure coefficient are significant. Note that the Hausman test in Tables 3.4 and 3.5 is rejected at the 5 per cent level of significance, implying that the fixed effects model appears to be appropriate.

In particular, an inspection of the fixed effects model in Table 3.4 indicates that income, price and technological progress have elasticities of 0.810, -0.296 and -0.091, respectively, with the expected signs and significant t-values. These findings are consistent with those of Beenstock and Willcocks (1981), Jones (1994) and Gately and Huntington (2002) which all point to the very significant effect of income, price and technical progress in developed countries. On the other hand, in the case of developing countries, Table 3.5 shows that income and economic structure have elasticity values of 0.559 and 0.643, respectively. The positive and significant value of the economic structure confirms the Adams and Shachmurove (2000) findings, who observed a strong connection between the degree of industrialisation and energy demand in developing countries.

Table 3.4: Panel Data Analysis on Energy Demand of 23 Developed Countries

Independent Variable	Pooled	Random Effects	Fixed Effects
Y	1.379***	0.896***	0.810***
	(3.511)	(8.388)	(6.739)
P	0.034	-0.296***	-0.296***
	(0.088)	(-5.071)	(-4.985)
I	0.501	0.253	0.255
	(0.689)	(1.380)	(1.311)
T	-0.009	-0.107***	-0.091***
	(-0.121)	(-3.443)	(-2.86)
constant	-14.595	-7.165	-6.355
	(-2.035)	(-5.406)	(-4.477)
Breusch-Pagan test		774.80	
Hausman test			3.45**
R-squared	0.61	0.41	0.40

Notes: The figures in parentheses are t-statistics. ***, ** and * indicate significance at 1%, 5% and 10%, respectively. The Breusch-Pagan and Hausman tests are χ^2 tests for the appropriateness of random effects (versus no effects and fixed effects, respectively).

Table 3.5: Panel Data Analysis on Energy Demand of 16 Developing Countries

Independent Variable	Pooled	Random Effects	Fixed Effects
Y	0.770**	0.576***	0.559***
	(4.170)	(11.398)	(10.477)
P	0.728	-0.028	-0.029
	(1.097)	(-1.35)	(-1.39)
I	3.054***	0.649***	0.643***
	(3.030)	(8.418)	(8.266)
T	0.277	-0.016	-0.016
	(1.287)	(-1.066)	(-0.990)
constant	-21.140	-6.663	-6.510
	(-2.918)	(-15.611)	(-15.574)
Breusch-Pagan test		3040.18	
Hausman test			64.28**
R-squared	0.77	0.65	0.65

Notes: The figures in parentheses are t-statistics. ***, ** and * indicate significance at 1%, 5% and 10%, respectively. The Breusch-Pagan and Hausman tests are χ^2 tests for the appropriateness of random effects (versus no effects and fixed effects, respectively).

3.4.2 The DFE, MG and PMG Estimation Results

The relationship between energy demand and the determinants identified above requires further investigation. The estimations in Section 3.4.1 are suspicious, because the data generating process might have complex county specific dynamics and involve slope heterogeneity, circumstances under which the traditional static estimators will not yield reliable estimates. Therefore, the MG and PMG estimation techniques, which allow for such effects, are likely to yield more reliable estimates.

The estimation results on energy demand for developed and developing countries from the heterogeneous dynamic panel estimation are presented in Table 3.6 and 3.7, respectively. The tables report the estimation of the long-run and short-run coefficients, the error correction coefficients and Hausman test statistics. In Table 3.6, the results consist of four panel data estimators: mean group (MG), pooled mean group (PMG), dynamic fixed effects (DFE) and static fixed effect (SFE) models. The econometric software used in this study is a program written in GAUSS.[18]

As outlined in the previous section, the consistency and efficiency of the PMG estimates rely on several specification conditions. The first is that the regression residuals are serially uncorrelated and that the explanatory variables can be treated as exogenous. In order to obtain residuals that are serially uncorrelated, lags of the dependent variable and regressors are included. In the case of developed countries (Table 3.6), a common lag order of two is imposed for the dependent variable and

[18] The program is available on http://www.econ.cam.ac.uk/faculty/pesaran.

for each of the regressors. In the case of developing countries (Table 3.7), the lag order is chosen by the Schwarz Bayesian Criterion (SBC), subject to a maximum lag of 1, and is allowed to vary between countries.[19]

The second specification condition refers to the existence of a long-run relationship (dynamic stability) and requires that the coefficient on the error-correction term be negative. The estimate of the error-correction coefficient and its corresponding standard error are reported in the second panel of Tables 3.6 and 3.7. This coefficient is significantly negative in the PMG estimator (and in MG and DFE), which is evidence that supports the dynamic stability of the model.

The third condition is that the long-run parameters be the same across countries. As explained in the econometric methodology section, the null hypothesis of homogeneity can be tested using a Hausman-type test, which compares the PMG and MG estimators. Tables 3.6 and 3.7 report the Hausman test statistic and the corresponding p-values. This test was carried out for the coefficients of each of the explanatory variables and for all of them jointly. The Hausman test statistic cannot reject the homogeneity restrictions on the long-run coefficients in all panel data estimations. This implies that the PMG method provides the efficient estimates of the common long-run parameters. Therefore, this analysis focuses on obtained with the PMG estimator, although the results for the MG, DFE and SFE estimators are also reported for comparison purposes.

[19] Several specifications have been estimated for the energy demand model. The best specification was with the form of a common lag order of two for developed countries and ARDL-SBC subject to maximum lag 1 for developing countries. Furthermore, diagnostic tests of country-specific regressions perform better when these lag structures are retained (see Tables 3.8 and 3.9).

Table 3.6 presents the dynamic panel data estimation results of the developed countries. The PMG estimates are statistically significant and have the correct signs. The income elasticity is 0.21 in the long-run and as expected, the magnitude of income elasticity is greater than in the short-run. The computed income elasticity is below unity, which implies income growth results in a less than proportional increase in energy demand. This is particularly true in the case of developed countries. As noted by Kouris (1983) and Samoulidis and Mitropoulos (1984), it should be reasonable to expect that income elasticity in developed countries could decrease because, growth in GDP is increasingly concentrated in services and less energy-intensive activities. The developing countries, in contrast, has yet to go through the stage of income growth in which demand for energy-intensive services is a large part of total consumption. Therefore, as income grows, demand for the energy-intensive services is likely to be quite income elastic.

The own-price elasticity is -0.12 in the long-run and is within the range of previous studies (for instance, Hunt and Ninomiya (2005) find the estimated price elasticity to be -0.18 for Japan). This result indicates a price inelastic demand, implying that the level of aggregate energy demand cannot be regulated extensively through price policies.

The long-run elasticity of the degree of industrialisation is 0.35, which indicates that a 1% increase in the degree of industrialization will increase the consumption of energy by 0.36%. This finding is consistent with the idea that an increase in industrialisation will increase the demand for energy use (Schäfer, 2005).

The technological progress elasticity is 0.09, which implies that there is a positive impact of technical progress on energy demand in developed countries. However, this impact is relatively small, with a 1% increase in technological progress increasing the demand for energy by only 0.09%. This finding is consistent with Mountain et al. (1989), who find that technical progress is positively and significantly related to energy demand in industrialised countries. In addition, as noted by Popp (2001), technological advancements are correlated with changes in energy prices, with technological change being energy using when energy prices are low, and energy saving when energy prices are high.

On the other hand, the estimates of short-run coefficients reveal a different pattern. As explained in the methodology section, short-run coefficients are not restricted to be the same across countries. Therefore, there will be no single common estimate for any coefficient. However, the average short-run effect can be analysed by considering the mean of the corresponding coefficients across countries. The average short-run parameters reveal significant short-run effects of income, the lagged effect of income, price, economic structure, technology progress and the technology progress. This finding suggests that short-run dynamics of energy consumption is significantly influenced by income, price, economic structure and technological progress.

Results for the developing countries are reported in Table 3.7. The PMG estimates of the long-run coefficients provide further supportive evidence of a strong positive relationship between energy demand with income and economic structure and a negative relationship with price and technological change. All the determinants are highly significant. The estimated coefficient for income is about 1.35, which is quite close to the long-run income elasticities reported by Ibrahim and Hurst (1990) and Pesaran et al. (1998). Moreover, this finding is also consistent with Dahl (1993), who finds that income elasticities fall between 0.79 and 1.40 for developing countries. The computed income elasticity is above unity, therefore income growth results in a more than proportional increase in energy demand. This suggests that the economic growth of developing countries is energy-intensive.

The estimated price elasticity is -0.04, implying the impact of a price change on the demand is much smaller than the impact of a change in income. Moreover, this result agrees with previous studies that find that developing countries have a lower price elasticity of energy demand (see Zilberfarb, 1983 and Gately and Huntington, 2002). Therefore, developing countries can rely even less than developed countries on taxes to reduce energy demand.

The long-run elasticity of the degree of industrialisation is 0.50, which indicates that a 1% increase in the level of industrialisation will increase the demand for energy in developing countries by 0.50%, which is larger than in developed countries. This is due to the fact that in the case of developed countries, the degree of industrialisation is becoming less significant as economies grow and it move away to less energy-intensive materials and products (Schäfer, 2005). The positive impact of the degree of industrialisation on energy demand in developing countries is consistent with the finding of Chan and Lee (1996) for China and Adams and Shachmurove (2000) for the group of East Asian countries.

The coefficient on technological progress is negative, which is in line with the majority of previous studies such as Berndt et al. (1993), Jones (1994), Popp (2001) and Welsch and Ochsen (2005). This result suggests that in developing countries, technological change is energy saving, that is, energy use per unit of output decreases over time.

With regards to the short-run coefficients, the results demonstrate that all the coefficients are consistent with the theory and are highly significant. Again, it can be concluded that income, energy price, structural change and technological advancement are important in explaining the short-run dynamics of energy consumption.

The results of diagnostic checks in OLS regression are presented in Table 3.8.[20] The results demonstrate that at the 5% level, there is evidence of serial correlation of residuals in Belgium, Finland, Germany, Japan, Netherlands, New Zealand, Switzerland, United Kingdom and United States and functional form mis-specification in Australia, Denmark, Finland, Germany, Korea, Norway, Portugal, Sweden and Switzerland. The R square, which measures the proportion of the changes in the logarithm per capita energy demand, is satisfactory where the average of the R square is 0.79.

With regards to the developing countries, at the 5% level, there is evidence of functional form mis-specification in Czech Republic, Hungary, Mexico, Poland and Russia; evidence of non-normal residuals in Russia and evidence of

[20] The tests conducted are Langrange multiplier statistics test for residual serial correlation, functional form of mis-specification, non normal errors and heteroscedasticity.

heteroscedasticity in China, Mexico and Russia. On the whole, the explanatory power of the model is rather satisfactory, and the average of the country-specific R square is 0.77.

Table 3.6: Alternative Pooled Estimators for ARDL of Developed Countries (1978-2003)
Dependent Variable: Energy Consumption Per Capita

	PMG Estimators	MG Estimators	Hausman Tests	DFE Estimators	SFE Estimators
Long-Run Coefficients					
Y	0.208***	0.572*	1.39	0.713***	0.732***
	(4.894)	(1.835)	(0.24)	(6.299)	(24.231)
P	-0.120***	-0.111**	0.03	-0.257***	-0.245***
	(-7.889)	(-1.938)	(0.87)	(-5.368)	(-16.195)
I	0.355***	-0.202	1.54	0.120	0.016
	(6.764)	(-0.447)	(0.21)	(0.717)	(0.335)
T	0.089***	-0.141	-0.451	-0.778***	-0.103***
	(3.036)	(-0.451)	(0.46)	(-4.249)	(-9.664)
	Joint Hausman Test: 4.01(0.40)				
Error Correction Coefficients					
Phi	-0.507***	-1.030***		-0.108***	
	(-8.211)	(-9.772)		(-7.159)	
Short-Run Coefficients					
Y	0.105***	0.386**		0.077***	
	(8.211)	(2.119)		(4.799)	
ΔY	0.245***	-0.112		0.261***	
	(2.310)	(-0.816)		(4.796)	
ΔY(-1)	-0.040	-0.039		0.007	
	(-0.386)	(-0.328)		(0.123)	
P	-0.061***	-0.105***		-0.028***	
	(-8.211)	(-3.617)		(-4.202)	
ΔP	0.006	0.041		-0.006	
	(0.465)	(1.979)		(-0.497)	
ΔP(-1)	0.064	0.073		0.025	
	(3.961)	(3.919)		(2.116)	
I	0.180***	0.211		0.013	
	(8.211)	(1.093)		(0.712)	
ΔI	-0.084	-0.197		0.062	
	(-1.138)	(-1.405)		(1.356)	
ΔI (-1)	0.001	-0.121		0.104**	
	(0.014)	(-1.348)		(2.297)	
T	0.045***	0.173		-0.084***	
	(8.211)	(1.302)		(-5.341)	
Intercept	-0.936	-3.531			
	(-7.883)	(-2.379)			
N x T	598				

Notes: Figures in parentheses are t-statistic except for Hausman test (H), which is p-value. Significance at the 1%, 5% and 10% levels are denoted by *** ,** and * respectively.

Table 3.7: Alternative Pooled Estimators for ARDL of Developing Countries (1978-2003)
Dependent Variable: Energy Consumption Per Capita

	PMG Estimators	MG Estimators	Hausman Tests	DFE Estimators	SFE Estimators
Long-Run Coefficients					
Y	1.350***	1.370**	0.00	N.A	0.606***
	(28.985)	(2.240)	(0.97)		(10.489)
P	-0.039**	-0.151	0.47		-0.032
	(-2.501)	(-0.916)	(0.49)		(-1.463)
I	0.500***	0.798	0.16		0.578***
	(9.078)	(1.059)	(0.69)		(7.008)
T	-0.080***	-0.033	0.40		-0.038*
	(-4.054)	(-0.436)	(0.53)		(-1.846)
	Joint Hausman Test: 3.06(0.55)				
Error Correction Coefficients					
Phi	-0.421***	-0.587***			
	(-3.838)	(-7.607)			
Short-Run Coefficients					
Y	0.556***	0.570***			
	(3.828)	(4.149)			
ΔY	-0.107	-0.102			
	(-0.666)	(-0.671)			
P	-0.016***	-0.027			
	(-3.828)	(-0.745)			
ΔP	-0.005	-0.018			
	(-0.163)	(-0.470)			
I	0.206***	0.180			
	(3.828)	(1.311)			
ΔI	0.172	0.190			
	(0.656)	(1.043)			
T	-0.033***	-0.020			
	(-3.828)	(-0.447)			
Intercept	-4.880	-5.058			
	(-3.803)	(-3.675)			
N x T	416				

Notes: Figures in parentheses are t-statistic except for Hausman test (H), which is p-value. Significance at the 1%, 5% and 10% levels are denoted by *** ,** and * respectively.

Table 3.8: Diagnostic Statistics for the OLS Regression of Developed and Developing Countries

Country	$\chi^2_{SC}(1)$	$\chi^2_{FF}(1)$	$\chi^2_N(2)$	$\chi^2_H(1)$	R^2
		DEVELOPED COUNTRIES			
Australia	0.44	9.22*	3.06	0.46	0.88
Austria	0.32	0.08	0.50	0.90	0.65
Belgium	15.03*	0.66	0.91	1.41	0.73
Canada	2.92	0.04	1.10	0.38	0.96
Denmark	1.84	9.35*	1.27	1.45	0.94
Finland	11.25*	12.44*	0.57	0.09	0.89
France	0.03	0.04	1.31	1.47	0.86
Germany	9.35*	9.82*	0.76	0.20	0.72
Greece	1.14	0.09	0.16	0.05	0.09
Ireland	1.83	1.44	0.57	0.06	0.62
Italy	0.38	1.08	1.11	1.35	0.81
Japan	12.08*	0.78	0.52	0.11	0.97
Korea	0.10	5.79*	1.25	2.96	0.90
Luxembourg	0.20	1.99	0.72	3.35	0.85
Netherlands	12.07*	0.52	0.62	0.04	0.98
New Zealand	5.28*	0.52	0.10	0.51	0.37
Norway	1.27	4.36*	1.58	0.18	0.76
Portugal	0.21	6.87*	0.48	0.13	0.98
Spain	0.11	0.74	1.61	0.01	0.93
Sweden	2.41	5.56*	1.16	1.46	0.96
Switzerland	4.23*	6.02*	0.54	0.00	0.56
United Kingdom	19.47*	0.04	0.08	0.40	0.85
United States	4.39*	3.33	0.86	0.99	0.98
		DEVELOPING COUNTRIES			
Brazil	1.38	1.16	0.61	0.12	0.80
China	0.05	4.81	0.02	4.49*	0.59
Czech Republic	0.00	15.00*	0.27	0.03	0.97
Hungary	1.03	5.83*	2.51	2.37	0.65
India	2.36	0.73	0.49	0.07	0.69
Indonesia	3.61	0.00	0.33	0.64	0.85
Kazakhstan	1.47	0.77	4.88	1.54	0.64
Mexico	2.89	4.11*	0.60	5.90*	0.86
Poland	0.14	6.81*	1.20	3.03	0.58
Romania	2.22	1.57	2.01	2.00	0.88
Russia	0.00	4.21*	10.04*	13.01*	0.67
Slovak Republic	0.89	3.35	1.04	0.12	0.88
South Africa	0.19	0.06	1.30	0.92	0.71
Thailand	0.03	0.01	0.38	0.10	0.99
Turkey	0.05	0.00	1.22	0.07	0.97
Venezuela	0.00	3.19	0.38	0.01	0.66

Notes: $\chi^2_{sc}(1)$, $\chi^2_{FF}(1)$, $\chi^2_N(2)$, $\chi^2_H(1)$ are Langrange multiplier statistics test for residual serial correlation, functional form mis-specification, non normal errors and heteroscedasticity. Critical values for the Chi-distribution with 1 and 2 degrees of freedoms are 3.84 and 5.99, respectively. Significance at 5% denoted by *.

3.5 Conclusions

This study examines the determinants of energy demand using the panel data framework for 23 developed countries and 16 developing countries. It also investigates the different patterns of energy demand across these two groups of countries. The empirical results of this study confirm the majority of the findings in the existing literature on energy demand. The elasticities of income and price obtained from the dynamic heterogeneous panel model are generally in line with the previous studies in the literature. Moreover, both the degree of industrialisation and also the technological progress appear to exert significant impacts on energy consumption in both developed and developing countries.

Given the fairly large differences in the determinants of energy demand between countries with varying level of economic development, the empirical results suggest that a uniform international policy for energy use may not prove to be as effective as one would expect. There are some further implications that follow from these findings. First, the estimated income elasticity of energy demand in developed countries is lower than in developing countries. This suggests that economic growth in developed countries is less energy-intensive. Therefore, it seems that as industrialised economies heads towards maturity, with more efficient processes and less energy intensive techniques, it is reasonable to expect that an increase in income will be associated with a smaller increase in energy. The implication of the findings is that the structural differences at different stages of development could lead to significant reductions in the income elasticity of energy demand.

Second, the effects of price on energy demand are larger in developed countries than in developing countries. One possible explanation for this is that at high levels of income there are more substitution possibilities for energy use. Thus, when energy price rises, developed countries will react more to price changes, whereas at low levels of income, energy is used as a necessity. In addition, the low value of the price elasticity of energy demand in both developed and developing countries may indicates that energy policies (such as energy conservation measures) based on the price mechanism are less effective, especially in developing countries.

Third, the level of industrialisation variable in the energy demand also appeared to be statistically significant, both in developed and developing countries. Therefore, the policy makers should take it into account for policy formulation. Finally, the results suggest that technological progress is energy saving in developing countries, whereas the opposite happens in developed countries.

Appendix 3.I

List of Countries Categorised by the World Bank

Table A.3.I.1: List of 23 Developed Countries

Developed Countries
Australia (AU)
Austria (AT)
Belgium (BE)
Canada (CA)
Denmark (DK)
Finland (FI)
France (FR)
Germany (DE)
Greece (GR)
Ireland (IE)
Italy (IT)
Japan (JP)
Korea (KR)
Luxembourg (LU)
Netherlands (NL)
New Zealand (NZ)
Norway (NO)
Portugal (PT)
Spain (ES)
Sweden (SE)
Switzerland (CH)
United Kingdom (UK)
United States (US)

Table A.3.I.2: List of 16 Developing Countries

Developing Countries
Brazil (BR)
China (CH)
Czech Republic (CZ)
Hungary (HU)
India (IN)
Indonesia (ID)
Kazakhstan (KZ)
Mexico (MX)
Poland (PL)
Romania (RO)
Russia (RU)
Slovak Republic (SK)
South Africa (ZA)
Thailand (TH)
Turkey (TR)
Venezuela (VE)

Appendix 3.II

List of Products for Energy Consumption

1. Petroleum

High Sulphur Fuel Oil (tonne)
Low Sulphur Fuel Oil (tonne)
Light Fuel Oil (1000 litres)
Automotive Diesel (litres)
Premium Leaded Gasoline (litre)
Regular Leaded Gasoline (litre)
Premium Unleaded Gasoline (98 RON) (litre)
Premium Unleaded Gasoline (98 RON) (litre)
Regular Unleaded Gasoline (litre)

2. Natural Gas (10*7 kcal)

3. Coal

Steam Coal (tonne)
Coking Coal (tonne)

4. Electricity (kWh)

CHAPTER FOUR

THE POSSIBILITIES OF ENERGY SUBSTITUTION IN INDUSTRIAL SECTOR

4.1 Introduction

The possibilities of energy substitution have been the subject of a number of studies over the last three decades.[21] After the 1973 oil crisis, most countries began tackling the issue of energy substitution in response to the high cost of energy. The primary objective of these studies has been to examine the impact of energy price increases on growth in the developing countries and the prospect of energy conservation in the developed countries.[22] Recently, the increasing concern over the issue of global warming and climate change has made energy substitution an important topic for energy economists. Fuel price increases have been examined as measures to constrain energy consumption.[23] In some cases, the possibility of fuel substitution has been examined as policy tool for reducing pollution.[24] Therefore, the impact of price on energy demand and energy

[21] See Fuss (1977), Pindyck (1979a, 1979b), Iqbal (1986) and Andrikopoulos *et al.* (1989) for early empirical studies, and Cho *et al.* (2004) and Floros and Vlachou (2005) for more recent ones.

[22] Saicheau (1987), Siddayaou *et al.* (1987) and McNown *et al.* (1991) showed that substitution possibilities have major growth implications for the developing countries. For instance, Saicheau (1987) suggests that the manufacturing sector in Thailand was able to reduce energy consumption in response to rising energy price. Siddayaou *et al.* (1987) showed that energy price increase can be partially compensated by the use of labour in Thailand and both capital and labour in the Philippines. On the other hand, McNown *et al.* (1991) show that, over the period 1953 to 1982, higher energy price can be partially compensated by use of capital in Bangladesh and both capital and labour in India and Pakistan. In the case of developed countries, see for example Hogan (1989) for the United States and Japan and Christopoulos and Tsionas (2002) for Greek manufacturing sector.

[21] The use of price mechanisms for mitigating environmental problems is discussed by Caloghirou *et al.* (1997). They suggested that an increase in the price of energy, through an energy carbon tax, will reduce the consumption of energy.

[22] See, for example Ko and Dahl (2001), Floros and Vlachou (2005) and Roy *et al.* (2006).

substitution should be examined in order to determine the effectiveness of fuel costs for the reduction of pollution in a region and in a country as a whole.

There are two important and inter-related issues involved in the energy substitution possibilities studies. The first is the degree of substitutability of energy by primary inputs of production (capital and labour), and the second is the degree of substitution between individual fuels (coal, electricity, natural gas and petroleum product). The degree of substitutability between energy and non-energy inputs is crucial for evaluating energy policies, such as energy taxes, and for understanding the impacts of energy price shocks. In general, if production inputs are easily substitutable, then changes in the input mix can occur without serious impairment of economic growth in response to resource price fluctuations. For example, if it is found that energy and capital are substitute inputs, then higher energy prices will increase the demand for capital in order to maintain the level of production. Likewise, capital-labour substitutability facilitates a movement toward labour intensity in the case of reduced availability of capital. On the other hand, energy-capital complementary is harmful because the discouragement of capital formation would affect long-term growth. Similarly, if capital and labour are complements, then income and economic growth will be seriously affected in response to scarcity of capital.

As defined by Hall (1986), inter-fuel substitution includes the process whereby shifts in relative fuel prices lead to changes in the degree of utilisation of individual fuels. In this context the issue of inter-fuel substitution becomes crucial, since the price changes for one type of fuel may influence demand for other types of fuel. Therefore, substitutability patterns between different types of energy in the production process will determine the degree to which one fuel can be switched for another fuel.

Previous empirical evidence has claimed considerable support for inter-factor and inter-fuel substitution possibilities in the industrial sector.[25] Most of this evidence refers to the period before 1990 and ignores the feedback effect between inter-factor and inter-fuel substitution. The interaction or feedback effect refers to the fact that changes in the relative consumption of factors (e.g. energy, capital, labour) will have an effect on the relative consumption of fuels, due to changes in total energy consumption (Cho et al., 2004). Similarly, the change of price of an individual fuel, for instance, will not only cause a substitution effect among individual fuels but also a substitution effect among factors of production that is transmitted through changes in aggregate energy demand. These questions are of great importance because ignoring this feedback effect may lead to unreliable conclusions that are based only on partial elasticities rather than total elasticities.[26]

The aim of the study is to estimate a two-stage translog model using data from 1978 to 2003 in the industrial sector of the five major countries of the OECD area, (i.e. the United States, Japan, Germany, France, Canada) and five major energy producers of the developing world, (Brazil, China, India, Indonesia and

[25] The importance of the industrial sector in the energy system is highlighted by the fact that the industrial sector is the largest of the end-use sectors, consuming 50% of delivered energy worldwide in 2003 (IEO, 2006). For an example of the empirical results, refer to Chapter 2, section 2.4.1 to 2.4.3.

[26] Fuss (1977) and Pindyck (1979b) were among the first to study the feedback effect in the analysis of inter-factor and inter-fuel substitution. This approach has also been followed by Kim and Labys (1988) to examine energy substitution in the Korean industrial sector, by Andrikopoulos *et al.* (1989) in the Ontario manufacturing sector and recently by Cho *et al.* (2004) and Floros and Vlachou (2005) in Korea and in the manufacturing sectors of Greece, respectively.

