Thesis Title: The European Union’s Technological and Economic Development: A Study on Production of Renewable Energy

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List of Abbreviations

GDP	Gross domestic product
MG	Mean group
NonRE	Non-renewable energy
PMG	Pooled mean group
PRE	Production of renewable energy
RDnonRE	Research and development in non-renewable energy
RDRE	Research and development in renewable energy
R&D	Research and development
SS	Supporting schemes

Table of contents

List of Tables

Abstract

This thesis answer the two main questions, firstly, the role of technological development in the production of RE with special reference to investment subsidy in supporting schemes and research and development (R&D). Investment subsidies in supporting schemes and R&D are widely used to promote RE technology and considered economical, efficient instruments than regulation approach. Secondly, the study investigates the relationship between the production of RE and the economic development. Panel data for twelve European Union (EU) countries are analysed for the period 1990 to 2013. The study uses a Cobb Douglas production function to estimate the EU's rational behaviour of investment subsidy between supporting schemes and R&D. For the estimation techniques, the study uses the unit root test, cointegration test, and dynamic pooling average group (PMG) model. The selection of the PMG model is based on the results of diagnostic tests, i.e. cross-sectional dependence, heteroskedasticity, serial correlation, and Hausman. Furthermore, the cointegration test confirms that in the long-run all the variables move together to achieve equilibrium. The PMG model confirms the effect of the independent variables on the dependent variable. Thus, it is concluded that the investment subsidies in supporting schemes have a positive and significant effect on the production of renewable energy in the long-run. However, the investment subsidy in research and development also has a positive but insignificant effect on the production of renewable energy in the long-run. Based on the long-run result, thus the study suggests that it is more rational to invest subsidy in supporting schemes than in R&D. In order to find the relationship between the production of RE and economic development, the result of the study confirms that economic development has a positive and significant impact on the production of renewable energy both in the short-and long-run. In addition, the test of the causality confirms the bidirectional relationship between production of RE and economic development. The bidirectional relationship states that both energy and economic growth are associated and complement each other.

Keywords: Renewable energy, Investment subsidy, Supporting schemes, Research and development, Technological Development, Pooling average mean technique

1. Introduction

The energy crisis in the 1970s spurred countries to find new sources of energy, particularly renewable energy (RE). Approximately 138 countries had set RE goals by the end of 2020 (REN21, 2013). The use of energy from renewable sources, such as wind, photovoltaic, ocean, biomass, solar, geothermal and waste has increased. The International Energy Agency (2015) reported that RE contributes 13.5 per cent of the world's Total Primary Energy Supply. In 2015 the investment in RE had reached $286 billion, which is more than six times the investment in 2014 (Frankfurt School-UNEP Centre, 2016). The European Commission report (2014) shows that the investment subsidy for RE amounted to €36 billion in the EU countries in 2011, which is more than half of the total worldwide subsidies for RE. Also, the cost to support RE varies from country to country. For example, Germany increased from €9.5 billion in 2010 to €12.7 billion by 2012 and Spain from €5.4 billion in 2010 to €8.4 billion in 2012 (European Commission, 2014). The report of Frankfurt School-UNEP Centre (2016) showed that the investment by developed countries in RE had reached $130 billion with a major interest in new technology or technological development. The technological development enables the country to efficiently increase output with the same amount of inputs (Sala i Martin, 1990). Solow (1956) was the pioneered who study the effect of technology in the growth model. Hence, this thesis aims to study the role of technology and economic growth regarding production of RE. Therefore, this thesis intends to answer the questions (1) What are the effects of technological development (i.e. supporting schemes and R&D) on the production of RE? and (2) What is the relationship between economic growth and the production of RE?

Firstly, this thesis discusses the effect of technological development on the production of RE with special reference to investment subsidy in supporting schemes and research and development (R&D). Menanteau, Finon, & Lamy (2003a) considered supporting schemes and research and development as economical, efficient instruments than regulation approach. Secondly, the study investigates the relationship between the economic development and the production of RE in twelve European Union (EU) countries.

The EU countries triggered the slow pace investment subsidy programme in the early 90s primarily focused on RE technology through supporting schemes and R&D programmes (European Commission, 2014; Haas et al., 2011) to increase the production of RE. The EU countries adopted an RE policy to achieve unilateral RE targets. However, the EU countries are free to choose distinctive measures to meet their targets. Article 4 of the Renewable Energy Directive 2009/28/EC, states that the EU aims to derive 20 per cent of its energy from RE sources by 2020 and at least 10 per cent of its transportation fuel from RE sources (European Commission, 2012). Furthermore, investment subsidies are provided through a wide range of supporting schemes such as quota system, tradable certificates and feed-in tariff.

The supporting schemes vary among the EU countries. For example, in Belgium, RE is promoted through a quota system combine with tradable certificates to generate electricity. The federal government sets the per cent, or an amount of energy that comes from renewable sources is mandated. At regional level certificate trading is regulated, which bounds the RE producers to have green certificates to fulfil the quota obligations for the energy they supply to final consumers. RE producers allowed selling their electricity to the government at the federal and regional level and thus motivated by tax exemption on their investment cost as well as by introducing several other policies to promote RE such as installation and usage of RES-installations (L´Hoost, Leysen, & Preillon, 2014). In Austria, RE mainly promoted through a feed-in tariff, which defined as: The public energy companies are obliged to buy renewable electricity from the local producers. In responses, the public energy companies pay 90 per cent of the average electricity price paid by the final consumer. By this way, the ordinary energy users are encouraged to produce more energy/electricity and increase their profit by bringing improvement in the RE technology and reducing cost per output. Lesser and Su (2008) consider a feed-in tariff more effective compared to other supporting scheme