Venezuela).[27] In the first stage, input demands for various energy components are estimated and hence an aggregate price index for energy is developed. In the second stage, this index is used as an instrument variable to estimate aggregate input demand for aggregate energy, capital and labour along with price and substitution elasticities.[28] More importantly, in order not to miss important substitution effects, the study takes into account the dynamic element of the adjustment process and the long-run structure of energy demand in the industrial sector.[29]

The empirical estimates of this study show that the dynamic two-stage translog model is consistent with the principle of cost minimising factor demand theory. The translog cost function satisfied the monotonicity and concavity conditions. Importantly, substitution possibilities are observed between capital and energy and labour and energy, hence confirming previous evidence that there is flexibility of input mix in the industrial sector. In other instances, this study provides evidence of substitutability among the fuels. Especially, there is a shift towards cleaner fuels such as natural gas.

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[27] The ten countries examined here reflect significant regional economic, demographic and energy resource diversity. While their circumstances vary widely, each of these countries is either a large consumer or a large producer of energy in the world. For instance, the United States is the world's largest consumer of oil and the second's largest producer of oil and natural gas; China is the world's sixth largest producer of oil and the world's largest producer of coal and second largest producer of hydro electricity and petroleum products.

[28] This is consistent with producers choosing cost-minimizing factor inputs in two stages; energy costs are minimised in the choice of fuel inputs, and total costs are minimised in the choice of energy, capital and labour inputs (Pindyck, 1979b).

[29] Most of the previous analyses have used a static model. Exceptions are Taheri (1994), Christopoulos (2000) and Cho *et al.* (2004). They incorporate the dynamic structure in the two-stage translog model, so that the elasticities of inter-factor and inter-fuel substitution will give reliable computed elasticities for policy design and policy making. Hogan (1989), Taheri (1994) and Cho *et al.* (2004) explained that the adjustment process might be slow during and after a period of rapid and large changes in relative prices among inputs. Therefore, by incorporating the dynamic structure, the results obtained will show adequate knowledge of the adjustment path and the long-run structure.

This chapter is organised as follows. Section 4.2 provides a brief profile of the countries. Section 4.3 describes the underlying economic model and the methodological approach. Section 4.4 explains the data. Section 4.5 reports the statistical estimation and interprets results. Section 4.6 discusses a summary of the main findings and concludes.

4.2 Country Profiles

Tables 4.1 to 4.3 summarize the most recent figures for Top World Oil Consumers, Top World Oil Producers and Top World Oil, Natural Gas, Coal and Hydro Electricity Producers, where countries in bold are the countries of interests in this chapter. A brief review of all these tables indicates that some of these countries are not only the world's largest energy consumer but also the largest energy producer in the world. As it can be seen in Table 4.1, the United States is the world's largest consumer of oil, followed by China, Japan, Germany, India, Canada, Brazil and France. In addition, the United States, China, Canada and Venezuela are also included as the top world oil producers. Moreover, most of the above countries are also recorded as the top producers of oil, natural gas, coal and electricity as shown in Table 4.3.

Energy markets in these countries have been influenced by many factors, including oil price changes and environmental pressures. Large oil price changes in 1973-1974, 1979 and 1985-86 had effects which depended on institutional factors and the degree of dependence on energy imports. This dependence was high for Germany, France, Japan and the United States because their total energy consumption exceeds their production and it was low for Canada (this country is a net energy exporter). With respect to the non-OECD countries, Brazil and India are net energy importers, due to the large imbalance between oil production and consumption. There is also a tendency for China to become a net energy importer since there is a large growth of energy demand, whereas Indonesia and Venezuela are net energy exporter countries (CSLF, 2006 and WRI, 2007).

The growing concern about the negative environmental impacts associated with major energy sources including coal, oil, natural gas and electricity, has also been a major issue in the energy policy debate in these countries. For example, one of Germany's energy policy goals is to ensure environmentally benign energy supply and use, by forcing the adoption of emission controls (McAvinchey and Yannopoulos, 2003). Given the similarities and also differences between these countries, it is therefore of value to understand the impacts of rising prices of energy commodities and the security of international energy supplies on the degree of inter-factor and inter-fuel substitution possibilities in the industrial sector. For example, in the case of OECD countries, an important issue has been whether or not these countries were able to deal effectively with increasing energy scarcity (given that the current energy policy debate relates to the feasibility of substantially reducing the use of crude oil (McAvinchey and Yannopoulos, 2003)). On the other hand, non-OECD countries face the challenge of sustaining rapid economic growth rates while prices of energy are rising.

Table 4.1: Top World Oil Consumers, 2004*

	Country	Total Oil Consumption (million barrels per day)
1)	**United States**	20.7
2)	**China**	6.5
3)	**Japan**	5.4
4)	**Germany**	2.6
5)	Russia	2.6
6)	**India**	2.3
7)	**Canada**	2.3
8)	**Brazil**	2.2
9)	South Korea	2.1
10)	**France**	2.0
11)	Mexico	2.0

Notes: * Table includes all countries that consumed more than 2 million barrels per day in 2004
Source: http://www.eia.doe.gov/emeu/cabs/topworldtables3_4.html

Table 4.2: Top World Oil Producers, 2004*

	Country	Total Oil Production** (million barrels per day)
1)	Saudi Arabia	10.37
2)	Russia	9.27
3)	**United States**	8.69
4)	Iran	4.09
5)	Mexico	3.83
6)	**China**	3.62
7)	Norway	3.18
8)	**Canada**	3.14
9)	**Venezuela**	2.86
10)	United Arab Emirates	2.76
11)	Kuwait	2.51
12)	Nigeria	2.51
13)	United Kingdom	2.08
14)	Iraq	2.03

Notes: * Table includes all countries total oil production exceeding 2 million barrels per day in 2004, ** Total oil production includes crude oil, natural gas liquids, condensate, refinery gain and other liqids.
Source:http://www.eia.doe.gov/emeu/cabs/topworldtables1_2.html

Table 4.3: Top World Oil, Natural Gas, Coal and Hydro Electricity Producers, 2003

A)	Top World Oil Producers	% of World total
1)	Saudi Arabia	12.7
2)	Russia	11.3
3)	**United States**	9.4
4)	Iran	5.2
5)	Mexico	5.1
6)	**China**	4.4
7)	Norway	4.1
8)	**Venezuela**	4.0
9)	**Canada**	3.7
10)	United Arab Emirates	3.2
Rest of the world		36.9
World		100.0
B)	**Top World Natural Gas Producers**	**% of World total**
1)	Russia	22.4
2)	**United States**	19.9
3)	**Canada**	6.7
4)	United Kingdom	4.0
5)	Algeria	3.2
6)	**Indonesia**	2.9
7)	Iran	2.9
8)	Norway	2.8
9)	Netherlands	2.7
10)	Saudi Arabia	2.2
Rest of the world		30.3
World		100.0
C)	**Top World Coal Producers**	**% of World total**
1)	**China**	37.2
2)	**United States**	22.1
3)	**India**	8.4
4)	Australia	6.8
5)	South Africa	5.9
6)	Russia	4.7
7)	**Indonesia**	3.0
8)	Poland	2.5
9)	Kazakhstan	1.9
10)	Ukraine	1.4
Rest of the world		6.2
World		100.0
D)	**Top World Hydro Electricty Producers**	**% of World total**
1)	**Canada**	13.1
2)	**China**	10.8
3)	**Brazil**	10.7
4)	**United States**	9.6
5)	Russia	6.1
6)	Norway	4.9
7)	**Japan**	3.4
8)	Sweden	2.5
9)	**France**	2.5
10)	**India**	2.4
Rest of the world		34.0
World		100.0

Source: IEA (2004), Key World Energy Statistics.

4.3 Methodology

The econometric approach adopted in this study is based on the framework of a translog cost function developed by Christensen et al. (1973). The translog functional form is often used in the empirical literature on energy substitution because of its flexibility. That is, this model imposing no restriction on the elasticities of substitution. The translog function has elasticities which vary depending in the fuel shares and thus allow a more flexible description of the relation between the various inputs.

The model used in this study requires certain assumptions regarding the underlying structure of production. First: since reliable data for prices of materials (M) cannot be obtained for all countries in this study, it is necessary to assume that M are weakly separable from the other inputs (capital (K), labour (L) and energy (E)).[30] This assumption is a necessary and sufficient condition for the production function to be of the form $Y = F(f(K,L,E);M)$. Next it is assumed that energy aggregate is homothetic in its coal (c), electricity (e), natural gas (g) and petroleum products (p) inputs. This means that relative input demands are independent of the level of output. This assumption permits the construction of an energy price index that aggregates the prices of four fuels.

From the above assumptions, the production function can be written as:

$$Y = F(f(K,L,E(p,e,g,c));M) \tag{4.1}$$

[30] In other words, it is assumed that the marginal rate of substitution between any two pairs of inputs retained in the model (K, L, E) is independent of the quantity of material input.

where E is a homothetic function of the four fuels.

Finally, assuming exogenously given input prices and output level, the above production function (4.1) can alternatively be described by a cost function that is also weakly separable, of the form

$$C = G(g(P_K, P_L, P_E(P_p, P_e, P_g, P_c)Y); P_M, Y) \quad (4.2)$$

where C is total cost, P_K is capital input price, P_L is labour input price and P_E is an aggregate price index of energy, that aggregates the prices of petroleum product, (P_p), electricity (P_e), natural gas (P_g) and coal (P_c) (see Section 4.3.1.2 for more details on the aggregate energy price). As assumed previously, this aggregator function is homothetic in the mix of energy types.[31]

Equation (4.2) provides a basis to estimate the two-stage procedure. First, the price of energy (P_E) can be represented by a homothetic translog cost function. From this cost function, the share equations can be estimated. The parameter estimates provide the partial own and cross price elasticities for the four fuels. In addition, the cost function itself yields an instrumental variable for the price of energy. Then, the non-homothetic translog cost-share equation for the factor input is estimated, where the parameter estimates yield total elasticities for capital, labour and energy. In the following sections, the two-stage process is discussed in detail.

[31] Similar aggregate functions can be formulated for capital and labour. However, the lack of disaggregated data for these inputs for industrial sector does not allow it.

4.3.1 The Static Model

4.3.1.1 The Model for Aggregate Inputs

Using a flexible functional form, the cost function with three inputs will be represented by the following non-homothetic translog cost function, which is characterized by neutral technical change:[32]

$$\ln C = \alpha_0 + \alpha_Y \ln Y + \sum_{i=1}^{n} \alpha_i \ln P_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln P_i \ln P_j + \sum_{i=1}^{n} \gamma_{iY} \ln P_i \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 \tag{4.3}$$

where i, j = K, L, E.[33] The variable C represents total cost of production, Y is the quantity of output, P_i is price of ith input, and α_0, α and γ are parameters to be estimated and ln represents the natural logarithm.

The firm's system of cost minimizing input demand functions can be obtained by differentiating the cost function (equation (4.3)) with respect to input prices. This yields the following input share equations

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i}{X_i} = S_i \tag{4.4}$$

where X_i is the amount of the ith input factor employed in the production process for i, j = K, L, E. The variable S_i indicates the cost share of the ith input factor, which is given by $P_i X_i / C$ with $C = P_K X_K + P_L X_L + P_E X_E$. Thus, combining

[32] It is not the scope of this chapter to address the issue of the non-neutral technical progress.
[33] The present study disregards materials as a factor of inputs due to the absence of data on prices and quantities of materials.

equations (4.3) and (4.4), the input demand functions in terms of cost share can be expressed as:

$$S_i = \alpha_i + \gamma_{iY} \ln Y + \sum_{j=1}^{n} \gamma_{ij} \ln P_j \tag{4.5}$$

where i, j = K, L, E.

As postulated in the theory, the cost function must be homogeneous of degree one in prices, and satisfy the properties of a well-behaved cost function. In addition, the system of equation (4.5) must satisfy the adding up condition, namely that the sum of all shares equals to unity ($\sum_i^n S_i = 1$). These conditions imply the following restrictions:

$$\sum_i^n \alpha_i = 1; \quad \sum_i^n \gamma_{ij} = 0; \quad \sum_i^n \gamma_{iY} = 0; \quad \gamma_{ij} = \gamma_{ji} \tag{4.6}$$

where i, j = K, L, E. Restrictions $\sum_i^n \alpha_i = 1$ and $\sum_i^n \gamma_{ij} = 0$ are due to the adding-up condition, restriction $\sum_i^n \gamma_{iY} = 0$ comes from the assumption of homogeneity, which ensures that quantities produced do not depend on the units in which prices and cost are expressed (because they do not influence producer's opportunities) and restriction $\gamma_{ij} = \gamma_{ji}$ is from the basic demand function property of symmetry, which ensures the consistency of consumer choices.

The tests for the validity of the translog cost function can be summarised as follows:

i) Homogeneity and symmetry can be tested using a Wald test

ii) Monotonically increasing in input prices and outputs requires the fitted cost shares to be non-negative at each observation

iii) Concavity of the cost function is satisfied if the Hessian matrix based on the parameter estimates is negative semi-definite. This condition can be translated into the condition that the matrix of Allen partial elasticities on substitution be negative semi-definite.

The degree of substitutability between factors of production can be measured with the Allen partial elasticity of substitution (AES) and the cross price elasticity of substitution.[34] These elasticities are crucial to describe the degree of substitutability and complementarity amongst the factors of production. The Allen own- and cross-partial elasticities of substitution (σ_{ii}, σ_{ij}) are estimated as:

$$\sigma_{ii} = \frac{(\gamma_{ii} + S_i^2 - S_i)}{S_i^2} \qquad \text{for all i, i = j;}$$
$$\sigma_{ij} = \frac{(\gamma_{ij} + S_i S_j)}{S_i S_j} \qquad \text{for i, i} \neq \text{j} \tag{4.7}$$

Positive and negative signs indicate that the factors are substitutes and complements, respectively. Own- and cross-partial elasticities of factor demand (η_{ii}, η_{ij}) are estimated as:

[34] It is not the scope of this chapter to address the issue of which substitution measure would be appropriate in an empirical study. See Frondel (2004) for a discussion on measures of substitution.

$$\eta_{ii} = \frac{\partial \ln X_i}{\partial \ln P_i} = \sigma_{ii} S_i \qquad \text{for all i, i = j;}$$
$$\eta_{ij} = \frac{\partial \ln X_i}{\partial \ln P_j} = \sigma_{ij} S_j \qquad \text{for i, i} \neq \text{j} \tag{4.8}$$

where S_i and S_j are the cost share of the *i*th and the *j*th factor relative to the total factor cost and with *i* and *j* equal to capital, labour and energy.

According to Pindyck (1979a), appropriate estimates of the standard errors can be obtained by the assumptions that the cost shares S_i are constant and equal to the means of their estimated values. Under this assumption, the variances (*V*) of the elasticity estimates are

$$\begin{aligned} V(\hat{\sigma}_{ij}) &= V(\hat{\gamma}_{ij}) / \hat{S}_i^2 \hat{S}_j^2 \\ V(\hat{\sigma}_{ii}) &= V(\hat{\gamma}_{ii}) / \hat{S}_i^4 \\ V(\hat{\eta}_{ij}) &= V(\hat{\gamma}_{ij}) / \hat{S}_i^2 \\ V(\hat{\eta}_{ii}) &= V(\hat{\gamma}_{ii}) / \hat{S}_i^2 \end{aligned} \tag{4.9}$$

4.3.1.2 The Model for Energy Inputs Component

The model developed so far relates only an aggregate production function with three inputs (K, L and E). Since a model of industrial energy use involves the breakdown of total costs of production into expenditure shares of capital, labour and energy, the estimation of this model therefore requires a price index for aggregate energy use. As Pindyck (1979a) noted, although price series for individual fuels are available, a price index that reflects the unit cost of energy will not be the same as a simple weighted average of fuel prices because fuels are not perfect substitutes. Therefore, Pindyck (1979a, 1979b) proposed to estimate an aggregator function that relates the aggregate price index to the component prices. This approach has been followed, among others, by Andrikopoulos et al. (1989) and Cho et al. (2004). The homothetic translog cost function is used to represent the aggregate price of energy, which takes the form[35]

$$\ln P_E = \beta_0 + \sum_{i=1}^{n} \beta_i \ln P_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \beta_{ij} \ln P_i \ln P_j \qquad i, j = p, e, g, c \qquad (4.10)$$

where P_E is the aggregate price of energy and also can be viewed as the cost per unit of energy to the optimizing agent and P_i and P_j are the prices of the individual fuels.

The cost of each input as a proportion of the total cost of energy can be obtained by differentiating the cost function (4.10) with respect to $\ln P = (\ln P_c, \ln P_e, \ln P_g, \ln P_p)$, and can be written as

$$S_{Ei} = \beta_i + \sum_{j}^{n} \beta_{ij} \ln P_j \qquad (4.11)$$

where S_{Ei} is the cost share of the ith fuel in the cost of aggregate energy. The adding up criterion and the properties of neoclassical production theory require the following restrictions:

[35] Fuss (1977) explained that by imposing homothethic weak separability conditions for energy allows ln P_E in equation (4.10) to be a function only of the individual fuel prices ln P_{Ei}.

$$\sum_{i}^{n} \beta_i = 1; \quad \sum_{i}^{n} \beta_{ij} = 0; \quad \beta_{ij} = \beta_{ji} \tag{4.12}$$

where the first two restrictions are implied by the adding up criteria and the third by the symmetry restriction.

Equation (4.11) is the basic equation used for estimating the parameters of the interfuel model (the β's in equation (4.10)). Once estimates of these parameters are obtained, the following steps are carried out to construct the energy price index. Initially, the estimated parameters β_i and β_{ij} are substituted into equation (4.10) and using data for the individual fuel prices P_{Ei}, an aggregate price index for energy can be obtained. As noted by Pindyck (1979b), the energy price index is determined only up to an unknown multiplicative scalar exp(β_0). In order to resolve this indeterminacy, the United States is chosen as a base country and then equation (4.10) is solved for β_0 so that the price of energy in the base country is equal to 1 in the base year (1995). Finally, the relative price indices are determined for all years for each country.

The Allen-Uzawa elasticities of substitution and the price elasticities for each energy type can be calculated using equations (4.7) and (4.8), respectively. However, these elasticities account only for substitution between fuels and are based on the assumption that the total quantity of energy consumed remains constant. Thus, these elasticities are partial price elasticities and cannot be used to determine the total effect of a change in price on the demand for a particular fuel.

Total own-price elasticity for each fuel $\eta_{ii}^{*} = d\ln X_i / d\ln P_i$ can be calculated following Pindyck (1979b) and Cho et al. (2004). The total own-price elasticity, which accounts for the inter-fuel substitution and the change in total consumption of energy, is given by:

$$\eta_{ii}^{*} = \frac{d\ln X_i}{d\ln P_i} = \frac{dX_i}{dP_i}\frac{P_i}{X_i} = \left[\frac{\partial X_i}{\partial P_i}\bigg|_{E\ cons} + \frac{\partial X_i}{\partial E}\frac{\partial E}{\partial P_E}\frac{\partial P_E}{\partial P_i}\right]\frac{P_i}{X_i} \tag{4.13}$$

where

$$\frac{dX_i}{dP_i} = \frac{\partial X_i}{\partial P_i}\bigg|_{E\ cons} + \frac{\partial X_i}{\partial E}\frac{\partial E}{\partial P_E}\frac{\partial P_E}{\partial P_i}$$

The terms E and P_E are, respectively, the total quantity of energy consumed and the price index for energy. The partial fuel-price elasticity, which is derived under a given level of aggregate energy consumption without considering the effect of changes in aggregate energy consumption, is shown as $(\partial X_i / \partial P_i)(P_i / X_i)$ in equation (4.13). The feedback effect between the inter-factor and inter-fuel substitution resulting from an individual price change is given by the term $(\partial X_i / \partial E_i)(\partial E / \partial P_E)(\partial P_E / \partial P_i)$. The total own-price elasticities of demand can be computed as follows:

$$\eta_{ii}^{*} = \eta_{ii} + \eta_{EE} S_i \tag{4.14}$$

with i equal c, e , g and p. Similarly, the total cross-price elasticity can be expressed as follows:

$$\eta_{ij}^{*} = \left[\frac{\partial X_i}{\partial P_j} \bigg|_{E\,cons} + \frac{\partial X_i}{\partial E} \frac{\partial E}{\partial P_E} \frac{\partial P_E}{\partial P_j} \right] = \eta_{ij} + \eta_{EE} S_j \qquad (4.15)$$

where i and j are individual fuel sources and η_{EE} is the own price elasticity of aggregate energy consumption.

4.3.2 The Dynamic Adjustment Model

The factor demand system (4.5) and (4.11) derived from the translog total cost functions (4.3) and (4.10), respectively, is static and holds only in equilibrium. Since fuel and factor demands are relatively fixed in the short run but may vary substantially in the long run, the analysis of a static cost function may miss important substitution effects. In order to model the dynamic form of the cost share, the partial adjustment model proposed by Nerlove (1958) is used. This dynamic structure is based on the partial adjustment mechanism in which a stochastic relationship between the desired fuel of factor cost-share (S_{it}^{*}) and the actual share (S_{it}) at time t can be explained according to the following linear function:

$$S_{it} - S_{i,t-1} = (1-\theta)(S_{it}^{*} - S_{i,t-1}) \qquad (4.16)$$

where $(1-\theta)$ is the rate of adjustment of S_{it} to S_{it}^{*} (which is to be estimated), S_{it}^{*} is the desired level of cost share of ith fuel or factor at time t and is given by the system in (4.5) and (4.11). Solving for S_{it}^{*} in (4.16) and substituting into (4.5) and (4.11), the dynamic (lagged) share system of fuels and factors is given by

$$S_{it}^{FACTOR} = \alpha_i^\bullet + \gamma_i^\bullet \ln y_t + \sum_j^n \gamma_{ij}^\bullet \ln p_{jt} + \theta_i S_{i,t-1}^{FACTOR} \qquad i,j = K,E,L \tag{4.17}$$

$$S_{it}^{FUEL} = \beta_i^\bullet + \sum_j^n \beta_{ij}^\bullet \ln p_{jt} + \widetilde{\theta}_i S_{i,t-1}^{FUEL} \qquad i,j = c,e,g,p \tag{4.18}$$

which is identical to the static version in equations (4.5) and (4.11) except for the lagged dependent variable terms, whose coefficients θ and $\widetilde{\theta}$ measures the rate of dynamic adjustment.

Taheri (1994) and Christopoulos (2000) showed that under the dynamic specification of share equations, the partial and total own-price and cross-price elasticities are calculated as:

$$\begin{aligned} \varepsilon_{ii} &= \frac{\eta_{ii}}{S_i} + S_i - 1 \\ \varepsilon_{ij} &= \frac{\eta_{ij}}{S_i} + S_j \qquad i \neq j \\ \varepsilon_{ii}^\bullet &= \eta_{ii} + \eta_{EE} S_i \\ \varepsilon_{ij}^\bullet &= \eta_{ij} + \eta_{EE} S_j \end{aligned} \tag{4.19}$$

where $i,j = c, e, g, p$. The long-run partial and total own-price and cross-price elasticities are calculated as:

$$\begin{aligned} \varepsilon_{ii}^{LR} &= \varepsilon_{ii} / (1-\theta) \\ \varepsilon_{ij}^{LR} &= \varepsilon_{ij} / (1-\theta) \\ \varepsilon_{ii}^{\bullet LR} &= \varepsilon_{ii}^\bullet / (1-\theta) \\ \varepsilon_{ij}^{\bullet LR} &= \varepsilon_{ij}^\bullet / (1-\theta) \end{aligned} \tag{4.20}$$

for all i,j and the ε_{ii}'s and ε_{ij}'s are the short-run elasticities, which are calculated as in equations (4.19).

4.3.3 Estimation Procedure and Estimation Technique

The parameters to be estimated are contained in the two systems of equations (4.5) and (4.11) for the static model and two systems of equations (4.17) and (4.18) for the dynamic model. This system of share equations can be specified in a stochastic framework if an error term is introduced as follows:

$$S_i = \alpha_i + \gamma_{iy} \ln y + \sum_j^n \gamma_{ij} \ln p_j + u_i \qquad i,j = K,E,L \qquad (4.21)$$

$$S_{Ei} = \beta_i + \sum_j^n \beta_{ij} \ln p_{Ej} + \varepsilon_i \qquad i,j = c,e,g,p \qquad (4.22)$$

$$S_{it}^{FACTOR} = \alpha_i^* + \gamma_i^* \ln y_t + \sum_j^n \gamma_{ij}^* \ln p_{jt} + \theta_i S_{i,t-1}^{FACTOR} + u_i \quad i,j = K,E,L \qquad (4.23)$$

$$S_{it}^{FUEL} = \beta_i^* + \sum_j^n \beta_{ij}^* \ln p_{jt} + \widetilde{\theta}_i S_{i,t-1}^{FUEL} + \varepsilon_i \qquad i,j = c,e,g,p \qquad (4.24)$$

where u_i and ε_i are error terms. With the additive errors appended, the system of share equations (4.21) to (4.24) can be written out in full as shown in Appendix 4.I. The technical details of this procedure are given in the Appendix 4.II.

The econometric methods used to estimate the systems in these equations need to allow for an adequate treatment of measurement errors in share equations as well as the imposition of the theoretical restrictions. As the sum of the factor shares sums to unity (adding-up criterion) the sum of the disturbances across the three (four) share factor input (energy) equations is zero at each observation. This implies a singular disturbance covariance matrix. In addition, due to the existence of contemporaneous correlation between the error terms in the share equations, OLS estimates are no longer efficient.[36]

An alternative estimation procedure, and the approach used here, is to estimate jointly the cost share equations as a multivariate regression system. The complete system of share equations is estimated using Zellner's methods for Seemingly Unrelated Regression Equations (SURE).[37] To avoid singularity of the variance-covariance matrix of errors, one of the equations need to be left out of the estimation and parameters of the omitted equation are calculated using the additivity restrictions.

This procedure is satisfactory since it yields estimates which converge to maximum likelihood parameter estimates. An important property of the SURE estimates is that the parameters are unique and independent of the share equation that is dropped.[38] Invariance can be obtained by iterating Zellner's method so that

[36] Note that the Zellner method is no more efficient than OLS when there are no restrictions and all the equations contain the same set of regressors (Johnston and Dinardo, 1997)

[37] The iterative SURE estimator is also known as the iterative Zellner's seemingly unrelated estimator. In brief, the iterative SURE method involves the following steps. Initially each of the equations is estimated using OLS. From these estimates the residuals are calculated and the covariance matrix of the residuals is estimated. The coefficients arrived at the initial stage are then revised to take into account the covariance between the residual. The residuals are recalculated and the same procedure is repeated till convergence is achieved.

[38] The estimation method will normally not be invariant to the equation deleted. Kmenta and Gilbert (1968) have demonstrated that iteration of the Zellner estimation procedure until convergence results in maximum-likelihood estimates and is a computationally efficient method. Barten (1969) has shown that maximum-likelihood estimates of a set of share equations are invariant to which equation is omitted.

the parameter estimates and residual covariance matrix converge (Berndt and Wood, 1975).

4.4 Data

The model described above was estimated for ten countries: United States, Japan, Germany, France and Canada, representing the developed countries and Brazil, China, India, Indonesia and Venezuela, representing the energy-producers developing countries. The study covers the industry sector for the period 1978 to 2003. The selection of this time period is largely guided by the availability of data. The data on individual fuel (coal, electricity, natural gas and petroleum products) consumption levels, which are in thousands of metric tons of oil equivalent are taken from Energy Balances of OECD and non-OECD countries. The price of individual fuels refers to energy end-use prices in industry sector for specific fuels and is taken from the Energy Prices and Taxes, International Energy Agency. Data on output, employment, wage and capital stock are obtained from the United Nations Industrial Development Organization (UNIDO), Industrial Statistics database. Data on the interest rate is obtained from the International Financial Statistics (IFS), which refers to the discount rate or bank rate and data on the real GDP and the GDP deflator are obtained from the United Nations Statistic Divisions. The variables are constructed as follows.

Output is defined as real value of output and covers only activities of an industrial nature. The value of output on a production basis comprises: a) the value of all products of the establishment; b) the net change between the beginning and the end of the reference period in the value of work in progress and stocks of goods to be shipped in the same condition as received; c) the value of industrial work done or industrial services rendered to others; d) the value of goods shipped in the same condition as received less the amount paid for these goods; and e) the value of fixed assets produce during the period by the unit for its own use.

Capital refers to the value of purchases and own-account construction of fixed assets during the reference year less the value of corresponding sales. Total cost is defined as the sum of compensation to labour, fuel and capital inputs. Using the formula provided in Andrikopoulos et al. (1989) and Cho et al. (2004), the total capital cost is calculated as $K_C = (\delta + r)K$ where δ is the depreciation rate, which refers to the ratio of capital consumption allowances to the gross domestic product (McNown et al., 1991), r is the market interest rate and K is the real capital stock normalized by the implicit GDP deflator. The price of labour is calculated by converting nominal wages into real terms with the GDP deflator. Total labour cost is calculated by the multiplication of the total labour by the real wage, while total energy cost is computed as the sum of the coal, electricity, natural gas and petroleum product costs measured in US dollar per tons of oil equivalent. The price of energy, which is used in the second stage of estimation, is an instrumental variable constructed as explained in Section 4.3.1.2.

4.5 Empirical Results

Different versions of both the inter-fuel and inter-factor models were estimated in static and dynamic models using the software-package Eviews 5. In the first version, not reported here, the equation system for the generalized translog cost function and its corresponding share equations were estimated without imposing linear homogeneity in prices and symmetry restrictions. In the second version, on the other hand, the share equations were estimated by imposing homogeneity and symmetry restrictions.[39]

The results for testing the validity of these restrictions can be referred in Appendix 4.III.1. The Chi-square values produced by the Wald test revealed that the null hypothesis of homogeneity is not rejected for most of the countries in both inter-factor and inter-fuel models. Regarding the test of symmetry restriction and for both homogeneity and symmetry restrictions, the tests show that the number of rejections is smaller in the dynamic model than in the static model.[40]

Since the static versions on both inter-factor and inter-fuel models indicate that there was a problem of autocorrelation, it was therefore concluded that the static specification was suspect, and is not referred to further in this study.[41] Thus, only

[39] In the literature of demand systems, testing of symmetry and homogeneity is a central theme. However, these restrictions are routinely rejected in applications. For a critical interpretation of this line of research, see Keuzenkamp and Barten (1995). In addition, Hunt (1984) claimed that the rejection of the restriction is not an unusual problem.

[40] Model misspecification and invalid statistical inference have often been put forward as two reasons for the extensive rejection of homogeneity. One example of model misspecification is omitted dynamic effects. Anderson and Blundell (1983) emphasize, in the context of an error correction framework that neglected dynamics could lead to rejection of homogeneity (as well as symmetry).

[41] Such results are not uncommon in static inter-fuel and inter-factor models (see, for example Jones, 1996; Considine, 1989 and Hall, 1986)

results from the dynamic version with economic theory restrictions imposed are reported in this section.[42]

4.5.1 Inter-factor Model

The estimated regression coefficients corresponding to the developed and developing countries of the restricted dynamic inter-factor model are reported in Table A.4.IV.1 in Appendix 4.IV. The majority of the estimated coefficients are statistically significant at a 5% level of statistical significance. In addition, the adjusted R^2 values, as shown in Table A.4.V.1 in Appendix 4.V, seem to suggest that the model fits to the data fairly well. These adjusted R-square values are much higher than in the static models. In the presence of lagged dependent variables, Durbin's h statistic is an appropriate test to check for serial correlation. As reported in the same table, the autocorrelation statistics are not statistically significant, indicating that the there is no serious problem of serial correlation (except for Germany and France).

Before proceeding to compare the implied price elasticities, it is important to check whether the cost functions are well behaved and consistent with economic theory. The cost functions are well behaved if its input demands functions are strictly positive and if they are concave in input prices. These two properties were checked at each data point for each cost share. Based on the SURE parameter estimates, the positivity conditions for the fitted cost shares are satisfied at each

[42] For a recent reference, see Raknerud *et al.* (2003) who suggest that statistical rejection of homogeneity may not be particularly alarming for practical purposes as they do not find evidence that the non-homogenous model performs better than the homogeneous one.

observation. The concavity conditions are also satisfied for Germany, France, India and Indonesia, since all own price elasticities have negative signs.

Two issues of main interest are the own price elasticities of demand for each of the three factors and the Allen partial elasticities of substitution between pairs of factor inputs. These elasticities, which are calculated at the mean values of cost shares, are presented in Tables 4.4 and 4.5, for both developed and developing countries, respectively. Both tables show that most of the countries have significant own price elasticities of energy (η_{EE}), capital (η_{KK}) and labour (η_{LL}) at 1% level in the short-run and in the long-run. These results imply that in general, increases in the price of a given factor decrease the demand for that particular factor. For instance, an increase by 1% of capital cost will decrease the demand for capital by 0.20% to 0.51 % for the group of developed countries. On the other hand, a 1% increment in the capital cost will decrease the demand for capital by 0.20% to 0.53% for the group of developing countries.

Among the three inputs, the demand for energy is found to be least responsive to its own price, and that of labour input most responsive to its own price in the case of developed countries. This indicates that there is flexibility in the labour market, especially for Canada, France and the United States, which may reflect a more significant adjustment in a firm's response to labour price changes than to other factors. With respect to developing countries, the results are mixed. The elasticities of demand for capital for most of the countries are small in magnitude, and indicate that investment will respond weakly to changes in real prices. In particular, in the case of Indonesia, the demand for capital is the least sensitive to own-price changes. Such estimates are intuitively plausible for a relatively capital-scarce country and reflect an almost general phenomenon in developing countries faced by capital deficiency. The demand for labour is relatively more responsive to changes in price, especially in India and Indonesia. These results appear related to an abundant labour supply and low wages in these two countries.

From Tables 4.4 and 4.5, it can be shown that the elasticity of substitution between capital and labour is positive, as is the elasticity between capital and energy and between labour and energy, indicating substitutability. The elasticity of substitution between capital and labour is significant in all countries except Japan, Canada, Brazil and Indonesia. In regard to the elasticity of substitution between capital and energy, all countries meet the established significance level (at 5% significance level). However, the t-statistics for the elasticity of substitution between labour and energy suggest that the estimates are not significantly different from zero.

Tables 4.4 and 4.5 also report the cross-price elasticities, which measure the responsiveness of the quantity demanded of a good to a change in the price of another good.[43] Examination of the cross-price elasticities confirms that all inputs are substitutes to each other, because the elasticities are found to be positive. The cross-price elasticities between capital and energy (η_{KE}) are highly significant for all countries. With regard to the energy and labour relationship, the cross-price elasticities (η_{EL}) are also significant for most of the countries, except in Canada and Indonesia. These results imply that there is a moderate responsiveness of

[43] In other words, a rise in the price of any of these factors will not only reduce its own demand, but will also lead to an increase in the demand for the other factor.

factor inputs to changing factor prices. Energy is found to be substitutable by non-energy factors in the industrial sector of five major countries in the OECD area and five major energy producers in the developing countries. Therefore, changes in energy prices can be accommodated by changes in the input mix, ameliorating adverse effects on economic growth. For example, energy price shocks do not lead to decrease in capital formation because higher energy prices will increase the demand for capital in order to maintain the level of production.

In general, energy prices have a much smaller effect on capital and labour in the developing countries than in the industrial countries. This result is similar to the earlier findings for some selected advanced countries by Apostolakis (1990) and on the Turkey industry by Dahl and Erdogan (2000). This result suggest that in response to an increase in the price of energy, the demand for labour (η_{LE}) will increase relatively more than the demand for capital (η_{KE}) in all countries, except in Japan.

There is a general agreement of the present study with the earlier findings in that capital and labour as well as capital and energy are found to be substitutes but in varying degrees. The result of substitutability between capital and energy is consistent with the previous findings for some selected advanced countries (Griffin and Gregory, 1976; Pindyck, 1979a, 1979b; McNown et al., 1991 and Caloghirou et al., 1997) and for some selected developing countries (Dahl and Erdogan, 2000 and Cho et al., 2004). Also, the result of substitutability between labour and energy is similar to earlier findings on a group of advanced countries (Griffin and Gregory, 1976; Apostolakis, 1990; Caloghirou et al., 1997 and

Christopoulos and Tsionas, 2002), and also on developing countries (Iqbal, 1986, Kim and Labys, 1988 and Cho et al., 2004). However, the elasticities reported by these studies lie in a wide range because they use different periods and methods.

4.5.2 Inter-fuel Model

The parameters of the estimated translog cost function constrained to satisfy symmetry and homogeneity together with their t statistics are reported in Table A.4.IV.2 in Appendix 4.IV. Most of the estimated coefficients are statistically significant at the conventional level. In addition, estimates of the effect of lagged dependent variables are strongly significant for most of the countries, which provides support to the partial (lagged) adjustment response. The adjusted R square values, which are shown in Table A.4.V.2 in Appendix 4.V range between 0.60 and 0.98. These values are extremely high indicating that the dynamic versions provide significantly better overall fits than their static version. The autocorrelation statistics are not statistically significant for most of the countries, indicating that there is no problem of serial correlation (except for the United States, Brazil and India). The system of equations is also examined for monotonicity and curvature properties. For both groups of countries, all data points exhibited positive cost shares, which confirm that monotonicity in factor prices holds. The own-price elasticities of factor demand are all negative, indicating that the postulates of cost minimizing fuel demand theory are well satisfied.

Tables 4.6 and 4.7 present the elasticities of inter-fuel substitution and (partial) own and cross-price elasticities of the fuels. The wide variations in elasticities of substitution and in price elasticities of fuels between countries are due to differences in the share composition of each fuel. For example, the cost share of petroleum product is the highest in United States, Japan, Germany, India, and Venezuela and as a result, its demand has the lowest price elasticity compare to the other type of fuels. Coal, on the other hand, has a high own-price elasticity of demand in the United States, Germany, France, Canada and Venezuela because of the very low cost share of coal in these countries. These results follow from the properties of equations (4.7) and (4.8) and are consistent with the idea that as the quantity of input demanded approaches zero, the elasticity approaches infinity.

As for the nature of the relationship between the fuels, the computed Allen partial elasticities of substitution show that there are significant substitution relationships between petroleum and electricity (σ_{pe}) (for all countries), petroleum and gas (σ_{pg}) (except for Indonesia), petroleum and coal (σ_{pc}) (except for Canada and Venezuela) electricity and gas (σ_{eg}) (except for Indonesia), electricity and coal (σ_{ec}) (for Japan, Germany, Canada, Brazil, China and India) and gas and coal (σ_{gc}) (except for China). Note that a higher value of the elasticity of substitution between fuels implies that there are more possibilities for producing a given level of output with different fuel combinations.

All own price elasticities are negative and significant. The computed price elasticities of fuel's demand are found to be more than unity for all the fuels.

Among the four inputs, the demand for coal is found to be the most responsive to its own price. This was expected because coal has a small fuel share in industrial energy consumption (except in China and India). The demand for natural gas is the next most responsive for most of the countries, followed by electricity and petroleum products. With regard to the partial cross-price elasticities the results indicate that there are significant substitution possibilities between the fuels, even though complementarity is observed in a number of countries. This is consistent with the Allen partial elasticities of substitution. In addition, both the degree of substitutability and complementarity, where observed, varies between countries.

Table 4.4: Elasticities of Substitution and Price Elasticities of Demand for Factors in Industrial Sector of Developed Countries

	UNITED STATES		JAPAN		GERMANY		FRANCE		CANADA	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Elasticities of substitution										
σ_{KL}	0.99***	1.24***	0.93	1.18	0.94***	1.04***	0.99***	2.00***	0.99	1.64
	(6.21)	(7.72)	(0.67)	(0.85)	(8.47)	(9.42)	(2.45)	(4.93)	(0.13)	(0.21)
σ_{KE}	0.92***	1.15***	0.95***	1.20***	0.89***	0.99***	0.87***	1.75***	0.92*	1.53***
	(17.02)	(21.17)	(3.43)	(4.35)	(15.38)	(17.11)	(5.25)	(10.56)	(1.76)	(2.92)
σ_{LE}	1.13	1.40	0.84	1.06	1.17	1.30	1.17	2.35	0.98	1.62
	(0.23)	(0.29)	(0.15)	(0.19)	(0.76)	(0.85)	(0.14)	(0.29)	(0.25)	(0.41)
Price elasticities										
η_{KK}	-0.26***	-0.32***	-0.16***	-0.20***	-0.12***	-0.13***	-0.26**	-0.51***	-0.14	-0.23**
	(-5.49)	(-6.83)	(-3.79)	(-4.80)	(-3.50)	(-3.89)	(-2.36)	(-4.74)	(-1.58)	(-2.63)
η_{LL}	-2.12***	-2.64***	-1.38***	-1.75***	-1.30***	-1.45***	-2.97***	-5.97***	-3.90***	-6.48***
	(-4.25)	(-5.28)	(-4.17)	(-5.29)	(-15.36)	(-17.08)	(-9.43)	(-18.97)	(-2.94)	(-4.89)
η_{EE}	0.44***	0.55***	0.02	0.03	-0.63***	-0.70***	-0.71***	-1.44***	0.55***	0.91***
	(8.06)	(10.03)	(0.55)	(0.70)	(-26.38)	(-29.34)	(-7.20)	(-14.49)	(8.78)	(14.61)
η_{KL}	0.09***	0.12***	0.14	0.18	0.23***	0.26***	0.17***	0.34***	0.05	0.08
	(6.21)	(7.72)	(0.67)	(0.85)	(8.47)	(9.42)	(2.45)	(4.93)	(0.13)	(0.21)
η_{KE}	0.71***	0.88***	0.63***	0.80***	0.42***	0.47***	0.38***	0.76***	0.76*	1.27***
	(17.02)	(21.17)	(3.43)	(4.35)	(15.38)	(17.11)	(5.25)	(10.56)	(1.76)	(2.92)
η_{LK}	0.14***	0.17***	0.17	0.22	0.26***	0.29***	0.40**	0.79***	0.12	0.20
	(6.21)	(7.72)	(0.67)	(0.85)	(8.47)	(9.42)	(2.45)	(4.93)	(0.13)	(0.21)
η_{LE}	0.87	1.08	0.56	0.71	0.56	0.62	0.51	1.02	0.81	1.34
	(0.23)	(0.29)	(0.15)	(0.19)	(0.76)	(0.85)	(0.14)	(0.29)	(0.25)	(0.41)
η_{EK}	0.13***	0.16***	0.18***	0.22***	0.25***	0.27***	0.35***	0.69***	0.11***	0.19***
	(7.64)	(9.51)	(19.04)	(24.13)	(8.89)	(9.89)	(5.42)	(10.90)	(9.05)	(15.06)
η_{EL}	0.11	0.13**	0.12***	0.16***	0.29***	0.33***	0.20*	0.39***	0.05	0.08
	(1.74)	(2.16)	(2.68)	(3.40)	(7.01)	(7.80)	(1.88)	(3.78)	(0.88)	(1.46)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Table 4.5: Elasticities of Substitution and Price Elasticities of Demand for Factors in Industrial Sector of Developing Countries

	BRAZIL		CHINA		INDIA		INDONESIA		VENEZUELA	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Elasticities of substitution										
σ_{KL}	0.96	1.97	0.97***	0.90***	0.86***	1.85***	0.98	1.35	1.00	2.34**
	(0.39)	(0.80)	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)	(0.94)	(2.21)
σ_{KE}	0.94**	1.94***	0.98***	0.91***	1.00***	2.15***	0.87***	1.20***	0.93	2.19**
	(2.00)	(4.12)	(4.73)	(4.36)	(9.29)	(19.91)	(9.57)	(13.25)	(1.10)	(2.57)
σ_{LE}	1.06	2.19	1.00	0.92	1.00	2.14	0.99	1.37	1.05	2.45
	(0.34)	(0.71)	(0.54)	(0.50)	(0.25)	(0.53)	(0.12)	(0.16)	(0.13)	(0.30)
Price elasticities										
η_{KK}	0.75***	1.55***	-0.35***	-0.32***	-0.25***	-0.53***	-0.15	-0.20**	0.06	0.15
	(6.45)	(13.29)	(-3.11)	(-2.87)	(-4.66)	(-9.99)	(-1.48)	(-2.04)	(0.11)	(0.25)
η_{LL}	-0.61**	-1.26***	0.24***	0.22***	-3.61***	-7.74***	-8.69***	-12.03***	-0.32***	-0.74***
	(-2.28)	(-4.71)	(4.72)	(4.35)	(-17.14)	(-36.75)	(-8.41)	(-11.63)	(-2.79)	(-6.55)
η_{EE}	0.55***	1.13***	0.03	0.03	-1.56***	-3.35***	-2.78***	-3.85***	0.51***	1.20***
	(12.49)	(25.74)	(1.22)	(1.12)	(-33.57)	(-71.99)	(-50.60)	(-70.03)	(6.99)	(16.39)
η_{KL}	0.12	0.25	0.44***	0.40***	0.12***	0.25***	0.09	0.12	0.24	0.55**
	(0.39)	(0.80)	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)	(0.94)	(2.21)
η_{KE}	0.76**	1.57***	0.46***	0.43***	0.42***	0.90***	0.26***	0.37***	0.65	1.52**
	(2.00)	(4.12)	(4.73)	(4.36)	(9.29)	(19.91)	(9.57)	(13.25)	(1.10)	(2.57)
η_{LK}	0.06	0.12	0.08***	0.07***	0.38***	0.82***	0.59	0.82	0.07	0.16**
	(0.39)	(0.80)	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)	(0.94)	(2.21)
η_{LE}	0.86	1.78	0.47***	0.43	0.42	0.90	0.30	0.42	0.73	1.70
	(0.34)	(0.71)	(0.54)	(0.50)	(0.25)	(0.53)	(0.12)	(0.16)	(0.13)	(0.30)
η_{EK}	0.06***	0.12***	0.08**	0.07**	0.44***	0.95***	0.53***	0.73***	0.06	0.15**
	(4.10)	(8.44)	(2.18)	(2.01)	(7.71)	(16.54)	(2.68)	(3.70)	(0.96)	(2.26)
η_{EL}	0.14***	0.28***	0.45***	0.41***	0.14**	0.29***	0.09	0.12	0.25***	0.58***
	(3.90)	(8.04)	(9.76)	(8.99)	(2.04)	(4.38)	(0.41)	(0.57)	(8.36)	(19.61)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Table 4.6: Elasticities of Substitution and Partial Price Elasticities of Demand for Fuels in Industrial Sector of Developed Countries

	UNITED STATES		JAPAN		GERMANY		FRANCE		CANADA	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Elasticities of substitution										
σ_{pe}	2.32***	3.15***	1.49***	4.29***	1.90***	4.44***	1.40***	11.57***	2.14***	3.91***
	(10.44)	(14.18)	(11.23)	(32.39)	(17.36)	(40.56)	(7.36)	(60.99)	(15.01)	(27.38)
σ_{pg}	0.61***	0.83***	2.05***	5.92***	0.63***	1.46***	0.59	4.90***	0.59***	1.08***
	(6.03)	(8.19)	(5.59)	(16.14)	(4.09)	(9.56)	(0.97)	(8.02)	(3.63)	(6.63)
σ_{pc}	-0.54*	-0.74***	1.31***	3.77***	0.64***	1.50***	1.91***	15.78***	-0.13	-0.23
	(-1.86)	(-2.52)	(3.56)	(10.28)	(2.69)	(6.29)	(2.82)	(23.32)	(-0.43)	(-0.79)
σ_{eg}	-1.03***	-1.40***	1.00***	2.89***	0.1	0.32*	0.65***	5.36***	0.17	0.31*
	(-5.98)	(-8.12)	(3.18)	(9.16)	(0.83)	(1.93)	(3.02)	(25.02)	(1.06)	(1.93)
σ_{ec}	0.05	0.07	0.59*	1.71***	-0.30	-0.69*	0.06	0.54	-0.62**	-1.14***
	(0.08)	(0.11)	(1.71)	(4.94)	(-0.72)	(-1.70)	(0.14)	(1.12)	(-2.09)	(-3.81)
σ_{gc}	1.23**	1.67***	-19.62***	-56.59***	-0.43	-1.00*	-0.97	-8.04***	1.19**	2.18***
	(2.34)	(3.18)	(-4.77)	(-13.76)	(-0.73)	(-1.71)	(-0.62)	(-5.14)	(2.31)	(4.22)
Price elasticities										
η_{pp}	-0.69***	-0.93***	-0.57***	-1.65***	-0.72***	-1.67***	-0.76***	-6.29***	-0.82***	-1.50***
	(-9.38)	(-12.74)	(-11.46)	(-33.06)	(-19.95)	(-46.60)	(-5.56)	(-46.06)	(-15.87)	(-28.95)
η_{ee}	-1.22***	-1.66***	-1.51***	-4.36***	-0.91***	-2.13***	-0.30***	-2.52***	-0.54***	-0.99***
	(-13.92)	(-18.91)	(-18.69)	(-53.91)	(-17.84)	(-41.68)	(-4.42)	(-36.60)	(-8.37)	(-15.27)
η_{gg}	-2.74***	-3.73***	-19.06***	-54.98***	-4.34***	-10.14***	-3.27***	-27.08***	-3.13***	-5.72***
	(-47.52)	(-64.53)	(-86.67)	(-250.01)	(-46.42)	(-108.44)	(-16.92)	(-140.17)	(-46.11)	(-84.14)
η_{cc}	-11.48***	-15.60***	-16.09***	-46.41***	-4.73***	-11.06***	-6.55***	-54.26***	-12.73***	-23.22***
	(-26.47)	(-35.95)	(-31.49)	(-90.82)	(-14.65)	(-34.22)	(-9.26)	(-76.74)	(-38.31)	(-69.91)
η_{pe}	0.57***	0.77***	0.46***	1.33***	0.58***	1.35***	0.60***	4.94***	0.72***	1.32***
	(10.44)	(14.18)	(11.23)	(32.39)	(17.36)	(40.56)	(7.36)	(60.99)	(15.01)	(27.38)
η_{pg}	0.14***	0.18***	0.08***	0.22***	0.09***	0.20***	0.09	0.76***	0.11***	0.19***
	(6.03)	(8.19)	(5.59)	(16.14)	(4.09)	(9.56)	(0.97)	(8.02)	(3.63)	(6.63)
η_{pc}	-0.02*	-0.03***	0.04***	0.11***	0.05***	0.12***	0.07***	0.60***	0.00	-0.01
	(-1.86)	(-2.52)	(3.56)	(10.28)	(2.69)	(6.29)	(2.82)	(23.32)	(-0.43)	(-0.79)
η_{ep}	1.16***	1.57***	0.93***	2.68***	0.91***	2.13***	0.53***	4.41***	0.98***	1.79***
	(10.44)	(14.18)	(11.23)	(32.39)	(17.36)	(40.56)	(7.36)	(60.99)	(15.01)	(27.38)

η_{eg}	-0.23***	-0.31***	0.04***	0.11***	0.02	0.04**	0.10***	0.83***	0.03	0.06*
	(-5.98)	(-8.12)	(3.18)	(9.16)	(0.83)	(1.93)	(3.02)	(25.02)	(1.06)	(1.93)
η_{ec}	0.00	0.00	0.02***	0.05***	-0.02	-0.05*	0.00	0.02	-0.02**	-0.03***
	(0.08)	(0.11)	(1.71)	(4.94)	(-0.73)	(-1.70)	(0.14)	(1.12)	(-2.09)	(-3.81)
η_{gp}	0.30***	0.41***	1.28***	3.70***	0.30***	0.70***	0.23	1.87***	0.27***	0.49***
	(6.03)	(8.19)	(5.59)	(16.14)	(4.09)	(9.56)	(0.97)	(8.02)	(3.63)	(6.63)
η_{ge}	-0.25***	-0.34***	0.31***	0.90***	0.04	0.10*	0.28***	2.29***	0.06	0.11**
	(-5.98)	(-8.12)	(3.18)	(9.16)	(0.83)	(1.93)	(3.02)	(25.02)	(1.06)	(1.93)
η_{gc}	0.04**	0.06***	-0.55***	-1.59***	-0.03	-0.08*	-0.04	-0.31***	0.03**	0.06***
	(2.34)	(3.18)	(-4.77)	(-13.76)	(-0.73)	(-1.71)	(-0.62)	(-5.14)	(2.31)	(4.22)
η_{cp}	-0.27*	-0.37**	0.82***	2.35***	0.31***	0.72***	0.73***	6.01***	-0.06	-0.11
	(-1.86)	(-2.52)	(3.56)	(10.28)	(2.69)	(6.29)	(2.82)	(23.32)	(-0.43)	(-0.79)
η_{ce}	0.01	0.02	0.18*	0.53***	-0.09	-0.21*	0.03	0.23	-0.21**	-0.38***
	(0.08)	(0.11)	(1.71)	(4.94)	(-0.72)	(-1.70)	(0.14)	(1.12)	(-2.09)	(-3.81)
η_{cg}	0.27**	0.37	-0.72***	-2.09***	-0.06	-0.14*	-0.15	-1.24***	0.21**	0.39***
	(2.34)	(3.18) ***	(-4.77)	(-13.76)	(-0.73)	(-1.71)	(-0.62)	(-5.14)	(2.31)	(4.22)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Table 4.7: Elasticities of Substitution and Partial Price Elasticities of Demand for Fuels in Industrial Sector of Developing Countries

	BRAZIL		CHINA		INDIA		INDONESIA		VENEZUELA	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Elasticities of substitution										
σ_{pe}	1.68***	3.89***	4.53***	4.73***	1.85***	2.51***	1.98***	4.73***	2.13***	3.97***
	(7.82)	(18.14)	(15.45)	(16.13)	(13.79)	(18.73)	(19.20)	(46.01)	(11.29)	(20.99)
σ_{pg}	1.27***	2.95***	-1.00***	-1.04***	-4.64***	-6.30***	0.06	0.15	0.44***	0.82***
	(2.34)	(5.44)	(-2.82)	(-2.94)	(-8.69)	(-11.81)	(0.32)	(0.76)	(4.82)	(8.96)
σ_{pc}	0.64*	1.49***	-0.28***	-0.29***	0.49***	0.66***	-1.47***	-3.52***	0.37	0.68
	(1.92)	(4.45)	(-3.44)	(-3.59)	(2.86)	(3.89)	(-3.51)	(-8.41)	(0.45)	(0.84)
σ_{eg}	-0.76	-1.77*	-3.73***	-3.89***	-20.04***	-27.21***	0.13	0.30	0.98	1.83***
	(-0.73)	(-1.69)	(-5.99)	(-6.25)	(-24.88)	(-33.79)	(0.60)	(1.44)	(1.63)	(3.03)
σ_{ec}	-1.67***	-3.88***	0.18**	0.19**	0.77***	1.05***	0.37	0.88	-0.49	-0.91
	(-2.93)	(-6.78)	(2.22)	(2.31)	(3.50)	(4.76)	(0.62)	(1.47)	(-0.10)	(-0.19)
σ_{gc}	29.54***	68.50***	-0.16	-0.16	2.25*	3.06**	5.00***	11.99***	-3.41	-6.34***
	(7.72)	(17.91)	(-1.40)	(-1.46)	(1.66)	(2.25)	(2.95)	(7.08)	(-1.10)	(-2.04)
Price elasticities										
η_{pp}	-0.78***	-1.81***	-0.80***	-0.83***	-0.65***	-0.88***	-1.04***	-2.49***	-0.32***	-0.60***
	(-9.93)	(-23.03)	(-14.94)	(-15.60)	(-13.62)	(-18.49)	(-26.65)	(-63.86)	(-13.61)	(-25.29)
η_{ee}	-0.44***	-1.02***	-0.06***	-0.06***	-0.66***	-0.90***	0.16***	0.39***	-6.25***	-11.61***
	(-3.22)	(-7.46)	(-0.51)	(-0.53)	(-9.88)	(-13.42)	(3.18)	(7.61)	(-40.22)	(-74.74)
η_{gg}	-18.85***	-43.73***	-78.25***	-81.73***	-49.05***	-66.61***	-4.13***	-9.89***	-3.91***	-7.26***
	(-92.11)	(-213.62)	(-762.96)	(-796.92)	(-358.51)	(-486.88)	(-37.51)	(-89.87)	(-40.66)	(-75.55)
η_{cc}	-17.56***	-40.73***	-0.53***	-0.56***	-3.98***	-5.40***	-1.71***	-4.10***	-12.62***	-23.45***
	(-31.25)	(-72.47)	(-9.37)	(-9.79)	(-18.87)	(-25.63)	(-2.41)	(-5.76)	(-7.22)	(-13.41)
η_{pe}	0.73***	1.69***	0.92***	0.97***	0.67***	0.91***	1.08***	2.58***	0.21***	0.40***
	(7.82)	(18.14)	(15.45)	(16.13)	(13.79)	(18.73)	(19.20)	(46.01)	(11.29)	(20.99)
η_{pg}	0.04**	0.09***	-0.01***	-0.01***	-0.07***	-0.09***	0.01	0.02	0.10***	0.19***
	(2.34)	(5.44)	(-2.82)	(-2.94)	(-8.69)	(-11.81)	(0.32)	(0.76)	(4.82)	(8.96)
η_{pc}	0.01*	0.03***	-0.12***	-0.12***	0.05***	0.06***	-0.05***	-0.11***	0.01	0.02
	(1.92)	(4.45)	(-3.44)	(-3.59)	(2.86)	(3.89)	(-3.51)	(-8.41)	(0.45)	(0.84)
η_{ep}	0.86***	1.99***	1.60***	1.67***	0.97***	1.32***	0.58***	1.39***	1.38***	2.56***
	(7.82)	(18.14)	(15.45)	(16.13)	(13.79)	(18.73)	(19.20)	(46.01)	(11.29)	(20.99)

	-0.02	-0.06*	-0.03***	-0.03***	-0.29***	-0.40***	0.02	0.04	0.23	0.42***
η_{eg}	(-0.73)	(-1.69)	(-5.99)	(-6.25)	(-24.88)	(-33.79)	(0.60)	(1.44)	(1.63)	(3.03)
	-0.04***	-0.08***	0.08**	0.08**	0.08***	0.10***	0.01	0.03	-0.01	-0.02
η_{ec}	(-2.93)	(-6.78)	(2.22)	(2.31)	(3.50)	(4.76)	(0.62)	(1.47)	(-0.10)	(-0.19)
	0.65**	1.51***	-0.35***	-0.37***	-2.45***	-3.32***	0.02	0.04	0.29***	0.53***
η_{gp}	(2.34)	(5.44)	(-2.82)	(-2.94)	(-8.69)	(-11.81)	(0.32)	(0.76)	(4.82)	(8.96)
	-0.33	-0.77*	-0.76***	-0.79***	-7.23***	-9.82***	0.07	0.17	0.10	0.18***
η_{ge}	(-0.73)	(-1.69)	(-5.99)	(-6.25)	(-24.88)	(-33.79)	(0.60)	(1.44)	(1.63)	(3.03)
	0.65***	1.50***	-0.07	-0.07	0.22*	0.30**	0.16***	0.38***	-0.09	-0.16**
η_{gc}	(7.72)	(17.91)	(-1.40)	(-1.46)	(1.66)	(2.25)	(2.95)	(7.08)	(-1.10)	(-2.04)
	0.33*	0.76***	-0.10***	-0.10***	0.26***	0.35***	-0.43***	-1.03***	0.24	0.44
η_{cp}	(1.92)	(4.45)	(-3.44)	(-3.59)	(2.86)	(3.89)	(-3.51)	(-8.41)	(0.45)	(0.84)
	-0.73***	-1.68***	0.04**	0.04**	0.28***	0.38***	0.20	0.48	-0.05	-0.09
η_{ce}	(-2.93)	(-6.78)	(2.22)	(2.31)	(3.50)	(4.76)	(0.62)	(1.47)	(-0.10)	(-0.19)
	0.93***	2.15***	0.00	0.00	0.03*	0.04**	0.65***	1.55***	-0.78	-1.45**
η_{cg}	(7.72)	(17.91)	(-1.40)	(-1.46)	(1.66)	(2.25)	(2.95)	(7.08)	(-1.10)	(-2.04)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Table 4.8: Total Fuel Price Elasticity of Demand for Fuels in Industrial Sector of Developed Countries

	UNITED STATES		JAPAN		GERMANY		FRANCE		CANADA	
	SR	LR	SR	LR	SR		SR	LR	SR	LR
η_{pp}	-0.47***	-0.63***	-0.56***	-1.61***	-1.02***	-2.38***	-1.03***	-8.55***	-0.57***	-1.05***
	(-6.37)	(-8.65)	(-11.17)	(-32.21)	(-28.36)	(-66.26)	(-7.55)	(-62.55)	(-11.03)	(-20.13)
η_{ee}	-1.11***	-1.51***	-1.50***	-4.34***	-1.10***	-2.58***	-0.61***	-5.04***	-0.36***	-0.66***
	(-12.69)	(-17.23)	(-18.60)	(-53.65)	(-21.60)	(-50.47	(-8.85)	(-73.29)	(-5.53)	(-10.09)
η_{gg}	-2.65***	-3.59***	-19.06***	-54.97***	-4.43***	-10.34***	-3.38***	-28.00***	-3.03***	-5.54***
	(-45.81)	(-62.21)	(-86.67)	(-250.00)	(-47.34)	(-110.60)	(-17.49)	(-144.90)	(-44.67)	(-81.50)
η_{cc}	-11.47***	-15.58***	-16.09***	-46.41***	-4.78***	-11.18***	-6.58***	-54.49***	-12.71***	-23.20***
	(-26.44)	(-35.90)	(-31.48)	(-90.82)	(-14.80)	(-34.58)	(-9.30)	(-77.06)	(-38.27)	(-69.83)
η_{pe}	0.68***	0.92***	0.47***	1.35***	0.39***	0.90***	0.29***	2.41***	0.91***	1.65***
	(12.44)	(16.89)	(11.41)	(32.90)	(11.61)	(27.11)	(3.60)	(29.80)	(18.85)	(34.39)
η_{pg}	0.23***	0.32***	0.08***	0.22***	0.00	0.00	-0.02	-0.16*	0.20***	0.37***
	(10.42)	(14.15)	(5.66)	(16.32)	(-0.03)	(-0.08)	(-0.20)	(-1.66)	(7.01)	(12.79)
η_{pc}	0.00	0.00	0.04***	0.11***	0.00	0.00	0.05*	0.38***	0.01	0.02***
	(-0.34)	(-0.46)	(3.63)	(10.47)	(0.04)	(0.10)	(1.76)	(14.58)	(1.43)	(2.62)
η_{ep}	1.38***	1.87***	0.94***	2.72***	0.61***	1.42***	0.26***	2.15***	1.23***	2.25***
	(12.44)	(16.89)	(11.41)	(32.90)	(11.61)	(27.11)	(3.60)	(29.80)	(18.85)	(34.39)
η_{eg}	-0.13***	-0.18	0.04***	0.11***	-0.07***	-0.16***	-0.01	-0.09***	0.13***	0.23***
	(-3.41)	(-4.63)	(3.25)	(9.38)	(-2.98)	(-6.96)	(-0.31)	(-2.58)	(4.45)	(8.12)
η_{ec}	0.02	0.02	0.02*	0.05***	-0.07**	-0.17***	-0.02	-0.20***	0.00	0.00
	(0.73)	(0.99)	(1.78)	(5.14)	(-2.27)	(-5.31)	(-1.36)	(-11.23)	(-0.25)	(-0.46)
η_{gp}	0.52***	0.71***	1.30***	3.74***	0.00	-0.01	-0.05	-0.39	0.52***	0.95***
	(10.42)	(14.15)	(5.66)	(16.32)	(-0.03)	(-0.08)	(-0.20)	(-1.66)	(7.01)	(12.79)
η_{ge}	-0.14***	-0.20***	0.32***	0.92***	-0.15***	-0.35***	-0.03	-0.24***	0.24***	0.44***
	(-3.41)	(-4.63)	(3.25)	(9.38)	(-2.98)	(-6.96)	(-0.31)	(-2.58)	(4.45)	(8.12)
η_{gc}	0.06***	0.08***	-0.55***	-1.59***	-0.08*	-0.20***	-0.06	-0.53***	0.05***	0.08***
	(3.18)	(4.32)	(-4.76)	(-13.74)	(-1.81)	(-4.23)	(-1.08)	(-8.91)	(3.38)	(6.16)
η_{cp}	-0.05	-0.07	0.83***	2.40***	0.00	0.01	0.45*	3.76***	0.19	0.35***
	(-0.34)	(-0.46)	(3.63)	(10.47)	(0.04)	(0.10)	(1.76)	(14.58)	(1.43)	(2.62)
η_{ce}	0.12	0.17	0.19*	0.55***	-0.28***	-0.66***	-0.28	-2.30***	-0.03	-0.05
	(0.73)	(0.99)	(1.78)	(5.14)	(-2.27)	(-5.31)	(-1.36)	(-11.23)	(-0.25)	(-0.46)
η_{cg}	0.37***	0.51***	-0.72***	-2.09***	-0.14*	-0.34***	-0.26	-2.16***	0.31***	0.57***
	(3.18)	(4.32)	(-4.76)	(-13.74)	(-1.81)	(-4.23)	(-1.08)	(-8.91)	(3.38)	(6.16)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Table 4.9: Total Fuel Price Elasticity of Demand for Fuels in Industrial Sector of Developing Countries

	BRAZIL		CHINA		INDIA		INDONESIA		VENEZUELA	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
η_{pp}	-0.50***	-1.16***	-0.79***	-0.82***	-1.47***	-2.00***	-1.86***	-4.45***	0.00	0.01
	(-6.36)	(-14.76)	(-14.74)	(-15.39)	(-30.99)	(-42.08)	(-47.56)	(-113.95)	(0.21)	(0.39)
η_{ee}	-0.20	-0.47***	-0.06	-0.06	-1.23***	-1.66***	-1.35***	-3.24***	-6.20***	-11.51***
	(-1.49)	(-3.45)	(-0.46)	(-0.48)	(-18.32)	(-24.87)	(-26.20)	(-62.78)	(-39.89)	(-74.14)
η_{gg}	-18.84***	-43.69***	-78.25***	-81.73***	-49.07***	-66.64***	-4.48***	-10.74***	-3.79***	-7.04***
	(-92.02)	(-213.42)	(-762.96)	(-796.92)	(-358.68)	(-487.11)	(-40.77)	(-97.67)	(-39.44)	(-73.29)
η_{cc}	-17.55***	-40.70***	-0.52***	-0.54***	-4.13***	-5.61***	-1.80**	-4.31***	-12.61***	-23.43***
	(-31.23)	(-72.43)	(-9.14)	(-9.55)	(-19.59)	(-26.61)	(-2.53)	(-6.06)	(-7.21)	(-13.40)
η_{pe}	0.97***	2.24***	0.93***	0.97***	0.10**	0.14***	-0.44***	-1.05***	0.26***	0.49***
	(10.38)	(24.06)	(15.55)	(16.24)	(2.12)	(2.88)	(-7.81)	(-18.71)	(13.99)	(26.00)
η_{pg}	0.06***	0.13***	-0.01***	-0.01***	-0.09***	-0.12***	-0.35***	-0.84***	0.22***	0.41***
	(3.35)	(7.77)	(-2.73)	(-2.85)	(-11.62)	(-15.78)	(-14.21)	(-34.04)	(10.38)	(19.28)
η_{pc}	0.03***	0.06***	-0.11***	-0.11***	-0.10***	-0.14***	-0.13***	-0.32***	0.02	0.04**
	(3.56)	(8.25)	(-3.06)	(-3.20)	(-6.32)	(-8.59)	(-10.15)	(-24.31)	(1.08)	(2.01)
η_{ep}	1.14***	2.64***	1.61***	1.69***	0.15**	0.20***	-0.24***	-0.57***	1.71***	3.17***
	(10.38)	(24.06)	(15.55)	(16.24)	(2.12)	(2.88)	(-7.81)	(-18.71)	(13.99)	(26.00)
η_{eg}	-0.01	-0.02	-0.03***	-0.03***	-0.32***	-0.43***	-0.34***	-0.82***	0.34***	0.64***
	(-0.21)	(-0.48)	(-5.94)	(-6.20)	(-26.83)	(-36.43)	(-12.64)	(-30.27)	(2.47)	(4.60)
η_{ec}	-0.02*	-0.06***	0.09***	0.10***	-0.08***	-0.10***	-0.08***	-0.18***	0.00	0.00
	(-1.97)	(-4.56)	(2.59)	(2.70)	(-3.58)	(-4.86)	(-4.04)	(-9.69)	(0.00)	(0.01)
η_{gp}	0.93***	2.16***	-0.34***	-0.36***	-3.27***	-4.44***	-0.80***	-1.91***	0.61***	1.14***
	(3.35)	(7.77)	(-2.73)	(-2.85)	(-11.62)	(-15.78)	(-14.21)	(-34.04)	(10.38)	(19.28)
η_{ge}	-0.09	-0.22	-0.75***	-0.79***	-7.79***	-10.58***	-1.45***	-3.47***	0.15**	0.28***
	(-0.21)	(-0.48)	(-5.94)	(-6.20)	(-26.83)	(-36.43)	(-12.64)	(-30.27)	(2.47)	(4.60)
η_{gc}	0.66***	1.53***	-0.06	-0.06	0.07	0.09	0.07	0.17***	-0.07	-0.14*
	(7.86)	(18.24)	(-1.13)	(-1.18)	(0.51)	(0.69)	(1.31)	(3.14)	(-0.93)	(-1.74)
η_{cp}	0.61***	1.41***	-0.09***	-0.09***	-0.57***	-0.77***	-1.25***	-2.99***	0.57	1.05***
	(3.56)	(8.25)	(-3.06)	(-3.20)	(-6.32)	(-8.59)	(-10.15)	(-24.31)	(1.08)	(2.01)
η_{ce}	-0.49*	-1.13***	0.04***	0.04***	-0.29***	-0.39***	-1.32***	-3.16***	0.00	0.00
	(-1.97)	(-4.56)	(2.59)	(2.70)	(-3.58)	(-4.86)	(-4.04)	(-9.69)	(0.00)	(0.01)
η_{cg}	0.95***	2.19***	0.00	0.00	0.01	0.01	0.29	0.69***	-0.67	-1.24*
	(7.86)	(18.24)	(-1.13)	(-1.18)	(0.51)	(0.69)	(1.31)	(3.14)	(-0.93)	(-1.74)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Total price elasticities for individual fuel demands for developed and developing countries are shown in Tables 4.8 and 4.9, respectively. As in the case of partial price elasticities, coal has the largest own price elasticity followed by natural gas. For China and India, own-price elasticities for natural gas are large. Similar results are derived by Pindyck (1979) and Hall (1986) for a group of advanced countries and Kim and Labys (1988) and Cho et al. (2004) for Korea, who reported that the own-price elasticity for coal was the most elastic.

With regards to the cross price elasticities the results indicate that electricity and petroleum (η_{ep}) have probably been substitutes in the industrial sector of all countries, except Indonesia, where complementarity prevails since the cross price elasticity is negative. There is also some evidence of inter-fuel substitution possibilities involving gas and petroleum (η_{gp}) for most of the countries, except for Germany and France. Coal and petroleum (η_{cp}) are found to be substitutes in Japan, France, Canada and in all five energy producers in the developing countries. These findings suggest that the effect of higher petroleum prices was to provide a stimulus to consumption of electricity, natural gas and coal. Therefore, the alternative sources to petroleum were electricity, natural gas and coal. This result is consistent with that reported by Griffin (1977) and Hall (1986) in the case of OECD countries, Mahmud and Chishti (1990) for Pakistan and Taheri (1994) for the United States based on earlier time periods.

The results of the cross-price elasticity also confirm a very inelastic response of electricity to a change in the price of natural gas for Canada and Venezuela and to a change in the price of coal for Japan and China. As noted by Andrikopoulos et al.

(1989), this result can be explained by the fact that electricity is the most inflexible form of energy, because it is used mainly for lighting and motive power. Thus, the substitution possibilities are rather weak. For example, the cross-price elasticity between electricity and natural gas in Canada is 0.23 and therefore an increase of 1% in the relative price of natural gas would lead to only 0.23% increase in the demand for electricity by the industrial sector. On the other hand, the cross price elasticity between electricity and coal is 0.05 and this indicates that an increase of 1% in the price of coal would lead to only 0.05% increase in the demand for electricity. This finding is substantially the same as that reported by Hall (1986) for the industrial sector in US, Japan, Italy and Canada from annual observations over the period 1960 to 1979 and Andrikoupoulos et al. (1989) for the industrial sector in Canada for the period of 1962 to 1982.

There is also some evidence of substitution possibilities between gas and coal in the United States, Canada, Brazil and Indonesia, where the elasticity of substitution for coal with respect to natural gas price is larger than the elasticity of substitution for natural gas with respect to coal price. These findings imply that natural gas, which is cleaner-burning and has lower environmental impact, has replaced coal as the preferred source of energy in the industrial sector for these countries.

4.6 Conclusions

This study has examined the scope for substitution between factors of production and type of fuels, and has taken into account possible feedback effects between inter-factor and inter-fuel substitution. To account for the feedback effect, the study has utilized the two-stage estimation method suggested by Pindyck (1979a, 1979b). Estimates of parameters and elasticities of fuel and factor substitution have been presented for a group of major developed countries and a group of energy-producer developing countries.

The empirical findings reported in this study show some interesting results. First, the dynamic two-stage translog model is consistent with the principles of cost-minimizing factor demand theory. To correspond to a well behaved production structure, the translog cost function must satisfy monotonocity and concavity conditions. Monotonicity is satisfied if the fitted cost shares are positive and this condition is met at every observation for the models estimated. Concavity was satisfied because own-price elasticities were negative for most of the countries in the aggregate model and for all the countries in the energy sub-model.

Second, in the inter-factor model, most of the input demands, with few exceptions, are price elastic. Moreover, substitutability is observed between capital and energy and labour and energy. These findings confirm previous evidence that production technologies in these countries allow flexibility in the capital-energy and labour-energy mix. Therefore, in response to energy price fluctuations, these countries could substitute labour and capital for energy, and therefore, to some extent, sustain their economic growth.

Third, in the inter-fuel model, own-price elasticities of demand for coal and natural gas tend to be higher than for electricity and petroleum product. In addition demands for these two fuels are very responsive to changes in their own price. This finding seems to suggest that, following growing concerns about global warming, the industrial sectors in these countries could reduce substantially their coal consumption in the long-run if, for example, coal was subjected to higher tax rates.

Fourth, the elasticities of substitution show that large substitution took place from petroleum to coal, natural gas and especially to electricity. This finding provides evidence that petroleum products can be substituted with coal, natural gas and electricity. In addition, the evidence for significant inter-fuel substitution between coal and natural gas may suggest that there have been changes in both the structure of production and the energy system, promoting the use of natural gas to shift away from high-carbon fuel technologies.

With regard to these empirical results, three conclusions seem evident. First, substantial inter-factor and inter-fuel substitutions are possible in the industrial sector of developed and developing countries. Next, the existence of moderate input substitution suggests that there is some flexibility in energy policy options and energy utilization. Finally, with gas considered a safer fuel alternative, there is the possibility of replacing the use of coal with natural gas in the industrial sector. This is important for future changes in energy use, given the recent improvements in the technology for production and use of gas (e.g. new gas turbines which increase the efficiency of gas).

Appendix 4.I

The System of Share Equations

With the additive errors appended, the system of share equations (4.21) to (4.24) can be written out in full as:

$$\left.\begin{aligned} S_K &= \alpha_K + \gamma_{KK} \ln P_K + \gamma_{KE} \ln P_E + \gamma_{KL} \ln P_L + \gamma_{Ky} \ln y + u_K, \\ S_E &= \alpha_E + \gamma_{EK} \ln P_K + \gamma_{EE} \ln P_E + \gamma_{EL} \ln P_L + \gamma_{Ey} \ln y + u_E, \\ S_L &= \alpha_L + \gamma_{LK} \ln P_K + \gamma_{LE} \ln P_E + \gamma_{LL} \ln P_L + \gamma_{Ly} \ln y + u_L. \end{aligned}\right\} \tag{4.I.1}$$

$$\left.\begin{aligned} S_p &= \beta_p + \beta_{pp} \ln p_p + \beta_{pe} \ln p_e + \beta_{pg} \ln p_g + \beta_{pc} \ln p_c + \varepsilon_p, \\ S_e &= \beta_e + \beta_{ep} \ln p_p + \beta_{ee} \ln p_e + \beta_{eg} \ln p_g + \beta_{ec} \ln p_c + \varepsilon_e, \\ S_g &= \beta_g + \beta_{gp} \ln p_p + \beta_{ge} \ln p_e + \beta_{gg} \ln p_g + \beta_{gc} \ln p_c + \varepsilon_g, \\ S_c &= \beta_c + \beta_{cp} \ln p_p + \beta_{ce} \ln p_e + \beta_{cg} \ln p_g + \beta_{cc} \ln p_c + \varepsilon_c. \end{aligned}\right\} \tag{4.I.2}$$

$$\left.\begin{aligned} S_K^{FACTOR} &= \alpha_K^* + \gamma_{KK}^* \ln P_K + \gamma_{KE}^* \ln P_E + \gamma_{KL}^* \ln P_L + \gamma_{Ky}^* \ln y + \theta_K S_{K-1} + u_K, \\ S_E^{FACTOR} &= \alpha_E^* + \gamma_{EK}^* \ln P_K + \gamma_{EE}^* \ln P_E + \gamma_{EL}^* \ln P_L + \gamma_{Ey}^* \ln y + \theta_E S_{E-1} + u_E, \\ S_L^{FACTOR} &= \alpha_L^* + \gamma_{LK}^* \ln P_K + \gamma_{LE}^* \ln P_E + \gamma_{LL}^* \ln P_L + \gamma_{Ly}^* \ln y + \theta_L S_{L-1} + u_L. \end{aligned}\right\} \tag{4.I.3}$$

$$\left.\begin{aligned} S_p^{FUEL} &= \beta_p^* + \beta_{pp}^* \ln p_p + \beta_{pe}^* \ln p_e + \beta_{pg}^* \ln p_g + \beta_{pc}^* \ln p_c + \theta_p S_{p-1} + \varepsilon_p, \\ S_e^{FUEL} &= \beta_e^* + \beta_{ep}^* \ln p_p + \beta_{ee}^* \ln p_e + \beta_{eg}^* \ln p_g + \beta_{ec}^* \ln p_c + \theta_e S_{e-1} + \varepsilon_e, \\ S_g^{FUEL} &= \beta_g^* + \beta_{gp}^* \ln p_p + \beta_{ge}^* \ln p_e + \beta_{gg}^* \ln p_g + \beta_{gc}^* \ln p_c + \theta_g S_{g-1} + \varepsilon_g, \\ S_c^{FUEL} &= \beta_c^* + \beta_{cp}^* \ln p_p + \beta_{ce}^* \ln p_e + \beta_{cg}^* \ln p_g + \beta_{cc}^* \ln p_c + \theta_c S_{c-1} + \varepsilon_c. \end{aligned}\right\} \tag{4.I.4}$$

Appendix 4.II

Technical Details on the Statistical Estimation

4.II.1: The estimation of the sub-energy model (inter-fuel)

In the first stage of the estimation (inter-fuel model), the unrestricted system of four input cost shares equations can be written as:

$$\begin{aligned}
S_p &= \beta_p + \beta_{pp}\ln p_p + \beta_{pe}\ln p_e + \beta_{pg}\ln p_g + \beta_{pc}\ln p_c \\
S_e &= \beta_e + \beta_{ep}\ln p_p + \beta_{ee}\ln p_e + \beta_{eg}\ln p_g + \beta_{ec}\ln p_c \\
S_g &= \beta_g + \beta_{gp}\ln p_p + \beta_{ge}\ln p_e + \beta_{gg}\ln p_g + \beta_{gc}\ln p_c \\
S_c &= \beta_c + \beta_{cp}\ln p_p + \beta_{ce}\ln p_e + \beta_{cg}\ln p_g + \beta_{cc}\ln p_c
\end{aligned} \qquad (4.II.1)$$

where β's are parameter to be estimated. Since the cost shares sum to unity at each observation, the parameter estimates must satisfy the following relations:

$$\begin{aligned}
&\beta_p + \beta_e + \beta_g + \beta_c = 1, \\
&\beta_{pp} + \beta_{ep} + \beta_{gp} + \beta_{cp} = 0, \\
&\beta_{pe} + \beta_{ee} + \beta_{ge} + \beta_{ce} = 0, \\
&\beta_{pg} + \beta_{eg} + \beta_{gg} + \beta_{cg} = 0, \\
&\beta_{pc} + \beta_{ec} + \beta_{gc} + \beta_{cc} = 0.
\end{aligned} \qquad (4.II.2)$$

Of the twenty estimated parameters, only fifteen are free. The free parameters can be estimated by arbitrarily dropping one equation. The choice of the equation to be dropped does not affect the results. The parameter estimates from the dropped equation can be derived from the parameter estimates of the other three equations. However, equations (4.II.1) can be considered a well defined production function if and only if their partial derivatives are symmetric in the inputs, i.e if β_{pe} in S_p is equal to β_{ep} in S_e, etc. Hence, when the six cross equation symmetry conditions are imposed ($\beta_{pe} = \beta_{ep}, \beta_{pg} = \beta_{gp}, \beta_{pc} = \beta_{cp}, \beta_{eg} = \beta_{ge}, \beta_{ec} = \beta_{ce}, \beta_{gc} = \beta_{cg}$), the number of parameters drops to 14. Thus, equations (4.II.2) can be written as:

$$\beta_p + \beta_e + \beta_g + \beta_c = 1$$

$$\sum_{i=1}^{n} \beta_{ij} = 0 \text{ (column sums equal zero)}$$

$$\sum_{j=1}^{n} \beta_{ij} = 0 \text{ (row sums equal zero)} \tag{4.II.3}$$

The stochastic version of the model, which provides the basis for estimation, introduces a random disturbance term ε_i to each share equation, $i = c, e, g, p$. Since the sum of shares equal one, the sum of the disturbances across equations must always equal zero. This implies that the disturbance covariance matrix is singular and non-diagonal. To solve the problem of singularity of the disturbance covariance matrix of the share equations, the common procedure is to drop an arbitrary equation. In this work, the coal equation was deleted. After imposing the symmetry restrictions and dropping the coal equation the resulting system to be estimated is:

$$\begin{aligned} S_p &= \beta_p + \beta_{pp} \ln(p_p/p_c) + \beta_{pe} \ln(p_e/p_c) + \beta_{pg} \ln(p_g/p_c) + \varepsilon_p, \\ S_e &= \beta_e + \beta_{pe} \ln(p_p/p_c) + \beta_{ee} \ln(p_e/p_c) + \beta_{eg} \ln(p_g/p_c) + \varepsilon_e, \\ S_g &= \beta_g + \beta_{pg} \ln(p_p/p_c) + \beta_{eg} \ln(p_e/p_c) + \beta_{gg} \ln(p_g/p_c) + \varepsilon_g. \end{aligned} \tag{4.II.4}$$

The parameters in the deleted equations can be calculated in accordance with the adding-up and symmetry restrictions. In other words, indirect estimates of the four other parameters in the omitted coal share equation may then be estimated in terms of the directly estimated parameters as follows:

$$\begin{aligned}
\beta_c &= 1 - \beta_p - \beta_e - \beta_g, \\
\beta_{pc} &= -\beta_{pp} - \beta_{pe} - \beta_{pg}, \\
\beta_{ec} &= -\beta_{pe} - \beta_{ee} - \beta_{eg}, \\
\beta_{cg} &= -\beta_{pg} - \beta_{eg} - \beta_{gg}, \\
\beta_{cc} &= -\beta_{pc} - \beta_{ec} - \beta_{cg}.
\end{aligned} \qquad (4.II.5)$$

Since these indirectly estimated parameters are linear combinations of the directly estimated coefficients, variances of the indirectly estimated parameters can be calculated as a linear combination of the directly estimated variances and covariances.

The parameter estimates of the coal equation may also be obtained by eliminating another equation while keeping the coal equation. In testing the translog estimation system the author considered it prudent to estimate, one by one, all the possible share equation combinations, and thereby ascertain that the system is invariant to the equation omitted. The parameter estimates were found to be invariant to the choice of equation that was dropped.

With regards to the dynamic model, the corresponding system of three input cost shares equations can be written as:

$$S_p^{FUEL} = \beta_p^* + \beta_{pp}^* \ln(p_p/p_c) + \beta_{pe}^* \ln(p_e/p_c) + \beta_{pg}^* \ln(p_g/p_c) + \theta S_{p-1} + \varepsilon_p,$$
$$S_e^{FUEL} = \beta_e^* + \beta_{pe}^* \ln(p_p/p_c) + \beta_{ee}^* \ln(p_e/p_c) + \beta_{eg}^* \ln(p_g/p_c) + \theta S_{e-1} + \varepsilon_e, \qquad (4.II.6)$$
$$S_g^{FUEL} = \beta_g^* + \beta_{pg}^* \ln(p_p/p_c) + \beta_{eg}^* \ln(p_e/p_c) + \beta_{gg}^* \ln(p_g/p_c) + \theta S_{g-1} + \varepsilon_g.$$

and the parameters in the deleted equations can be calculated with the adding-up and symmetry restrictions as follows:

$$\begin{aligned} \beta_c &= 1 - \beta_p - \beta_e - \beta_g - \theta, \\ \beta_{pc} &= -\beta_{pp} - \beta_{pe} - \beta_{pg}, \\ \beta_{ec} &= -\beta_{pe} - \beta_{ee} - \beta_{eg}, \\ \beta_{cg} &= -\beta_{pg} - \beta_{eg} - \beta_{gg}, \\ \beta_{cc} &= -\beta_{pc} - \beta_{ec} - \beta_{cg}, \\ \theta_c &= \theta_p = \theta_e = \theta_g = \theta \end{aligned} \qquad (4.II.7)$$

Note that the coefficient of the lagged share (theta) needs to be the same in each equation because of adding-up restrictions.

4.I.2: The estimation of the aggregate-energy model (interfactor)

The estimated parameters from the sub-energy model are used to estimate the aggregate price index for energy. Thus, an aggregate price index is obtained which serves as an instrumental variable for the price of energy in the estimation of the system of the shares of total cost. The remaining procedure is the same as that applied in the first stage.

Symmetry and Homogeneity Tests

Table A.4.III.1: Symmetry and Homogeneity Tests for Inter-factor Model

	Homogeneity		Symmetry		Homogeneity and Symmetry	
Country	Static	Dynamic	Static	Dynamic	Static	Dynamic
US	0.9410	11.5639	10.1833	2.4147	11.5655	13.9345
	(0.9186)	(0.0209)	(0.0171)	(0.4909)	(0.1158)	(0.0524)
JA	4.1275	1.8713	26.5401*	17.6542*	34.4702*	18.8315
	(0.3890)	(0.7594)	(0.0000)	(0.0005)	(0.0000)	(0.0087)
GE	5.9788	6.0330	22.8699*	45.4072*	30.3517*	50.1386*
	(0.2007)	(0.1967)	(0.0000)	(0.0000)	(0.0001)	(0.0000)
FR	0.0000	0.0000	7.8453	12.7494	15.2517	23.2235
	(1.0000)	(1.0000)	(0.0493)	(0.0052)	(0.0329)	(0.0216)
CA	3.4950	14.4325	10.3357	9.1095	16.4297	23.6462
	(0.4786)	(0.0060)	(0.0159)	(0.0279)	(0.0215)	(0.0113)
BR	5.3120	0.8300	68.8185*	4.5352	77.4958*	5.2079
	(0.2568)	(0.9344)	(0.0000)	(0.2092)	(0.0000)	(0.6346)
CH	1.1876	4.5953*	26.0405*	28.1276*	26.2131*	31.7008*
	(0.8801)	(0.0000)	(0.0000)	(0.0000)	(0.0005)	(0.0000)
IN	2.5016	0.6451	7.4210	4.3899	10.8155	5.0488
	(0.6443)	(0.3314)	(0.0596)	(0.2223)	(0.1469)	(0.6540)
ID	1.1515	4.7959	42.7522*	114.0998*	45.8612*	117.6682*
	(0.8860)	(0.3089)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
VE	0.0000	0.0000	65.2964*	18.9609*	76.1920*	28.2399*
	(1.0000)	(1.0000)	(0.0000)	(0.0003)	(0.0000)	(0.0002)

Notes: The figures in parentheses are p-value. * indicates significance at 1% significance level.

Table A.4.III.2: Symmetry and Homogeneity Tests for Inter-fuel Model

	Homogeneity		Symmetry		Homogeneity and Symmetry	
Country	Static	Dynamic	Static	Dynamic	Static	Dynamic
US	0.0000	0.0000	168.1964*	74.7635*	370.3589*	86.6258*
	(1.0000)	(1.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
JA	0.0000	0.0000	41.1413*	40.1651*	94.5296*	68.6129*
	(1.0000)	(1.0000)	(0.0000)	(0.0000	(0.0000)	(0.0000)
GE	0.0000	0.0000	24.3899*	17.3796	32.7211*	18.2967
	(1.0000)	(1.0000)	(0.0001)	(0.0016)	(0.0001)	(0.0191)
FR	0.0000	0.0000	5.0134	8.8134	13.3877	8.9359
	(1.0000)	(1.0000)	(0.2859)	(0.0659)	(0.0992)	(0.3477)
CA	0.0000	0.0000	39.3529*	45.3983*	105.3277*	58.1264*
	(1.0000)	(1.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
BR	0.0000	0.0000	0.1940	3.1504	1.4383	3.9124
	(1.0000)	(1.0000)	(0.9956)	(0.5330)	(0.9937)	(0.8649)
CH	0.0000	0.0000	38.0210*	5.4225	73.0246*	39.1770
	(1.0000)	(1.0000)	(0.0000)	(0.2466)	(0.0000)	(0.0000)
IN	0.0000	0.0000	20.6849*	5.6954	30.4404*	6.0146
	(1.0000)	(1.0000)	(0.0004)	(0.2231)	(0.0002)	(0.6456)
ID	0.0000	0.0000	12.2608	13.0707	32.8520*	27.4895*
	(1.0000)	(1.0000)	(0.0155)	(0.0109)	(0.0001)	(0.0006)
VE	0.0000	0.0000	16.1997	3.7655	17.6271	3.9049
	(1.0000)	(1.0000)	(0.0028)	(0.4387)	(0.0242)	(0.8656)

Notes: The figures in parentheses are p-value. * indicates significance at 1% significance level.

Parameter Estimates of the Dynamic Translog Factor and Fuel Cost-Share in Industrial Sector

Table A.4.IV.1: Parameter Estimates of the Dynamic Translog Factor Cost-Share Model in Industrial Sector

	US	JA	GE	FR	CA	BR	CH	IN	ID	VE
$\hat{\alpha}_K$	-1.9128*	-7.8484***	-2.3148***	-1.8758	-2.0260***	-2.1566***	0.6689***	-2.9779***	-2.7023**	-1.9004*
	(-1.7132)	(-6.8093)	(-9.3414)	(-1.5958)	(-3.2391)	(-3.1728)	(2.9825)	(-4.2672)	(-2.4180)	(-1.9448)
$\hat{\gamma}_{KK}$	0.0834***	0.1218***	0.1677***	0.1378***	0.0911***	0.1038***	0.0459***	0.1366***	0.1508**	0.0688*
	(12.9976)	(15.7203)	(18.1880)	(3.1961)	(8.2570)	(4.8612)	(5.9861)	(6.8858)	(2.5312)	(1.6480)
$\hat{\gamma}_{KE}$	-0.0777***	-0.0546	-0.1068***	-0.1317***	-0.0779	-0.0604	-0.0174**	0.0021	-0.1296***	-0.0655
	(-13.5668)	(-1.6044)	(-14.0518)	(-4.6070)	(-1.4487)	(-0.8578)	(-2.4770)	(0.0316)	(-7.7326)	(-1.6001)
$\hat{\gamma}_{KL}$	-0.0058***	-0.0673*	-0.0609***	-0.0062	-0.0133	-0.0434**	-0.0285***	-0.1387***	-0.0213	-0.0033
	(-2.7606)	(-1.7497)	(-7.9519)	(-0.2282)	(-0.2781)	(-2.2208)	(-3.4273)	(-21.3521)	(-0.3244)	(-0.1929)
$\hat{\gamma}_{Ky}$	0.0792*	0.3466***	0.1119***	0.0785	0.0922***	0.1093**	-0.0245***	0.1870***	0.1346**	0.0959*
	(1.7102)	(6.6802)	(9.9435)	(1.4637)	(3.1420)	(2.5683)	(-2.2879)	(7.0834)	(2.1666)	(1.8180)
$\hat{\alpha}_E$	2.4152**	7.1252***	2.9548***	1.6378*	2.6251***	0.8635***	-0.0352	0.0431***	3.0964***	1.8532*
	(2.4476)	(8.0762)	(12.0229)	(1.6448)	(4.6289)	(6.4426)	(-0.1184)	(2.9603)	(2.7019)	(1.8355)
$\hat{\gamma}_{EE}$	-0.0497	0.2162***	-0.0659***	-0.0363	0.1015*	-0.0035	0.0190	-0.0003	0.1377***	0.0195
	(-1.1783)	(7.5399)	(-5.8246)	(-0.8413)	(1.9671)	(-0.3093)	(1.2972)	(-0.1744)	(8.2444)	(0.3841)
$\hat{\gamma}_{EL}$	0.1273***	-0.1616***	0.1727***	0.1679***	-0.0236	0.0639**	-0.0016	-0.0018	-0.0081	0.0460**
	(2.6967)	(-5.2144)	(8.7275)	(3.6979)	(-0.5155)	(2.2444)	(-0.0740)	(-0.0653)	(-0.1231)	(2.2417)
$\hat{\gamma}_{Ey}$	0.1783***	-0.2470***	0.1169***	0.4225***	-0.0878***	-0.0404***	0.7029***	-0.0026***	-0.1139*	-0.0678
	(2.8857)	(-6.3044)	(2.7979)	(5.1927)	(-3.1357)	(-5.5139)	(6.0591)	(-6.1044)	(-1.8108)	(-1.2662)
$\hat{\alpha}_L$	0.4976	1.7232***	0.3600**	1.2380*	0.4009***	2.2931***	0.3662	3.9348***	0.6058***	1.0473
	(1.4179)	(3.0679)	(1.9870)	(2.0970)	(2.8367)	(7.1415)	(0.9431)	(16.9408)	(3.0197)	(0.7777)
$\hat{\gamma}_{LL}$	-0.1216**	0.2289***	-0.1118***	-0.1617***	0.0369	-0.0206	0.0301	0.1405***	0.0294	-0.0427
	(-2.5722)	(4.6348)	(-5.2682)	(-3.0606)	(0.5576)	(-0.5953)	(1.2986)	(4.8648)	(0.3161)	(-1.5921)
$\hat{\gamma}_{Ly}$	-0.2575	-0.0996	-0.2289	-0.5010	-0.0044	-0.0690	-0.6783*	-0.1844	-0.0207	-0.0281
	(-0.7145)	(-0.1741)	(-1.2350)	(-0.8360)	(-0.0220)	(-0.2100)	(-1.7364)	(-0.7751)	(-0.0736)	(-0.0209)
θ	0.1962***	0.2109***	0.1008**	0.5030***	0.3991***	0.5148***	-0.0853	0.5336***	0.2774***	0.5736***
	(3.0979)	(5.3621)	(2.1813)	(5.9471)	(4.5207)	(6.8694)	(-0.7245)	(10.7478)	(4.0022)	(6.1582)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Table A.4.IV.2: Parameter Estimates of the Dynamic Translog Fuel Cost-Share Model in Industrial Sector

	US	JA	GE	FR	CA	BR	CH	IN	ID	VE
$\hat{\beta}_p$	0.1650***	0.0912***	0.0785***	0.0217	0.1576***	0.1196***	-0.0160	0.2308***	-0.1105***	0.1669***
	(5.5259)	(2.9578)	(3.8728)	(0.7628)	(8.1233)	(2.6710)	(-0.8329)	(8.4541)	(-5.3859)	(3.8227)
$\hat{\beta}_{pp}$	-0.0915**	-0.1238***	-0.0932***	-0.0535	-0.1296***	-0.1508***	-0.0533***	-0.1830***	-0.0979***	0.0200
	(-2.5135)	(-3.9618)	(-5.4238)	(-1.0285)	(-5.4415)	(-3.7386)	(-2.8248)	(-7.3130)	(-8.5493)	(1.3002)
$\hat{\beta}_{pe}$	0.1613***	0.0942***	0.1315***	0.0644**	0.1765***	0.1505***	0.2549***	0.2093***	0.1564***	0.0730***
	(5.9447)	(3.6730)	(8.2292)	(2.0902)	(8.0051)	(3.1553)	(12.0382)	(8.2149)	(9.4854)	(6.0038)
$\hat{\beta}_{pg}$	-0.0435***	0.0243***	-0.0246**	-0.0240	-0.0336**	0.0044	-0.0056***	-0.0105**	-0.0355***	-0.0825***
	(-3.8926)	(2.8681)	(-2.4523)	(-0.6680)	(-2.5211)	(0.5020)	(-5.6429)	(-2.5492)	(-4.9088)	(-6.0753)
$\hat{\beta}_{pc}$	-0.0263***	0.0054	-0.0137	0.0131	-0.0134***	-0.0040	-0.1960***	-0.0158*	-0.0229***	-0.0105
	(-5.2762)	(0.8360)	(-1.5130)	(1.3375)	(-3.8382)	(-1.0721)	(-15.9320)	(-1.8126)	(-5.8971)	(-0.7802)
$\hat{\beta}_e$	0.1772***	0.2228***	0.1240***	0.0208	0.1462***	0.1919***	0.1938***	0.2547***	0.2306***	0.2081***
	(6.9022)	(4.4947)	(4.7931)	(0.7014)	(7.3765)	(3.0555)	(10.4396)	(7.0627)	(3.4551)	(5.3860)
$\hat{\beta}_{ee}$	-0.0423**	-0.0907***	-0.0641***	-0.0260	-0.1124***	-0.1010*	-0.1746***	-0.1218***	-0.0840***	-0.0688***
	(-1.9646)	(-3.6139)	(-4.1218)	(-0.8862)	(-5.1330)	(-1.6952)	(-7.0816)	(-5.0472)	(-2.9790)	(-4.4419)
$\hat{\beta}_{eg}$	-0.1110***	0.0000	-0.0361***	-0.0232	-0.0499***	-0.0241*	-0.0076***	-0.0073*	-0.0615***	-0.0004
	(-11.7698)	(0.0071)	(-5.2105)	(-1.6451)	(-5.1299)	(-1.6852)	(-7.5920)	(-1.7123)	(-4.1597)	(-0.0274)
$\hat{\beta}_{ec}$	-0.0080	-0.0035	-0.0313***	-0.0152*	-0.0142***	-0.0254***	-0.0727***	-0.0802***	-0.0109	-0.0038
	(-1.3916)	(-1.1719)	(-3.1771)	(-1.9532)	(-5.4312)	(-4.6759)	(-10.0965)	(-10.3468)	(-1.0607)	(-0.3056)
$\hat{\beta}_g$	0.3280***	-0.0162***	0.1160***	0.0587**	0.1950***	0.0548***	0.0407***	0.0597***	0.2332***	0.1596***
	(16.6749)	(-2.5790)	(7.6870)	(2.5693)	(10.7692)	(3.4967)	(23.8562)	(8.1627)	(6.8468)	(3.4359)
$\hat{\beta}_{gg}$	0.1527***	-0.0028	0.0762***	0.0588*	0.0826***	0.0087	0.0171***	0.0151***	0.0807***	0.1089***
	(11.8745)	(-0.3507)	(5.9434)	(1.9713)	(6.8009)	(1.3515)	(21.1929)	(7.5269)	(5.6887)	(4.9416)
$\hat{\beta}_{gc}$	0.0018	-0.0214***	-0.0155**	-0.0116	0.0009	0.0110	-0.0040***	0.0027	0.0163**	-0.0260
	(0.4430)	(-5.0137)	(-2.4433)	(-1.2587)	(0.3766)	(4.1603)	(-10.2715)	(1.4016)	(2.3629)	(-1.4195)
$\hat{\beta}_c$	0.3299***	0.7022***	0.6814***	0.8988***	0.5012***	0.6338***	0.7815***	0.4549***	0.6467***	0.4654***
	(7.4606)	(12.0451)	(15.8648)	(17.4496)	(12.5866)	(12.7855)	(42.7382)	(11.9535)	(12.0915)	(9.7256)
$\hat{\beta}_{cc}$	0.0325***	0.0196	0.0605**	0.0136	0.0267***	0.0185	0.2726***	0.0934***	0.0175	0.0404
	(2.1846)	(1.3612)	(2.3597)	(0.5074)	(3.0976)	(1.4991)	(11.0396)	(4.5526)	(0.7783)	(0.8975)
θ	0.2637***	0.6533***	0.5719***	0.8793***	0.4520***	0.5688***	0.0426	0.1039*	0.5826***	0.4619***
	(5.1430)	(10.1280)	(11.5567)	(21.9270)	(9.5029)	(10.1947)	1.1162	(1.6644)	(13.1606)	(7.4472)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Adjusted R-Square, Durbin h-statistics and Jarque-Bera Statistics

Table A.4.V.1: Adjusted R-Square, Durbin h-statistics and Jarque-Bera statistics of the Dynamic Translog Factor Cost-Share Model

Countries	US	JA	GE	FR	CA	BR	CH	IN	ID	VE
Adjusted R square										
S_K	0.9369	0.9725	0.9755	0.7125	0.8807	0.9406	0.9408	0.9751	0.9142	0.4860
S_E	0.9388	0.9877	0.9861	0.7616	0.8844	0.9381	0.8330	0.9098	0.9282	0.7740
Durbin h-statistic										
S_K	-2.3297	-2.3854	-1.6763	-1.3147	-2.0456	-4.9628	-2.6120	-4.6286	-5.1104	-2.0929
S_E	-2.7534	-3.5729	-1.8420	-1.2486	-2.3937	-3.0448	-2.9381	-4.7486	-5.1264	-3.9516
Jarque-Bera (χ^2)										
S_K	0.0227	2.2444	2.0685	0.0087	1.3036	2.7655	2.1010	2.6567	3.0551	1.9739
	(0.9887)	(0.3256)	(0.3555)	(0.9956)	(0.5211)	(0.2509)	(0.3498)	(0.2649)	(0.2171)	(0.3727)
S_E	0.2741	2.3873	2.5183	2.0019	1.2485	2.2520	2.1087	1.9741	4.4587	0.0780
	(0.8719)	(0.3031)	(0.2839)	(0.3675)	(0.5357)	(0.3243)	(0.3484)	(0.3727)	(0.1076)	(0.9617)
S_L	1.5543	0.7911	2.0612	2.2394	0.4246	1.9925	2.7497	2.7383	0.7071	2.1751
	(0.4597)	(0.6733)	(0.3568)	(0.3264)	(0.8087)	(0.3693)	(0.2529)	(0.2543)	(0.7022)	(0.3370)

Notes: 1) The figures in parentheses are p-values. 2) When lagged values of the dependent variable are used as an explanatory variable, the Durbin-Watson test is no longer appropriate. An alternative approach is the Durbin's h. The null hypothesis = H_0: Autocorrelation exists in the first lag of the residuals. Reject H_0 if h (the test statistic)>1.96 or h<-1.96 (0.05 level of significance).

Table A.4.V.2: Adjusted R-Square, Durbin h-statistics and Jarque-Bera statistics of the Dynamic Translog Fuel Cost-Share Model

Countries	US	JA	GE	FR	CA	BR	CH	IN	ID	VE
Adjusted R square										
S_p	0.6013	0.8693	0.9115	0.8559	0.9281	0.7853	0.9058	0.8064	0.9826	0.8597
S_e	0.5594	0.8649	0.9159	0.8714	0.8367	0.7629	0.9716	0.7324	0.9569	0.6650
S_g	0.8832	0.8763	0.8410	0.8596	0.8539	0.6655	0.7577	0.8907	0.6159	0.9512
Durbin h-statistic										
S_p	0.4039	-4.3587	-2.4209	-3.0274	-1.6742	-1.9270	-3.0003	0.2755	-3.4968	-4.0948
S_e	0.2218	-4.8693	-2.3834	-3.8385	-1.9841	-1.4468	-1.9549	0.2831	-1.5770	-3.1153
S_g	-2.5183	-2.4361	-1.5924	-2.4190	-2.7669	-0.7719	-2.9528	-2.7059	-1.2668	-2.3085
Jarque-Bera (χ^2)										
S_p	1.5467	2.8847	3.3729	2.3011	1.7980	1.9216	2.5782	1.1739	3.2060	2.6298
	(0.4615)	(0.2364)	(0.1852)	(0.3165)	(0.4070)	(0.3826)	(0.2755)	(0.5560)	(0.2013)	(0.2685)
S_e	2.2505	3.4946	1.5525	3.1960	6.4128	3.1043	4.9404	1.1191	2.2180	1.1233
	(0.3246)	(0.1742)	(0.4601)	(0.2023)	(0.0405)	(0.2118)	(0.0846)	(0.5715)	(0.3299)	(0.5703)
S_g	0.7307	7.2103	1.6083	1.2858	2.8243	2.0808	1.9008	1.4667	2.1771	5.1946
	(0.6939)	(0.0272)	(0.4475)	(0.5258)	(0.2436)	(0.3533)	(0.3866)	(0.4803)	(0.3367)	(0.0745)
S_c	1.5260	2.1000	3.2989	1.1609	4.6929	0.0385	3.2614	2.5562	3.8929	174.7300
	(0.4663)	(0.3499)	(0.1922)	(0.5597)	(0.0957)	(0.9810)	(0.1958)	(0.2786)	(0.1428)	(0.0000)

Notes: The figures in parentheses are p-values. 2) When lagged values of the dependent variable are used as an explanatory variable, the Durbin-Watson test is no longer appropriate. An alternative approach is the Durbin's h. The null hypothesis = H_0: Autocorrelation exists in the first lag of the residuals. Reject H_0 if h (the test statistic)>1.96 or h<-1.96 (0.05 level of significance).

CHAPTER FIVE

ENERGY CONSUMPTION AND ECONOMIC GROWTH: THE CASE OF 23 DEVELOPED COUNTRIES AND 16 DEVELOPING COUNTRIES

5.1 Introduction

Ever since the seminal works by Kraft and Kraft (1978), the relationship between energy consumption and economic growth has remained an important issue in the literature of energy economics. Numerous studies have been conducted to examine this relationship and the overall findings show that there is a strong relationship between energy consumption and economic growth.[44] In spite of this, the existence of this relationship does not necessary imply a causal relationship. Furthermore, even if there was a causal relationship, the causality could run in either direction. For example, the relationship may run from economic growth to energy consumption or from energy consumption to economic growth, or it could run in both directions (i.e. bi-directional causality). In this respect published empirical evidence is ambiguous and finds different results for different countries as well as for different time periods within the same country.[45]

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[44] Ferguson *et al.* (2000) show that there is strong correlation between increases in wealth over time and increases in energy consumption in the case of developed countries. IEA (2002) also provides evidence that energy, in particular electricity consumption is strongly correlated with wealth and lack of electricity is strongly correlated with the number of people living below $2 per day.

[45] For example, in the case of industrialised countries, causality was found to be running from energy use to income by Erol and Yu (1987) for Japan; Stern (1993, 2000) for the United States; Soytas and Sari (2003) for France, Germany and Japan. This was also found in developing countries by Masih and Masih (1996) for India; Asafu-Adjaye (2000) for Indonesia; Soytas and Sari (2003) for Turkey; Wolde-Rufael (2004) for Shanghai; Shiu and Lam (2004) and Zhou and Chau (2006) for China and Lee (2005) for 18 developing countries. Causality was also found to be running from income to energy use. These include Masih and Masih (1996) for Indonesia and Pakistan; Cheng and Lai (1997) for Taiwan; Ghosh (2002) for India; Fatai *et al.* (2004) and Narayan and Symth (2005) for Australia, Wolde-Rufael (2005) for 5 African countries; Lee (2006) for France, Italy and Japan; Yoo (2006) for Indonesia and Mehrara (2007) for Venezuela. There are also cases where causality between energy use and income was found to be running in both directions. These are in Taiwan (Yang, 2000 and Chang *et*

There are fundamental reasons why it is crucially important to identify the causal directions between energy consumption and economic growth. As reported by IEA (2002), energy sources are necessary requirements for economic and social development.[46] In general, this implies that energy is important to determine economic growth. However, the growing concerns over energy scarcity and more importantly, the concerns over energy's environmental costs, call for the implementation of energy conservation processes. [47] As a consequence the shortage of energy may negatively affect economic growth or may cause poor economic performance.[48] Therefore the knowledge of the causal directions between energy consumption and economic growth is of prime importance if appropriate energy policies and energy conservation measures are to be advised.

In this chapter, the existence and the direction of the causality patterns in 23 developed countries and 16 developing countries are examined using the multivariate approach. The framework for the analysis is the economic interaction between the supply side of the economy, with an associated production function, and energy

al., 2001); in Korea (Glassure, 2002), in Thailand and the Phillipines (Asafu-Adjaye, 2000), in Greece (Hondroyianais *et al.*, 2002); in Argentina (Soytas and Sari, 2003); in Canada (Ghali and El-Sakka, 2004); India (Paul and Bhattacharya, 2004); in Gabon and Zambia (Wolde-Rufael, 2005) and in the US (Lee, 2006). Finally, there are cases where no causality was found in Malaysia, Singapore and Phillipines (Masih and Masih, 1996); in Mexico and Venezuela (Cheng, 1997); in Indonesia and India (Asafu-Adjaye, 2000); in the case of 11 African countries (Wolde-Rufael, 2006) and in the UK, Germany and Sweden (Lee, 2006).

[46] Rosernberg (1998) show that the experience of developed countries confirms that energy played a crucial role in their economic growth as a key input in the industrial development and as a factor in improving the quality of life of their people.

[47] Ebohon (1996) noted that Tanzania and Nigeria have a problem of energy shortage. The problem of foreign supply dependence has been highlighted by Al-Iriani (2006) in the six countries of the Gulf Cooperation Council (GCC). Energy conservation policy that responds to the effect of energy crises and the high levels of energy prices has been empirically studied by Hondroyiannis *et al.* (2002) in the case of Greece; Lee (2006) in G-11 countries and Mahadevan and Asafu-Adjaye (2007) for 20 net energy importers and exporters.

[48] The causality from energy consumption to GDP implies that an economy is energy dependent (Jumbe, 2004). Hence energy is a stimulus to growth implying that a shortage of energy may affect economic growth, leading to a fall in income. On the other hand, if causality runs from GDP to energy consumption, an economy is not energy dependent and energy conservation policy may be implemented with no adverse effect on economic growth (Masih and Masih, 1997).

demand. On the supply side, energy, labour and capital are considered to be important factors for generating GDP (as discussed in Chapter 4). On the demand side, GDP, energy price and level of industrialisation are the determinants for energy consumption (as discussed in Chapter 3). The Vector Error Correction Model (VECM) approach used in this chapter allows all these variables to be endogenous, thereby allowing for additional channels of causality.[49] For example, it allows for both energy and GDP to have a causal relationship with a third endogenous variable, without restricting the direction of this relationship. This would explain the correlation between GDP and energy without implying that there is a causal relationship between the two. Another advantage of the approach taken in this chapter is that it models both the supply and the demand sides of the economy, allowing therefore for two cointegrating relationships.

Section 5.2 presents the model specification, which accounts for the dual role of energy in the demand and supply. It also explains the methodology applied in this study. Panel unit root tests (Levine et al., 2002; Im et al., 2003 and Hadri, 2000) and a panel cointegration test (Larsson et al., 2001) were used due to the short time spans of individual data sets.[50] Next, it is explained how the VECM was employed to examine the direction of causality between energy and economic growth.

Section 5.3 explains the data used in the study and section 5.4 presents the empirical evidence. Consistent with most of the previous findings, the results show that there exists a long-run relationship between energy consumption and economic growth.

[49] Related works that have considered the multivariate approach were Masih and Masih (1997, 1998), Asafu-Adjaye (2000), Chang (2001), Glasure (2002), Hondroyiannis *et al.* (2002) and Ghali and El-Sakka (2004), all of whom allow all variables to be endogenous.

[50] The use of panel data techniques in relation to unit roots and cointegration could eliminate problems associated with the low power of the traditional unit root and cointegration tests (Al-Iriani, 2006).

Moreover, this study also shows that the direction of causality between these two variables varies across countries. Section 5.5 then concludes.

5.2 Methodology

5.2.1 Model Specification

The model specification to examine the link between energy consumption and economic growth is based on a multivariate framework, which accounts for the important dual role of energy in both the demand and supply side. On the demand side, the model is based on the importance of energy for consumer's utility maximization, where the relationship can be specified as.[51]

$$E = f(Y, P, I) \tag{5.1}$$

On the supply side, the model is based on the importance of energy use as a key factor of production.[52] Following Oh and Lee (2003) and Ghali and El-Sakka (2004) the relationship can be written as

$$Y = f(K, L, E) \tag{5.2}$$

In (5.1), E represents energy consumption, and Y, P and I represent aggregate output or real income, energy price and the structure of economy (which is proxied by the

[51] For example, as set out by Bentzen and Engsted (1993), Chan and Lee (1996), Masih and Masih (1997, 1998) and Hondroyiannis *et al.* (2002).

[52] Stern (1993, 2000) and Stern and Cleveland (2004) suggested that energy is a key factor of the production process.

share of industry in GDP), respectively. Aggregate output in turn is produced through the application of capital (K), labour (L) and energy use (E) in (5.2).

5.2.2 Econometric Methodology

Following established procedures, the test of the causal relationship between energy consumption and economic growth is conducted in three stages. First, a test is carried out to ascertain the order of integration in all variables (i.e. energy consumption, income, the price of energy, level of industrialisation, capital and labour). Since the time span of the individual series is relatively short, recently developed panel unit root techniques will be utilised in order to increase the power of such tests. Next, having established the order of integration in the series, the panel cointegration tests are carried out to investigate the existence of long-run relationships between the variables. Finally, the VECM is estimated separately for each country to assess the direction of causality between energy consumption and economic growth.

Recent developments in the literature suggest that unit root and cointegration tests based on panel data are more powerful than based on individual time series data (see Banerjee, 1999 or Baltagi and Kao, 2000 amongst others). Further, as pointed by Nagayasu (1998), pooling the data helps to draw a general conclusion that applies to a broad group of countries. Moreover, in the case of cointegration, Pedroni (1999) explains that panel data tests not only allow the dynamics and fixed effects to differ across members of the panels, but also allow the cointegrating vector to differ across members under the alternative hypothesis.

5.2.2.1 Panel Unit Root Tests

Levin and Lin (1993, 2002) (LLC) tests

LLC test is a panel version of the Augmented Dickey Fuller test, and is based on analysis of the equation:

$$\Delta y_{it} = \alpha_i + \theta_t + \delta_{it} + \rho_i y_{i,t-1} + \varepsilon_{it} \qquad i = 1,\ldots, N \qquad t = 1,\ldots, T \qquad (5.3)$$

where i represents a country and t a period of time. This model allows for two-way fixed effects (α and θ) and unit-specific time trends. The unit-specific fixed effects are an important source of heterogeneity, since the coefficient of the lagged dependent variable is restricted to be homogeneous across all units of the panel. The test involves the null hypothesis of $H_0 : \rho_i = 0$ for all i against the alternative of $H_A : \rho_i = \rho < 0$ for all i. Therefore, this test restricts parameters ρ_i to be identical across cross-sectional units, that is $\rho_i = \rho$ for all i. However, this assumption is clearly restrictive and thus the test might be subject to heterogeneity bias.

Im et al. (2003) (IPS) tests

IPS test extends the LLC test to allow for heterogeneity in the value of ρ_i under the alternative hypothesis. This test is based on the average of ADF statistics computed for each group in the panel. Given the same equation as in (5.3), the null and alternative hypotheses are defined as $H_0 : \rho_i = 0$ for all i against the alternative of $H_A : \rho_i < 0$ for at least one i. Thus, under the null hypothesis, all series in the panel are nonstationary processes, whereas under the alternative, a fraction of the series in the panel is assumed to be stationary. Note that this is in contrast to the LLC test, which presumes that all series are stationary under the alternative hypothesis. The errors ε_{it} are allowed to be serially autocorrelated, with different serial correlation properties and differing variances across units. The corresponding t-statistic (t_b), which is based on the average of statistics obtained from individual test, (t_{iT}), can be calculated as follows:[53]

$$t_b = \frac{\sqrt{N}(t_{NT} - Et_T)}{\sqrt{Var(t_T)}} \tag{5.4}$$

where t_{NT} is the cross-sectional average of the t_{iT} statistics, (i.e. $t_{NT} = 1/N\sum_{i=1}^{N} t_{iT}$), which are the t-statistics used to evaluate the null hypothesis of the unit root in the standard individual augmented Dickey Fuller (ADF) test. The terms Et_T and $Var(t_T)$ are the finite common mean and variance of t_{iT}, respectively, under the null. For $N \rightarrow \infty$ this test statistic (t_b) is distributed as a normal distribution under the null hypothesis.

Hadri (2000) test

The Lagrange multiplier (LM) test of Hadri (2000) differs from the LLC and IPS tests in that its null hypothesis is stationarity while the alternative assumes a unit root. The test statistic is distributed as a standard normal under the null hypothesis. The LM statistic can be written as

$$LM = \frac{\frac{1}{N}\sum_{i}^{N} \frac{1}{T^2}\sum_{t=1}^{T} S_{it}^2}{\hat{\sigma}_{\varepsilon}^2} \tag{5.5}$$

[53] IPS proposes the use of a group-mean t-bar statistic, where the t-statistics from each ADF test are averaged across the panel.

where S_{it} is defined as $\sum_{j=1}^{t} \hat{\varepsilon}_{ij}$, which refers to the partial sum of the residuals, and $\hat{\sigma}_{\varepsilon}^{2}$ is the consistent estimate of the long-run variance of the disturbance term.

5.2.2.2 Panel Cointegration Test

In the conventional time-series case, it is common to test for cointegration in the multivariate system using Johansen's (1988, 1990) maximum likelihood approach. This procedure can be used to identify the number of cointegrating relationships between the variables of interest. However, the power of the conventional test in multivariate systems with small sample sizes can be severely distorted. To address this issue, therefore, there is need to combine the data across individual members, from time series as well as cross-section data.

For this purpose, in this study the Larsson et al. (2001) test is utilised. Larsson et al. (2001) proposed a likelihood-based panel test of cointegration rank in heterogeneous panel models based on the average of the individual rank trace statistics developed by Johansen (1995). Compared to the residual based test (Kao, 1999 and Pedroni, 1999) this test has the advantage of testing for the multiple cointegrating vectors amongst the variables.

Given N countries with the sample number of periods T and a set of p variables, the Johansen VECM is estimated for each country *i*, using the maximum likelihood method. The test statistic is given by

$$\overline{LR}_{NT}\left(H(r)\middle|\, H(p)\right)=\frac{1}{N}\sum_{i=1}^{N} LR_{iT}\left(H(r)\middle|\, H(p)\right) \tag{5.6}$$

where $\overline{LR}_{NT}\left(H(r)\middle|\, H(p)\right)$ is the LR-bar statistic, which is defined as the average of the N individual trace statistic $LR_{iT}\left(H(r)\middle|\, H(p)\right)$. The individual trace statistic is the Johansen trace statistic to test the null hypothesis H_0: rank (Π_i) $\leq r$ against the alternative H_1: rank (Π_i) = p.

Larson et al. (2001) tests the null hypothesis that there are at most r cointegrating relationships among the p variables. That is, the null hypothesis is written as:

H_0: rank (Π_i) = $r_i \leq r$ for all i = 1,..., N, (5.7)

and the alternative as:

H_1: rank (Π_i) = p for all i = 1,..., N. (5.8)

The standardized LR-bar statistic for the panel cointegration rank test is

$$Y_{\overline{LR}}\left(H(r)\middle|\, H(p)\right)=\frac{\sqrt{N}\left(\overline{LR}_{NT}\left(H(r)\middle|\, H(p)\right)-E(Z_k)\right)}{\sqrt{Var(Z_k)}} \tag{5.9}$$

where $E(Z_k)$ and $Var(Z_k)$ are the mean and variance of the asymptotic trace statistic.

Larsson et al. (2001) show that the panel standardised cointegration trace statistic has an asymptotic standard normal distribution. The testing procedure follows the sequential procedure suggested by Johansen (1988). First, the hypothesis that r = 0 is tested. If this hypothesis is rejected, the hypothesis that r = 1 is tested. This procedure is continued until the null is not rejected. To perform the panel rank test the expected value $E(Z_k)$ and variance $Var(Z_k)$ of the asymptotic trace statistics is needed for the calculation of the standardized panel rank statistic and can be obtained from Table 1 in Larsson et al. (2001).

5.2.2.3 Testing for Causality

The procedures described above test only for the existence of long-run relationships. However, they do not indicate the direction of causality. Thus, in order to identify the direction of causality, the next step is to estimate a VECM after the number of cointegrating relationships has been determined.[54] This model is estimated with the variables in first differences and including the long-run relationships as error-correction terms in the system. The VECM equations take the form:

$$\begin{aligned}\Delta E_t &= \alpha_1 + \sum_{i=1}^{p} \beta_{1i} \Delta Y_{t-1} + \sum_{i=1}^{p} \gamma_{1i} \Delta E_{t-1} + \sum_{i=1}^{p} \delta_{1i} \Delta P_{t-1} + \sum_{i=1}^{p} \phi_{1i} \Delta I_{t-1} + \sum_{i=1}^{p} \varphi_{1i} \Delta K_{t-1} \\ &+ \sum_{i=1}^{p} \psi_{1i} \Delta L_{t-1} + \theta_{1,1} ECT_{1,t-1} + \theta_{1,2} ECT_{2,t-1} + \varepsilon_{1t}\end{aligned} \qquad (5.10)$$

$$\begin{aligned}\Delta Y_t &= \alpha_2 + \sum_{i=1}^{p} \beta_{2i} \Delta Y_{t-1} + \sum_{i=1}^{p} \gamma_{2i} \Delta E_{t-1} + \sum_{i=1}^{p} \delta_{2i} \Delta P_{t-1} + \sum_{i=1}^{p} \phi_{2i} \Delta I_{t-1} + \sum_{i=1}^{p} \varphi_{2i} \Delta K_{t-1} \\ &+ \sum_{i=1}^{p} \psi_{2i} \Delta L_{t-1} + \theta_{2,1} ECT_{1,t-1} + \theta_{2,2} ECT_{2,t-1} + \varepsilon_{2t}\end{aligned} \qquad (5.11)$$

[54] Otherwise, the analysis may be conducted as a standard Vector Autoregressive Model (VAR) model. The causality test is usually applied within the VAR framework by examining the statistical significance of the parameters on the lagged terms in each equation. But a problem arises within the unrestricted VAR procedure if the underlying long-run data are integrated and of the same order (which means that they are non-stationary) and cointegrated. If the variables in a system are cointegrated, then the short-run analysis of the system should incorporate the error-correction term (ECT) to model the adjustment towards its long-run equilibrium. Thus, when an ECT is added to the VAR model, the modified model is referred to as the VECM.

$$\Delta P_t = \alpha_3 + \sum_{i=1}^{p} \beta_{3i} \Delta Y_{t-1} + \sum_{i=1}^{p} \gamma_{3i} \Delta E_{t-1} + \sum_{i=1}^{p} \delta_{3i} \Delta P_{t-1} + \sum_{i=1}^{p} \phi_{3i} \Delta I_{t-1} + \sum_{i=1}^{p} \varphi_{3i} \Delta K_{t-1} + \sum_{i=1}^{p} \psi_{3i} \Delta L_{t-1} + \theta_{3,1} ECT_{1,t-1} + \theta_{3,2} ECT_{2,t-1} + \varepsilon_{3t} \quad (5.12)$$

$$\Delta I_t = \alpha_4 + \sum_{i=1}^{p} \beta_{4i} \Delta Y_{t-1} + \sum_{i=1}^{p} \gamma_{4i} \Delta E_{t-1} + \sum_{i=1}^{p} \delta_{4i} \Delta P_{t-1} + \sum_{i=1}^{p} \phi_{4i} \Delta I_{t-1} + \sum_{i=1}^{p} \varphi_{4i} \Delta K_{t-1} + \sum_{i=1}^{p} \psi_{4i} \Delta L_{t-1} + \theta_{4,1} ECT_{1,t-1} + \theta_{4,2} ECT_{2,t-1} + \varepsilon_{4t} \quad (5.13)$$

$$\Delta K_t = \alpha_5 + \sum_{i=1}^{p} \beta_{5i} \Delta Y_{t-1} + \sum_{i=1}^{p} \gamma_{5i} \Delta E_{t-1} + \sum_{i=1}^{p} \delta_{5i} \Delta P_{t-1} + \sum_{i=1}^{p} \phi_{5i} \Delta I_{t-1} + \sum_{i=1}^{p} \varphi_{5i} \Delta K_{t-1} + \sum_{i=1}^{p} \psi_{5i} \Delta L_{t-1} + \theta_{5,1} ECT_{1,t-1} + \theta_{5,2} ECT_{2,t-1} + \varepsilon_{5t} \quad (5.14)$$

$$\Delta L_t = \alpha_6 + \sum_{i=1}^{p} \beta_{6i} \Delta Y_{t-1} + \sum_{i=1}^{p} \gamma_{6i} \Delta E_{t-1} + \sum_{i=1}^{p} \delta_{6i} \Delta P_{t-1} + \sum_{i=1}^{p} \phi_{6i} \Delta I_{t-1} + \sum_{i=1}^{p} \varphi_{6i} \Delta K_{t-1} + \sum_{i=1}^{p} \psi_{6i} \Delta L_{t-1} + \theta_{6,1} ECT_{1,t-1} + \theta_{6,2} ECT_{2,t-1} + \varepsilon_{6t} \quad (5.15)$$

where E, Y, P, I, K and L are defined as in section 5.2.1. The symbol Δ indicates first differences. The terms ECT_i refer to the error correction terms, whose coefficients measure speeds of adjustment and are derived from the long-run cointegrating relationships (i.e. $E_t = \lambda_1 Y_t + \lambda_2 P_t + \lambda_3 I_t + \lambda_4 K_t + \lambda_5 L_t + \mu$ where μ is the stationary residuals). α_t are intercepts, and p is the lag lengths. In each equation, the right hand side variable is regressed against past values of itself and past values of other variables.

The VECM captures both short-run dynamics and long-run equilibrium. For instance, the coefficients β_i 's of lagged variables ΔY_{t-1} reflect the immediate response of Y to changes in X (the left hand-side variable). Thus, they refer to the short-run elasticity of Y with respect to X. In the ECT, the cointegrating vector (the long-run cointegrating relationships), represents the long-run equilibrium between variables. Therefore, the coefficient λ_1 for instance, represents the long-run elasticity of Y with respect to E. In addition, the coefficient θ_i of the ECT measures the speed of adjustment towards the long-run equilibrium, or the proportion of the long-term imbalance of the dependent variable that is corrected in each short-run period. Thus, the size and the statistical significance of this coefficient measure the extent to which each dependent variable has a tendency to return to its long-run equilibrium.

The ECTs in the VECM provide an additional channel for Granger causality to emerge that is completely ignored by the standard (VAR based) Granger causality tests. The Granger causality test in the VECM can be divided into short-and long-run tests. Masih and Masih (1996, 1997 and 1998) indicate that the tests of lagged parameters give the indications of short-term causal effect and significance of ECT indicates the long-term causal effect. Thus, the short-run test considers restrictions on the lagged first differenced terms (since the coefficients of lagged variables capture the short-run dynamic). In this case, a joint F test or Wald χ^2 test is used to detect the Granger causal relation. On the other hand, the test for the long-run considers restrictions on the coefficient of ECT (since the ECT captures the long-run equilibrium between variables). This test is based on the null hypothesis that there is no Granger causality (i.e. the coefficients are zero, $\theta_i = 0$). The t-test is used to detect the Granger causal relation in the long-run (see for example, Zachariadis, 2006; Zou and Chau 2006 and Narayan and Singh, in press). In addition, the joint significance of the lags of explanatory variable (*Y* and *E*) and the lagged error correction term is also performed to test for the Granger causality. In the energy equation (5.10), the test for Granger causality of income is $H_0 : \beta_1 = \theta_{1,1} = \theta_{1,2} = 0$.

Rejection of the null suggests that GDP Granger –causes energy. In the income equation (5.11), the test for Granger causality of energy is $H_0 : \gamma_2 = \theta_{2,1} = \theta_{2,2} = 0$. Rejection of the null suggests that energy Granger –causes GDP.

5.3 Data

Annual data covering the period 1978 to 2003 are used for this study. 39 countries are selected, comprising 23 developed countries and 16 developing countries, which are listed in Appendix 3.I. The choice of the countries was constrained by the availability of data on energy price. All the series are obtained from the 2006 World Development Indicators (WDI), except for the energy consumption and the price of energy, which are collected from the International Energy Agency (IEA) database. Data on real gross domestic product (GDP) are based on purchasing power parity and denominated in constant 2000 US$. Energy consumption is represented by energy use in thousand tonnes of oil equivalent (ktoe). The weighted average of the prices for four fuels (coal, electricity, natural gas and petroleum products) is used to proxy energy price. The share of industry in GDP is used to proxy structural changes in the economy. Capital is measured in terms of gross fixed capital formation and is expressed in real terms by deflating it with the GDP deflator. Finally, labour force is used to proxy total employment. All the series are transformed into natural logarithms.

The econometric softwares applied in this study are Eviews 5.0 and Stata 9.2. The VECM model and three kinds of panel unit root tests (LLC, 2002; IPS, 2003; Hadri,

2000) were obtained using Eviews 5.0 while the panel cointegration procedure was executed with Stata 9.2.

5.4 Empirical Results

5.4.1 Test Results for Panel Unit Root

The results of the panel unit root tests are summarized in Table 5.1. Columns 1 and 2 report the Levin et al. (2002) test (LLC) and Im et al. (2003) test (IPS), whose null hypothesis is the existence of a unit root, and column 3 reports the Hadri test, whose null hypothesis is that the series are stationary.

The results show that the null of a unit root in the LL and IPS tests cannot be rejected in any of the relevant variables. Similarly, the null of a stationarity in the Hadri test is rejected, which confirms that all the series are non-stationary. Moreover, the tests overall suggest that the series in first differences are stationary. Therefore, the combined results of the tests suggest that all the series appear to be integrated of order one, i.e I(1) over the sample under consideration.

5.4.2 Test Results for Panel Cointegration

Given the non-stationarity of the variables, the existence of two cointegrating relationships between energy and output can be investigated. The results of the cointegration tests between energy consumption, economic growth, energy price, level of industrialisation, capital and labour for 39 countries are shown in Table 5.2. The table reports country-by-country (Johansen's test) and panel cointegration test

(Larsson's test) results based on the trace test procedure and panel cointegration rank test described in Section 5.2.2.2. The column labelled r = 0 tests a null of no cointegration, while r = 1, r = 2, r = 3, r = 4 and r = 5 refers to a null of at most one, two, three, four and five cointegrating vectors, respectively. Due to the small sample, T = 26, the lag length was chosen in all cases to be equal to 1.

From Table 5.2, country-by-country results show that the most common selected rank is r = 1 for both developed and developing countries. The null of cointegration is rejected in all countries, except for 3 developed and 3 developing countries (i.e. Germany, Luxembourg, Sweden and Hungary, Romania, Slovak Republic). However, the null of at most one cointegrating relationship is rejected only in 9 countries and in only one country (Thailand) there seems to be evidence of three cointegrating relationships. Regarding the panel cointegration rank trace statistics, the results suggest that there are two cointegrating relationships for both developed and developing countries.

Consequently, there appears to be clear evidence from the range of individual and panel cointegration tests that there is at least one cointegrating relationship between the variables. In addition, taking account of the fact that panel unit root and cointegration tests utilise the data in a more efficient way, it can be concluded that there is clear evidence that there are two independent long-run relationships (i.e. cointegrating vectors) between these variables.

Table 5.1: Panel unit root tests

Variables	LLC Ho: Unit root	IPS Ho: Unit root	Hadri Ho: No unit root	Order of Integration
Levels				
E_{it}^{d}	-1.3717 (0.0851)	2.5732(0.9950)	22.1269(0.0000)	I(1)
Y_{it}^{d}	1.2627(0.8967)	6.0506(1.0000)	22.8703(0.0000)	I(1)
P_{it}^{d}	-2.7519(0.0030)	-2.2451(0.0524)	17.0215(0.0000)	I(1)
I_{it}^{d}	-0.2546(0.3995)	5.2510(1.0000)	20.4789(0.0000)	I(1)
K_{it}^{s}	-0.7258(0.2340)	2.6800(0.9963)	19.2618(0.0000)	I(1)
L_{it}^{s}	-1.0906(0.1377)	2.9988(0.9986)	23.1253(0.0000)	I(1)
First differences				
ΔE_{it}^{d}	-20.2331(0.0000)	-23.4320(0.0000)	-0.5887(0.7220)	I(0)
ΔY_{it}^{d}	-15.5995(0.0000)	-20.3073(0.0000)	2.6311(0.0043)	I(0)
ΔP_{it}^{d}	-18.5372(0.0000)	-20.3803(0.0000)	1.0225(0.1533)	I(0)
ΔI_{it}^{d}	-20.2502(0.0000)	-18.5105(0.0000)	1.5519(0.0603)	I(0)
ΔK_{it}^{s}	-20.8151(0.0000)	-20.5743(0.0000)	0.0199(0.4921)	I(0)
ΔL_{it}^{s}	-20.7028(0.0000)	-27.0861(0.0000)	0.7943(0.2135)	I(0)

Figure in the parentheses are p-values.

Table 5.2: Johansen Test Statistics and Larsson et al., (2001) Panel Cointegration Tests between E, Y, P, I, K and L.

Country	Trace Statistics H_o: rank = r						Rank
	r = 0 (102.14)	r = 1 (76.07)	r = 2 (53.12)	r = 3 (34.91)	r = 4 (19.96)	r =5 (9.24)	(r_i)
Developed Countries : N = 23							
Individual countries' trace statistics							
Australia (AU)	108.7589*	25.8728	9.4823	4.8946	1.2147	0.0037	1
Austria (AT)	137.0873*	60.4532	26.9929	7.4667	2.1636	0.2443	1
Belgium (BE)	120.1420*	39.2883	19.6113	4.8528	1.2148	0.1428	1
Canada (CA)	126.2199*	41.9593	16.1520	5.3013	1.0465	0.0814	1
Denmark (DK)	112.7476*	52.0086	31.5907	11.2833	4.3314	1.5014	1
Finland (FI)	176.2829*	88.5395*	30.5514	4.6495	0.7761	0.0693	2
France (FR)	159.3132*	65.8289	19.8927	6.3307	1.8893	0.0556	1
Germany (DE)	82.0643	35.5330	13.9842	4.4277	0.9988	0.0015	0
Greece (GR)	131.3503*	7.0103	1.6640	0.2694	0.0634	0.0051	0
Ireland (IE)	215.3103*	99.2716*	46.8937	14.2575	1.7672	0.0808	2
Italy (IT)	210.7380*	89.3403*	16.7954	2.0151	0.4808	0.0274	2
Japan (JP)	136.7685*	35.2740	11.0871	4.2933	1.0473	0.0101	1
Korea (KR)	206.0470*	72.2369	22.0195	0.2706	0.0951	0.0129	1
Luxembourg (LU)	55.3307	25.3389	5.1996	1.7186	0.5379	0.0053	0
Netherlands (NL)	161.1091*	36.9720	12.2241	5.0547	1.4207	0.0142	1
New Zealand (NZ)	142.2734*	84.4542*	40.1371	7.7556	1.1829	0.0051	1
Norway (NO)	122.5123*	41.3635	21.0946	9.7291	4.3829	0.0615	1
Portugal (PT)	193.1237*	84.0190*	31.2410	11.6962	1.3226	0.0590	2
Spain (ES)	199.1813*	94.8272*	28.8639	9.1725	0.2987	0.0170	2
Sweden (SE)	85.9780	45.1940	9.1541	1.9110	0.1514	0.0449	0
Switzerland (CH)	121.2620*	49.4872	23.0535	4.6708	0.5947	0.1002	1
United Kingdom(GB)	111.9915*	47.8323	19.4722	6.2407	1.4250	0.0701	1
United States (US)	154.6226*	61.9909	11.3918	5.5734	1.0893	0.1212	1
The panel test statistics							
$\overline{LR}_{NT}$	142.1832	55.8303	20.3717	5.8189	1.2824	0.1189	
$Y_{\overline{LR}}$ test	36.4118*	6.4972*	-5.2445	-8.8101	-7.0976	-3.2829	2
$E(Z_k)$	64.960	44.392	27.7290	14.9550	6.0860	1.1370	
$Var(Z_k)$	103.452	71.284	45.2640	24.7330	10.5350	2.2120	
Developing Countries : N = 16							
Individual countries' trace statistics							
Brazil (BR)	145.2313*	51.7696	5.0344	1.7529	0.4070	0.0068	1
China (CH)	182.4893*	63.3679	21.4251	3.9913	1.1365	0.0036	1
Czech Republic (CZ)	113.6269*	37.7343	3.2121	1.1487	0.2880	0.0709	1
Hungary (HU)	82.8182	31.4611	10.3612	4.4480	0.5404	0.0755	0
India (IN)	207.6280*	107.6181*	21.1133	5.0818	2.0602	0.2203	2
Indonesia (ID)	137.1447*	85.9963*	38.9807	5.3279	0.0859	0.0198	2
Kazakhstan (KZ)	101.1590*	35.3939	17.5077	6.8075	1.4969	0.0009	1
Mexico (MX)	135.5838*	35.1460	10.3809	3.4528	0.2373	0.0767	1
Poland (PL)	149.7888*	73.5177	40.8799	15.9596	2.7276	0.0160	1
Romania (RO)	70.7527	10.2267	3.2215	0.2299	0.0094	0.0031	0
Russia (RU)	178.0044*	96.2851*	27.2664	5.8687	0.4220	0.0319	2
Slovak Republic (SK)	39.9164	11.8179	4.4510	0.4725	0.1639	0.0277	0
South Africa (ZA)	183.2882*	71.3847	33.9906	14.9269	1.4979	0.4552	1
Thailand (TH)	254.7898*	132.2975*	61.8308*	15.6302	2.1185	0.1934	3
Turkey (TR)	146.3661*	86.3223*	37.6334	14.6994	0.1599	0.0414	2
Venezuela (VE)	103.0489*	46.3402	22.8177	8.0987	1.8407	0.0461	1
The panel test statistics							
$\overline{LR}_{NT}$	139.4773	61.0425	22.5067	6.7436	0.9495	0.0806	
$Y_{\overline{LR}}$ test	29.3053*	7.8884*	-3.1049	-6.6045	-6.3300	-2.8412	2
$E(Z_k)$	64.960	44.392	27.7290	14.9550	6.0860	1.1370	
$Var(Z_k)$	103.452	71.284	45.2640	24.7330	10.5350	2.2120	

Notes: (i) r denotes the number of cointegrating vectors (ii) The critical value for the country-by-country tests are 102.14, 76.07, 53.12, 34.91, 19.96 and 9.24 for testing r = 0, 1, 2, 3, 4 and 5 at the 5% level (iii) The panel rank test has a critical value 1.96 at 5% level (iv) * Indicates rejection of the null hypothesis of rank equal to r at a 5% level of significance.

5.4.3 Test Results for Granger Causality based on VECM

Before testing for Granger-causality, the robustness of the estimated VECM models in equations (5.16) to (5.21) are diagnostically tested for possible misspecification (refer to Table A.5.I.1 in Appendix 5.I). The residuals from all equations pass the diagnostic tests in that they do not violate the standard assumptions of normality (Jarque-Bera tests), homoscedasticity and serial correlation (LM tests). The results of the diagnostic tests therefore suggest that all VECM models are relatively well specified.

Since all the variables are I(1) and there is evidence of cointegration, the Granger causality test should be performed in the VECM, which allows a distinction to be made between short-run and long-run causality. Recall that the panel cointegration test suggested the existence of two independent cointegrating relationships. In order to interpret these two relationships as demand and supply equations and to obtain more efficient estimates, a number of constraints for the right-hand-side variables need to be imposed. Let v_1 and v_2 be the two independent cointegrating vectors. Let us relate v_1 to the long-run demand equation, and therefore let us normalise the coefficient of energy consumption in v_1 to one. Note that this restriction implies that energy has a non-zero coefficient in v_1. Similarly, since v_2 is interpreted as the supply-of-output equation, the coefficient of output in v_2 is normalised to be one. In addition, the coefficients of K and L are restricted to be zero in v_1. Finally, the coefficients of P and I in v_2 are both restricted to be 0.

Tables 5.3 and 5.4 present the results of causality tests based on the VECM framework for developed and developing countries, respectively. The test, which is referred as the short-run causality test, is conducted using a joint F-statistic for the exclusion of two variables from each equation, as explained above. Since this study aims to examine the causality between energy consumption and income, emphasis is placed only on the relationships between these two variables (energy and GDP). The first hypothesis is that GDP does not cause energy and the second hypothesis is that energy does not cause GDP. The results suggest that the first hypothesis is rejected in 8 developed countries (Australia, Austria, Belgium, Denmark, Finland, Germany, Sweden and United Kingdom) and 5 developing countries (India, Indonesia, Romania, Russia and Venezuela), at the 5% significance level. This result implies that there is evidence of unidirectional causality running from GDP to energy. The results also indicate that the second hypothesis is rejected in 3 developed countries (Greece, Japan and Norway) and 2 developing countries (Brazil and Thailand). Therefore, it is concluded that there is evidence of unidirectional causality running from energy to GDP. In addition, the results show that there is bidirectional causality for Portugal and Kazakhstan, where both hypotheses are rejected.

With regards to the long-run causality test, it can be referred to as the ECT (Error-Correction-Term) test. In this case, let ECT1 be the ECT corresponding to the long-run demand equation (v_1) and let ECT2 correspond to the long-run supply equation (v_2). Estimates of the parameters show that at least one of the ECT terms is significant in the energy equation in 10 developed countries and in 3 developing countries, while none of the ECT coefficients are significant in the income equation.[55]

[55] In the case of OECD countries, both ECT1 and ECT2 are significant for Portugal and Ireland, ECT1 is significant for Finland, New Zealand and Norway and ECT2 is significant for Austria, Denmark, Sweden, Switzerland and United States. On the other hand, in the case of non-OECD countries, both ECT1 and ECT2 are significant for Czech Republic and Indonesia and for Romania, it is the ECT2 which is significant.

This implies that for these 13 countries, when there is a deviation from the equilibrium cointegrating relationship as measured by the ECT, it is energy consumption, not output, that adjusts to restore the long-term equilibrium within the system. Therefore, there is evidence that unidirectional causality runs from income to energy consumption in the long run, which implies that economic growth stimulates energy consumption in these countries. This result can be interpreted as follows. In those countries experiencing the advancement of the economy, there has been a particularly rapid growth in energy consumption in the industrial, commercial and service sectors. Thus, it is reasonable to expect that economic growth, which takes place mostly in industrial, commercial and service sectors, enhance energy consumption in these countries. Hence, given that the causality from economic growth to energy consumption is more prevalent in developed countries, these results explain that most of advanced industrialised countries use more energy than developing countries (Toman and Jemelkova, 2002).

There are 3 developed countries (France, Japan and the Netherlands) and 2 developing countries (Romania and China) where there is unidirectional causality from energy to output. This can be observed in the income equation, where at least one of the ECT coefficients is statistically significant, while the ECT coefficients in the energy equation are not significant.[56] Thus, in the long run, causality runs through the error correction term from energy consumption to income. This result implies that a high level of energy consumption leads to a high level of economic growth in these 5 countries. That is, any changes in energy consumption will have a significant impact on economic growth for this group of countries. This is particularly true for

[56] ECT1 is significant in France and ECT2 is significant in Japan and the Netherlands. On the other hand, in the case of non-OECD countries, ECT1 is significant in Romania and ECT2 is significant in China.

China, which is a country that has been regarded as a "world factory" and therefore the consumption of energy has great effects on economic growth (Shiu and Lam, 2006).

The results also reveal that there is bidirectional causality or feedback between energy consumption and GDP in Russia. This implies that a high level of economic growth may demand a high level of energy consumption while energy use may induce economic growth. Therefore, energy consumption and economic growth complement each other and energy conservation measures may negatively affect economic growth in Russia.

In addition to the above tests, the Granger causality test is also conducted, which is referred to the test of joint significance of the lags of explanatory variable and the lagged error correction term. Table 5.7 presents the Granger causality results for 39 countries. From the F statistics reported in Table 5.7, it is evident that GDP Granger-causes energy in 12 out of 23 developed countries and 5 out of 16 developing countries. The results also indicate that energy Granger-cause GDP in Netherlands and there is bidirectional causality between energy and GDP in Slovak Republic. The results seem to re-confirm the earlier findings that causality runs from GDP to energy in most of the countries

Table 5.3: The Wald Tests in the VECM of Developed Countries

Country	Null Hypothesis	Source of Causation ΔE	ΔY	ΔP	ΔI	ΔK	ΔL
AU	1		13.82(0.00)*	0.73(0.39)	2.15(0.14)		
	2	1.46(0.22)				0.50(0.47)	0.54(0.46)
AT	1		16.17(0.00)*	8.38(0.00)*	0.10(0.74)		
	2	0.09(0.76)				0.23(0.62)	0.27(0.59)
BE	1		8.29 (0.00)*	0.03(0.85)	0.48(0.48)		
	2	1.42(0.23)				0.68(0.40)	0.09(0.75)
CA	1		1.20 (0.27)	2.46(0.11)	2.38(0.12)		
	2	1.04(0.30)				0.01(0.93)	0.68(0.40)
DK	1		22.42(0.00)*	1.99(0.15)	3.24(0.07)		
	2	3.06(0.08)				4.05(0.04)*	0.23(0.62)
FI	1		8.59 (0.00)*	0.33(0.56)	0.01(0.90)		
	2	0.02(0.87)				0.20(0.64)	1.16(0.27)
FR	1		3.25 (0.071)	0.09(0.76)	0.00(0.98)		
	2	2.38(0.12)				0.95(0.32)	1.63(0.20)
DE	1		8.360(0.00)*	6.03(0.01)*	0.12(0.72)		
	2	0.91(0.33)				1.31(0.25)	0.04(0.84)
GR	1		0.02 (0.88)	0.00(0.94)	1.06(0.30)		
	2	5.34(0.02)*				0.29(0.58)	0.74(0.38)
IE	1		2.68(0.10)	0.24(0.61)	2.50(0.11)		
	2	0.09 (0.75)				1.36(0.24)	0.26(0.60)
IT	1		0.74(0.38)	1.54 (0.23)	3.06 (0.09)		
	2	2.63 (0.10)				0.90(0.34)	0.24(0.61)
JP	1		0.82(0.36)	0.79(0.37)	0.03(0.85)		
	2	11.08(0.00)*				2.74(0.09)	5.22(0.02)*
KR	1		0.03(0.85)	0.04(0.83)	0.31(0.57)		
	2	1.39 (0.23)				0.00(0.95)	0.50(0.47)
LU	1		2.74(0.09)	0.11(0.73)	1.51(0.21)		
	2	2.21 (0.13)				0.19(0.66)	0.09(0.75)
NL	1		1.79(0.18)	11.73(0.00)*	0.46(0.49)		
	2	0.71 (0.39)				18.65(0.00)*	5.84(0.01)*
NZ	1		0.58(0.44)	6.05(0.01)*	4.86(0.02) *		
	2	0.29 (0.58)				0.61(0.43)	1.45(0.22)
NO	1		1.51(0.21)	5.57(0.01)	25.30(0.00)*		
	2	4.45 (0.03)*				0.13(0.70)	0.00(0.99)
PT	1		30.16(0.00)*	30.31(0.0)*	0.01(0.91)		
	2	4.36 (0.03)*				10.98(0.00)*	1.03(0.30)
ES	1		0.04 (0.83)	1.85(0.17)	2.15(0.14)		
	2	0.04 (0.83)				4.05(0.04)	0.12(0.72)
SE	1		16.22(0.00)*	0.08(0.76)	2.32(0.12)		
	2	0.30 (0.58)				0.57(0.45)	0.12(0.71)
CH	1		0.08(0.77)	1.15(0.28)	0.77(0.37)		
	2	0.91 (0.33)				1.07(0.29)	3.19(0.07)
GB	1		7.16(0.00)*	0.14(0.69)	8.76(0.00)*		
	2	0.57 (0.44)				0.00(0.94)	0.69(0.40)
US	1		0.201(0.65)	0.06(0.79)	0.13(0.71)		
	2	0.53 (0.46)				0.22(0.63)	0.11(0.72)

Notes: Null hypothesis 1: GDP does not Granger-cause energy. Null hypothesis 2: Energy does not Granger-cause GDP. The reported estimates are F-statistics. The values in parentheses are p-values indicating the level of significance to reject the null hypothesis of non-causality. * indicates significance at 5% level.

Table 5.4: The Wald Tests in the VECM of Developing Countries

Country	Null Hypothesis	Source of Causation ΔE	ΔY	ΔP	ΔI	ΔK	ΔL
BR	1		0.00(0.94)	2.57(0.10)	6.51(0.01)*		
	2	0.00(0.00)*				0.64(0.42)	0.04(0.82)
CN	1		1.45(0.22)	4.40(0.03)	5.03(0.02)		
	2	1.35(0.24)				0.43(0.50)	0.03(0.95)
CZ	1		5.63(0.01)	4.72(0.02)	10.61(0.01)*		
	2	0.76(0.38)				1.51(0.21)	2.41(0.12)
HU	1		2.40(0.12)	0.10(0.74)	0.014(0.96)		
	2	1.45(0.22)				4.64(0.03)*	1.42(0.23)
IN	1		8.64(0.00)*	0.42(0.51)	0.02(0.87)		
	2	0.35(0.55)				1.82(0.17)	2.26(0.13)
ID	1		8.64(0.00)*	0.42(0.51)	0.02(0.87)		
	2	1.20(0.27)				0.24(0.62)	0.25(0.61)
KZ	1		10.76(0.00)*	1.48(0.22)	0.01(0.98)		
	2	6.05(0.01)*				5.28(0.02)	1.73(0.18)
MX	1		0.13(0.71)	5.04(0.02)	0.02(0.87)		
	2	0.00(0.98)				0.14(0.70)	0.46(0.49)
PL	1		0.03(0.84)	0.04(0.83)	0.49(0.48)		
	2	0.00(0.96)				0.35(0.55)	3.96(0.04)*
RO	1		20.11(0.00)*	0.04(0.82)	5.73(0.01)		
	2	1.74(0.18)				0.01(0.98)	4.41(0.03)*
RU	1		51.03(0.00)*	7.19(0.00)*	59.69(0.00)*		
	2	0.23(0.62)				1.15(0.28)	3.01(0.08)
SK	1		1.10(0.29)	1.09(0.29)	0.78(0.37)		
	2	0.22(0.63)				0.63(0.42)	0.14(0.70)
ZA	1		2.91(0.08)	2.72(0.09)	12.62(0.04)*		
	2	0.31(0.57)				3.42(0.06)	5.25(0.028)*
TH	1		2.74(0.09)	2.58(0.10)	0.33(0.56)		
	2	4.84(0.02)*				3.77(0.05)	4.05(0.04)
TR	1		0.23(0.63)	0.35(0.55)	0.84(0.35)		
	2	1.97(0.16)				0.08(0.77)	2.85(0.091)
VE	1		5.54(0.01)*	0.71(0.39)	0.02(0.90)		
	2	0.36(0.54)				0.79(0.37)	2.87(0.08)

Notes: Null hypothesis 1: GDP does not Granger-cause energy. Null hypothesis 2: Energy does not Granger-cause GDP. The reported estimates are F-statistics. The values in parentheses are p-values indicating the level of significance to reject the null hypothesis of non-causality. * indicates significance at 5% level.

Table 5.5: The t-tests of the ECT in the VECM of Developed Countries

Country	θ	Equations					
		ΔE	ΔY	ΔP	ΔI	ΔK	ΔL
AU	1	0.00(0.06)	0.00(0.09)	0.09(1.86)	0.04(4.77)	0.02 (0.44)	0.02(0.68)
	2	0.00(0.55)	-0.01(-0.71)	-0.08(-1.86)	-0.03(-4.43)*	-0.02(-0.37)	-0.02(-0.81)
AT	1	0.04(4.48)	-0.00(-0.26)	-0.03(-0.86)	-0.00 (-1.49)	0.03(1.89)	-0.00(-0.56)
	2	-0.01(-2.36)*	0.00(0.72)	0.03(0.90)	0.00 (-1.24)	-0.02(-1.73)	0.00(1.74)
BE	1	0.06(2.63)	-0.01(-0.51)	-0.18(-1.74)	-0.05(-3.16)*	-0.09(-1.01)	0.00(0.21)
	2	0.06(2.58)	-0.01(-0.50)	-0.19(-1.74)	-0.05(-3.16)*	-0.09(-1.01)	0.00(0.20)
CA	1	-0.00(-0.30)	-0.00(-0.50)	-0.10(-2.01)*	0.02 (1.11)	-0.07(-1.53)	-0.01(-3.70)*
	2	-0.00(-0.38)	-0.00(-0.57)	-0.05(-2.00)*	0.01 (1.09)	-0.04(-1.57)	-0.01(-3.79)*
DK	1	0.01(1.70)	0.00(0.60)	0.00(0.01)	0.01 (8.85)	0.01(0.35)	0.00(0.00)
	2	-0.01(-3.50)*	-0.00(-1.03)	0.00(0.03)	-0.01(-6.11)*	-0.01(-0.53)	-0.00(-0.16)
FI	1	-0.01(-2.22)*	-0.00(-0.57)	0.09(2.13)	0.00 (0.19)	-0.02(-0.75)	-0.00(-4.11)*
	2	-0.00(-1.19)	-0.00(-0.58)	0.04(2.25)	0.00 (0.03)	-0.02(-1.18)	-0.00(-4.08)*
FR	1	0.00(0.50)	-0.01(-2.32)	0.19(2.10)	-0.01 (-0.86)	0.00(0.05)	-0.00(-0.22)
	2	-0.00(-0.56)	0.00(2.31)	-0.08(2.09)*	0.00 (0.87)	-0.00(-0.02)	0.00(0.18)
DE	1	0.02(4.71)	0.00(1.02)	0.01(0.36)	-0.00 (-0.26)	0.08(3.84)	-0.00(-0.92)
	2	0.01(3.36)	0.01(1.39)	0.01(0.44)	-0.00 (-0.08)	0.06(4.01)	-0.00(-0.71)
GR	1	-0.01(-0.36)	-0.01(-0.46)	-0.14(-1.09)	-0.10(-4.43)*	-0.10(-1.00)	0.01(0.79)
	2	0.01(0.37)	0.01(0.47)	0.17(1.03)	0.12 (4.35)	0.10(0.89)	-0.01(-0.78)
IE	1	-0.04(-2.66)*	-0.04(-1.61)	0.11(1.36)	0.01 (0.67)	-0.15(2.02)*	-0.01(-2.68)*
	2	-0.03(-2.45)*	-0.03(-1.26)	0.08(1.42)	0.01 (0.70)	-0.11(1.98)*	-0.01(-2.73)*
IT	1	0.01(1.62)	0.00(0.05)	-0.09(2.53)*	0.00 (1.60)	0.06(0.36)	-0.00(-2.98)*
	2	0.00(0.11)	-0.00(-0.10)	-0.10(2.24)*	0.01 (1.85)	0.10(0.46)	-0.01(-3.17)*
JP	1	0.01(3.82)	0.00(2.94)	-0.04(1.98)*	-0.01(-1.75)	0.03(3.49)	0.00(6.22)
	2	0.00(0.48)	-0.00(-2.42)*	-0.00(-0.22)	-0.01(2.62)*	-0.00(-0.19)	0.00(1.00)
KR	1	0.05(2.28)	0.01(0.88)	-0.00(-0.19)	-0.01(-1.39)	0.00(0.12)	0.01(2.44)
	2	0.03(2.24)	0.01(0.83)	-0.00(-0.09)	-0.00 (-1.42)	0.00(0.15)	0.00(2.43)
LU	1	0.01(0.76)	-0.020-0.70)	0.07(2.61)	-0.01(-0.55)	0.05(1.15)	0.00(0.51)
	2	0.01(0.86)	0.01(0.73)	-0.07(-3.36)*	0.02 (1.86)	-0.03(-1.06)	-0.00(-1.33)
NL	1	-0.01(-3.42)*	-0.00(-0.27)	0.01(0.65)	-0.00 (-0.90)	0.01(1.67)	-0.00(-3.92)*
	2	0.01(6.20)	-0.05(-3.47)*	-0.01(-1.03)	0.00 (0.06)	0.00(1.417)	0.00(0.13)
NZ	1	-0.01(-1.29)	-0.04(-0.47)	-0.02(-0.61)	-0.02(-2.49)*	-0.08(-2.13)*	-0.00(-0.24)
	2	0.04(2.86)	0.02(1.198)	-0.00(-0.05)	0.02 (1.66)	-0.08(-1.16)	0.01(1.39)
NO	1	-0.01(-7.70)*	-0.09(-1.67)	-0.01(-0.44)	0.01 (0.62)	-0.05(-2.85)*	-0.00(-0.59)
	2	-0.00(-1.17)	-0.00(-1.66)	-0.01(-0.46)	-0.02 (-1.11)	0.08(5.10)	0.00(1.71)
PT	1	-0.02(-2.57)*	0.01(1.088)	0.12(1.37)	-0.03 (-1.81)	0.03(0.59)	0.01(1.13)
	2	-0.07(-3.41)*	0.01(0.73)	0.25(1.32)	-0.08 (-1.86)	0.04(0.321)	0.02(1.17)
ES	1	0.01(1.20)	0.00(0.79)	0.03(0.67)	0.020(3.25)	0.02(0.85)	-0.01(-2.48)*
	2	0.01(1.31)	0.01(1.50)	0.06(0.96)	0.03 (3.21)	0.03(0.82)	-0.01(-1.64)
SE	1	-0.00(-0.32)	0.00(0.20)	0.02(0.28)	0.04 (3.53)	-0.00(-0.06)	0.00(0.65)
	2	-0.01(3.21)*	-0.01(-0.40)	0.02(1.44)	0.00 (1.74)	0.01(0.98)	0.00(0.26)
CH	1	-0.02(-1.86)	0.00(0.75)	-0.04(-1.29)	0.00 (0.23)	0.00(0.18)	-0.00(-2.60)*
	2	-0.01(-2.29)*	-0.00(-0.84)	-0.03(-1.60)	-0.00 (-0.64)	-0.02(-2.79)*	0.00(2.22)
GB	1	0.00(0.09)	0.00(0.27)	-0.02(-0.49)	0.03 (4.51)	-0.01(-0.37)	0.00(0.01)
	2	0.01(3.08)	-0.02(-0.06)	0.00(0.34)	-0.01(-2.00)*	0.03(2.22)	0.00(0.97)
US	1	0.00(0.09)	-0.04(-1.21)	0.00(0.37)	0.00 (0.84)	-0.01(-0.09)	-0.00(-3.66)*
	2	-0.01(-2.28)*	0.00(0.07)	0.02(1.45)	0.00 (0.72)	-0.01(0.152)	-0.00(-0.64)

Notes: Since there are two cointegrating vectors for each of the country, there exist two ECTs (θ). 1 indicates the error correction term in the demand side and 2 indicates the error correction term in the supply side. A significant ECT coefficient implies that each series in the system is adjusting towards the long-run equilibrium relation and the adjustment is initiated by the combination of all variables jointly. Figures in parentheses are estimated t-statistics testing the null that the lagged ECT is statistically insignificant for each equation. * indicates significance at 5% level.

Table 5.6: The t-tests of the ECT in the VECM of Developing Countries

Country	θ	Equations					
		ΔE	ΔY	ΔP	ΔI	ΔK	ΔL
BR	1	0.02(3.04)	0.04(4.18)	0.08(1.15)	0.00(0.14)	0.12(1.63)	-0.01(-3.53)*
	2	0.01(2.199)	0.02(3.39)	0.03(0.79)	0.00(0.23)	0.05(1.11)	-0.01(-5.79)*
CN	1	0.02(3.00)	0.00(1.32)	-0.00(-0.16)	0.00(1.18)	0.02(1.63)	0.00 (1.60)
	2	0.01(0.52)	-0.02(-1.97)*	0.09(1.24)	-0.01(-0.52)	0.00(0.09)	0.00(0.92)
CZ	1	-0.18(-13.1)*	0.00(0.72)	-0.04(-1.25)	-0.04(11.6)*	0.01(0.35)	-0.00(-0.17)
	2	-0.09(-12.6)*	0.00(0.720)	-0.02(-1.27)	-0.02(11.2)*	0.01(0.46)	0.00(-0.00)
HU	1	0.02 (1.60)	0.00(0.24)	0.10(2.12)	-0.08(3.31)*	0.02(0.52)	0.00(0.42)
	2	0.02(1.53)	0.01(0.74)	0.10(1.91)	-0.07(2.42)*	0.01(0.15)	0.00(0.39)
IN	1	-0.00(-0.50)	-0.00(-0.30)	0.24(3.88)	-0.01(-0.95)	-0.08(-2.11)*	-0.00(2.61)*
	2	0.00(0.47)	-0.00(-0.19)	0.17(4.23)	-0.00(-0.81)	-0.05(-2.48)*	-0.00(2.04)*
ID	1	-0.00(-2.36)*	-0.00(-0.77)	0.24(0.90)	-0.01(-1.11)	-0.08(-1.16)	-0.00(-3.51)*
	2	-0.02-(2.34)*	0.01(0.77)	-0.16(-0.94)	-0.01(-1.16)	0.08(1.09)	0.01(3.67)
KZ	1	0.06(4.34)	-0.00(-0.35)	0.20(5.30)	0.06(4.21)	0.45(5.01)	-0.00(-0.40)
	2	0.04(5.90)	0.02(3.84)	-0.00(-0.36)	0.01(1.95)	0.03(0.80)	-0.00(-0.05)
MX	1	-0.00(-0.09)	-0.02(-1.03)	0.00(0.07)	-0.00(-0.24)	0.05(0.39)	-0.01(-1.86)
	2	-0.01(-0.48)	0.01 (1.01)	-0.02(-0.38)	0.01(0.44)	-0.00(-0.08)	-0.00(-0.20)
PL	1	-0.02(-1.40)	-0.00(0.249)	0.11(3.22)	0.01(2.37)	0.07(1.95)	0.00(1.74)
	2	-0.01(-0.74)	-0.00(-1.52)	0.07(1.85)	0.00(1.10)	0.06(1.85)	0.00(2.69)
RO	1	0.01(0.58)	-0.02(2.26)*	-0.09(-2.31)*	0.00(0.17)	-0.08(2.00)*	0.01(6.37)
	2	-0.03(-2.29)*	0.00(0.17)	-0.18(-4.7)*	-0.06(-1.88)	-0.22(5.41)*	-0.04(-3.45)*
RU	1	-0.05(-15.0)*	-0.03(-2.70)*	0.26(21.11)	0.00(0.98)	0.27(5.61)	-0.00(-0.89)
	2	-0.05(-11.5)*	-0.03(-2.05)*	0.32(19.91)	0.03(3.43)	0.44(7.15)	-0.00(-1.58)
SK	1	0.04(2.18)	0.02(1.77)	0.00(0.12)	-0.09(-1.16)	0.18(9.54)	0.00(2.543)
	2	-0.00(-0.06)	0.00(0.00)	0.02(0.60)	-0.08(-0.45)	-0.08(-7.99)*	-0.00(-0.39)
ZA	1	-0.00(-0.24)	-0.00(-0.17)	-0.11(-4.78)*	-0.01(-2.98)*	-0.01(-0.48)	0.00(3.933)
	2	0.02(3.02)	0.00(0.93)	-0.09(-3.72)*	0.00 (0.13)	0.06(2.39)	-0.00(-1.42)
TH	1	0.00(0.37)	0.01(0.71)	0.05(0.77)	0.04(4.65)	-0.01(-0.20)	0.01(2.38)
	2	0.03(6.88)	0.02(4.05)	-0.03(-1.36)	0.02(6.60)	0.14(4.95)	0.00(0.81)
TR	1	0.02(2.88)	0.00(0.64)	-0.05(-1.15)	-0.01(-0.94)	-0.04(-0.93)	-0.00(-1.08)
	2	0.04(3.29)	0.01(0.86)	-0.07(-1.04)	0.00(0.34)	0.11 (1.40)	-0.01(-1.88)
VE	1	0.02(3.47)	-0.00(-0.57)	0.00(0.05)	-0.07(-2.63)*	0.06(0.55)	0.00(1.12)
	2	0.01(2.94)	-0.01(-1.60)	0.04(0.71)	0.01(0.74)	-0.07(-0.66)	-0.01(-3.82)*

Notes: Since there are two cointegrating vectors for each of the country, there exist two ECTs (θ). 1 indicates the error correction term in the demand side and 2 indicates the error correction term in the supply side. A significant ECT coefficient implies that each series in the system is adjusting towards the long-run equilibrium relation and the adjustment is initiated by the combination of all variables jointly. Figures in parentheses are estimated t-statistics testing the null that the lagged ECT is statistically insignificant for each equation. * indicates significance at 5% level.

Table 5.7: Granger Causality Test (Test of Joint Significant)

Country	ΔE Equation (GDP $\rightarrow$ Energy)	ΔY Equation (Energy $\rightarrow$ Income)
	DEVELOPED COUNTRIES	
Australia (AU)	-2.1931	0.0973
Austria (AT)	6.7672*	-0.2676
Belgium (BE)	1.8776	1.4437
Canada (CA)	2.1362	-0.0938
Denmark (DK)	2.8218*	1.5522
Finland (FI)	-1.7678	0.0937
France (FR)	15.5076*	1.2574
Germany (DE)	-1.0034	-0.6303
Greece (GR)	3.5800*	2.6230
Ireland (IE)	-2.2252	-0.4070
Italy (IT)	6.1032*	0.0795
Japan (JP)	6.0207*	0.3271
Korea (KR)	3.3411*	-0.0268
Luxembourg (LU)	-2.2811	-1.7729
Netherlands (NL)	0.1419	18.7090*
New Zealand (NZ)	9.2486*	-3.4527
Norway (NO)	-2.2368	-0.5829
Portugal (PT)	-1.1009	-1.3546
Spain (ES)	4.4230*	0.0456
Sweden (SE)	7.1484*	1.7615
Switzerland (CH)	4.8010*	2.6948
United Kingdom(GB)	4.0234*	0.1389
United States (US)	0.1048	1.3437
	DEVELOPING COUNTRIES	
Brazil (BR)	-0.7717	1.1061
China (CH)	5.1858*	-1.1228
Czech Republic (CZ)	3.9520*	2.4875
Hungary (HU)	0.6714	-0.5923
India (IN)	-1.1758	0.0957
Indonesia (ID)	-2.1114	0.0060
Kazakhstan (KZ)	3.5178*	1.1643
Mexico (MX)	-1.0452	0.2163
Poland (PL)	10.8660*	0.7636
Romania (RO)	10.4948*	0.3368
Russia (RU)	-3.9701	-0.0568
Slovak Republic (SK)	5.0178*	3.2772*
South Africa (ZA)	0.9963	-0.1185
Thailand (TH)	-0.7004	0.7053
Turkey (TR)	-0.3904	-0.1044
Venezuela (VE)	-2.9917	1.0818

Notes: Rejection of the null suggests that GDP Granger-causes energy in the E equation and energy Granger-causes GDP in the Y equation. Critical value is 2.96 at 5% level.* indicates significance at 5% level.

The summary of the causality results is given in Appendix A.5.II, in Table A.5.II.1. These results show that the type of relationship between energy and economic growth varies substantially across countries. The results contradict the findings of Oh and Lee (2004) for Korea, Masih and Masih (1996) for India, Asafu-Adjaye (2000) for India, Indonesia and Thailand, Soytas and Sari (2003) for Italy, Korea and Turkey, Ghali and El-Sakka (2004) for Canada and Lee (2006) for Belgium, Canada, France, Switzerland and the United States. However, the results obtained here are highly consistent with those of Erol and Yu (1987) (for Japan), Cheng (1997) (for Brazil), Masih and Masih (1998) (for Thailand), Soytas and Sari (2003) (for Germany and Japan), Shiu and Lam (2004) and Zou and Chau (2006) (for China), all of whom found evidence of causality running from energy to income. In addition, the results are also consistent with the findings of Masih and Masih (1996) (for Indonesia), Ghosh (2002) (for India), Fatai et al. (2004) and Narayan and Smyth (2005) (for Australia), Yoo (2006) (for Indonesia) and Mehrara (2007) (for Venezuela), all of whom found evidence of causality running from income to energy. With respect to evidence of no causality between the two series, the result obtained for Venezuela is consistent with the result of Wolde-Rufael (2006).

It is sufficient to note that there is a possibility for changes in the direction of causality, due to changes in structure as changes in the long-run relationships or in causality links. For example, suppose that x causes y before 1980. Presume that in 1980 there is a big change in the economy, and that this changes the direction of causality, in such a way that y causes x after 1980. However, it is not the scope of this chapter to address the issue of the structural change. Nevertheless, an elaborate discussion of the changes in structure and whether this change in the direction of causality occurs at some time period in the sample can be found in Barassi et al., (2005a, 2005b).

5.5 Conclusions

This study examines the link between energy consumption and economic growth for 23 developed and 16 developing countries over the period from 1978 to 2003. In order to account for the dual role of energy in both the demand and supply side, a multivariate model of GDP, energy use, energy price, level of industrialisation, capital and labour is utilised. In addition, by allowing more variables to be endogeneous, this model accounts for more channels of adjustment than most of the previous literature. Due to the short time span of the data, the panel unit root and the panel cointegration test procedures were used to analyse the properties of the variables. The evidence of cointegration between the variables suggests that there exist stable long-run relationships among them. Moreover, the evidence of cointegration also implies that Granger causality must exist among these variables either unidirectional or bidirectional. Furthermore, using a vector error-correction model, the direction of short-run and long-run Granger causality was detected.

The main conclusion from this study is that the direction of causality between energy consumption and economic growth varies substantially across countries. Thus, empirical results from previous literature are hardly comparable as different individual or set of countries are studied in each case. However, the interpretations and implications of the results can be further discussed in three important aspects. In the first place, the results indicate that there is a unidirectional causality running from

GDP to energy consumption in 12 developed countries and in 5 developing countries. This suggests that it is GDP that drives energy consumption and not vice versa for these particular countries. These empirical findings have important policy implications. Since causality is shown to run from GDP to energy consumption, it could imply that energy conservation policies may be implemented with little or no adverse effect on economic growth. Therefore, there is relatively more scope for more energy conservation measures as a feasible set of policies in these countries.

Second, this study finds that unidirectional causality from energy consumption to GDP exists in Netherlands. This suggests that energy consumption is a stimulus for economic growth, implying that shortage of energy may affect the economy for Netherlands. Therefore, an energy conservation policy could harm this country as any changes in energy consumption could lead to a fall in economic growth.

Third, bidirectional causality between energy consumption and GDP exists in Slovak Republic, which indicates economic growth and energy consumption mutually influence each other. This suggests that in order to achieve economic balances, energy conservation policies that aim at reducing energy use must also, at the same time, find ways to foster economic growth. Such a policy may be achieved by improvements in economic efficiency, which would promote economic growth and at the same time, would activate an energy conservation mechanism, which in its turn would positively affect the economic growth of that particular country.

In summary, the results on causality between energy consumption and economic growth in this work partly explain the disparity of conclusions about this issue in previous literature. Moreover, these results could lead to a more precise policy recommendation as to where energy conservation policies would not harm the economy. While the study may help to understand the causal relationship between energy consumption and economic growth, the research however is limited in that it did not take into consideration the importance of sector-specific analysis. This might be important because each sector utilize a different fuel mix. Thus, future research could analyse the relationship between energy consumption and output in each sector (e.g. industry, residential and transportation).

Diagnostic Tests for VECM

Table A.5.I.1: Diagnostic tests for VECM

Country	Autocorrelation LM test		Normality test (χ^2 statistics)		Heteroscedasticity test	
AU	42.5440	(0.2100)	17.4906	(0.1321)	348.4310	(0.3088)
AT	24.2981	(0.9311)	24.0729	(0.0199)	363.3784	(0.1459)
BE	24.8686	(0.9189)	20.9384	(0.0500)	342.5386	(0.3912)
CA	46.8446	(0.1065)	16.8614	(0.1549)	346.5452	(0.3342)
DK	37.5054	(0.4000)	17.4844	(0.1323)	348.1472	(0.3125)
FI	38.0313	(0.3770)	19.8837	(0.0493)	349.1754	(0.2990)
FR	28.2837	(0.8169)	16.0383	(0.1895)	347.2059	(0.3252)
DE	41.9343	(0.2291)	22.7155	(0.0302)	348.0747	(0.3135)
GR	34.6078	(0.5348)	21.7130	(0.0409)	347.5535	(0.3205)
IE	27.4545	(0.8461)	22.3092	(0.0342)	341.5150	(0.4062)
IT	40.2068	(0.2892)	22.8797	(0.0288)	342.3075	(0.3945)
JP	27.5005	(0.8445)	18.7837	(0.0459)	353.1624	(0.2493)
KR	27.1290	(0.8568)	14.8131	(0.2518)	355.7975	(0.2192)
LU	24.3701	(0.9297)	19.9450	(0.0481)	342.8879	(0.3861)
NL	31.4143	(0.6864)	23.0168	(0.0276)	359.8285	(0.1778)
NZ	41.7697	(0.2344)	19.0271	(0.0479)	351.1011	(0.2744)
NO	43.4180	(0.1846)	18.5507	(0.1000)	346.0707	(0.3408)
PT	28.9955	(0.7899)	22.7742	(0.0297)	349.9055	(0.2895)
ES	14.8962	(0.9993)	23.5532	(0.0234)	356.6277	(0.2102)
SE	24.1867	(0.9334)	17.1816	(0.1429)	350.8030	(0.2781)
CH	54.8716	(0.0228)	22.2970	(0.0343)	351.9127	(0.2643)
GB	42.8151	(0.2019)	17.7848	(0.1224)	345.5804	(0.3476)
US	37.8488	(0.3849)	23.5901	(0.0231)	354.2148	(0.2370)
BR	48.1781	(0.0844)	18.1693	(0.1106)	348.1098	(0.3130)
CN	38.4314	(0.3600)	14.0299	(0.2988)	351.5672	(0.2686)
CZ	43.1293	(0.1927)	17.3848	(0.1357)	347.9981	(0.3145)
HU	29.7042	(0.7613)	20.6562	(0.0456)	362.9415	(0.1496)
IN	31.2499	(0.6939)	21.1327	(0.0485)	353.4444	(0.2460)
ID	37.6455	(0.3938)	19.9309	(0.0484)	359.0059	(0.1858)
KZ	38.2421	(0.3680)	12.5992	(0.3988)	351.7041	(0.2669)
MX	38.6898	(0.3491)	21.0264	(0.0500)	343.3685	(0.3791)
PL	47.6299	(0.0930)	15.7748	(0.2018)	353.1084	(0.2499)
RO	48.0133	(0.0869)	14.5080	(0.2694)	360.9243	(0.1675)
RU	93.5614	(0.0000)*	11.9810	(0.4472)	354.3970	(0.2349)
SK	44.7951	(0.1493)	14.2026	(0.2880)	344.4200	(0.3640)
ZA	33.2438	(0.6004)	19.2926	(0.0417)	359.9937	(0.1762)
TH	44.3114	(0.1610)	22.1494	(0.0359)	342.3782	(0.3935)
TR	23.8218	(0.9404)	16.9671	(0.1508)	345.3351	(0.3510)
VE	34.3910	(0.5452)	21.1196	(0.0487)	348.0650	(0.3136)

Notes: Figures in parentheses represents p-values associated with the tests. The autocorrelation LM test, tests the null hypothesis of no serial correlation, normality test reports the Jarque-Bera residual normality tests (null hypothesis of residuals are multivariate normal) and heteroscedasticity test, tests the null of homoscedasticity. Significance at 1 % denoted by *.

APPENDIX 5.II

Causal Relationship between Energy Consumption and Economic Growth

Table A.5.II.1: Summary Results of the Causal Relationship

Country	GDP →Energy	Energy →GDP
	DEVELOPED COUNTRIES	
Australia (AU)		
Austria (AT)	√	
Belgium (BE)		
Canada (CA)		
Denmark (DK)	√	
Finland (FI)		
France (FR)	√	
Germany (DE)		
Greece (GR)	√	
Ireland (IE)		
Italy (IT)	√	
Japan (JP)	√	
Korea (KR)	√	
Luxembourg (LU)		
Netherlands (NL)		√
New Zealand (NZ)	√	
Norway (NO)		
Portugal (PT)		
Spain (ES)	√	
Sweden (SE)	√	
Switzerland (CH)	√	
United Kingdom(GB)	√	
United States (US)		
	DEVELOPING COUNTRIES	
Brazil (BR)		
China (CH)	√	
Czech Republic (CZ)	√	
Hungary (HU)		
India (IN)		
Indonesia (ID)		
Kazakhstan (KZ)	√	
Mexico (MX)		
Poland (PL)	√	
Romania (RO)	√	
Russia (RU)		
Slovak Republic (SK)	√	√
South Africa (ZA)		
Thailand (TH)		
Turkey (TR)		
Venezuela (VE)		

Notes: $E \leftrightarrow Y$, $E \rightarrow Y$ and $Y \rightarrow E$ indicate bidirectional causality between energy and output, unidirectional causality running from energy to output and unidirectional causality running from output to energy.

CHAPTER SIX

CONCLUSIONS

6.1 Introduction

This study has addressed the fundamental questions on energy demand, energy input substitution and the effect of energy restrictions on economic growth for a group of developed and developing countries. More specifically, this study examines three issues: (i) the determinants of energy demand; (ii) the degree of substitutability of energy with other factors of production and the degree of substitutability among individual fuels and (iii) the relationship between energy use and economic growth. Panel data with both cross section and time series dimensions were used to analyse these issues.

6.2 Summary of the Empirical Results

A panel data set of 23 developed countries and 16 developing countries during the time period 1978 to 2003 was analysed to examine the determinants of energy demand. The energy demand model was estimated using two distinct approaches: (i) traditional panel data techniques for static models such as pooled ordinary least square (OLS), fixed effects (FE) model and random effects (RE) model and (ii) estimators for a dynamic heterogeneous panel model, namely the mean group (MG) and the pooled mean group (PMG) estimators. The empirical result indicates that income is positive and significant. Moreover, the income elasticity is larger in developing countries than in developed countries. This is consistent with income elasticity rising with income at low levels of income and falling with income at high levels of income. That is, energy demand grows more rapidly in the developing countries, as commercial energy sources are substituted for biomass fuels and industry replaces agriculture. As developed countries develop, on the contrary, information-intensive production might replace material-intensive production, lowering the income elasticity below unity. On the other hand, the estimated price elasticity is significant and negative. This effect is larger in developed countries than in developing countries, suggesting that at low levels of income most energy is consumed as necessity, while as incomes increase, energy use becomes more flexible. Therefore, developed countries will react more to price changes as there are greater substitution possibilities in the developed countries. Degree of industrialisation has a positive and significant impact, although smaller in developed countries. This result is consistent with the finding of smaller income elasticity in developed countries. As the economy grows, the impact of the degree of industrialisation decreases, because information-intensive production has partly replaced material-intensive production. Technological progress is also significant on explaining energy demand. It has a positive impact on developed countries and a negative impact on developing countries. This result suggests that technological change is energy using in developed countries and energy saving in developing countries. One possible explanation for this is that, as demonstrated by Ishiguro and Akiyama (1995a, 1995b), technologies used in developing countries are considerably less energy efficient and more polluting. Moreover, the developing countries are more reluctant to increase energy efficiency and reduce pollution from energy use because of the large investment required.

The role of energy use in the industrial sector has also been examined in Chapter 4 of this dissertation. Using the time series data sets for a group of major developed countries and a group of energy-producer developing countries, this study analysed the scope for substitution between factors of production and type of fuels in a framework that allowed interaction between inter-factor and inter-fuel substitution effects. The econometric approach used was the Seemingly Unrelated Regression Equations (SURE), which allows for an adequate treatment of measurement errors in share equations as well as the imposition of theoretical restrictions. The empirical finding shows that there is substitutability between energy and both capital and labour, implying that there is a moderate responsiveness of factor inputs to changing factor prices. This result suggests that there is flexibility in the factor input mix in the inter-factor substitution model. In the inter-fuel substitution model, the results show that large substitution took place from petroleum to coal, natural gas and especially to electricity. The substitution relationship between coal and natural gas is significant, suggesting that the use of coal in the industrial sector can be replaced by the use of natural gas, which is cleaner-burning and has lower environmental impact.

In Chapters 3 and 4, we have showed that there is a strong relationship between energy use and economic growth. In particular, Chapter 3 showed that income is one of the important determinants of energy demand. Chapter 4, on the other hand, examined the importance of energy as an input to the production process that generates GDP. This led to further investigation to empirically examine the causality between energy consumption and economic growth for 23 developed countries and 16 developing countries. In Chapter 5, the test of the causal relationship between energy consumption and economic growth is conducted in three stages: (i) the panel unit root test, (ii) the panel cointegration test and (iii) the VECM. The first two approaches are panel based to overcome the problem of a short time span in the data. The panel unit root tests suggest that all the series are integrated of order one, I(1). The panel cointegration test (Larsson's test) provides evidence that there are two cointegrating vectors between the series. The results of the Granger causality tests based on VECM indicate that there is a unidirectional causality running from GDP to energy consumption in 12 developed countries and in 5 developing countries, suggesting that it is GDP that drives energy consumption in these countries. The results also provide evidence of unidirectional causality from energy to GDP in Netherlands and bidirectional causality is found in Slovak Republic.

6.2 Policy Implications

The empirical evidences obtained from Chapters 3 to 5 provide a basis for the formulation of economic or energy policy. The elasticities obtained in Chapter 3 could be used for further policy analysis. The higher levels of long-run income elasticity in developing countries compared to developed countries imply that developing countries are playing an increasingly important role in the world energy market. The response of energy demand to income will be larger in developing countries than in developed countries. If this continues to be the scenario, there will be major implications for world energy markets. Future energy demands are likely to have a major impact both for the environment and for energy supply policy within developing countries, unless the government takes measures for energy conservation. The low price elasticities indicate that higher prices will have only a minor effect in energy consumption. This result suggests that policies that levy taxes on energy are unlikely to be effective, especially in the case of developing countries. In other words, policy makers could not rely on the price of energy as a policy instrument. This highlights that another policy initiative is needed. For instance, developing countries should consider measures such as R&D incentives that discourage the use of inefficient and high polluting equipments and machinery, in favour of the more efficient and low polluting ones. Additional measures, such as education on energy conservation and advertising campaigns, might be able to change people's life styles.

The existence of input substitution in Chapter 4 suggests that there is some flexibility in energy policy options and energy utilisation. This study has shown that energy markets and the price mechanism are likely to work reasonably well by inducing substitution both between energy and non-energy products and across fuels. In view of this, therefore, increases in the price of energy can to some extent be accommodated by replacing energy with other non-energy inputs. With regards to inter-fuel substitution, there is scope for shifting towards cleaner fuels such as natural gas, in the United States, Canada, Brazil and Indonesia. In order to encourage more countries to use natural gas as opposed to coal, a government for instance could give incentives to the industrial sector to use environmentally-friendly sources of energy and impose a tax on coal.

With respect to the relationships between energy consumption and economic growth, the results obtained in Chapter 5 show that the direction of causality varies across countries. A causality running from GDP to energy consumption is more likely to be found in developed countries. Thus, energy conservation policies would have a less damaging effect on growth in developed countries. Furthermore, as shown in Chapter

3, given the relative price insensitivity, it is unlikely that market mechanisms such as energy taxes will succeed. As before, to deal with the problem of growing energy demand, the best policy would be to change energy using technologies for more efficient ones. Hence, developing countries should aim for decreasing energy intensity, decreasing emission intensity and increasing energy efficiency. Equally importantly, developed countries can provide international support and action and also introduce multilateral programmes to transfer the technology to developing countries, so that these policies may be feasible.

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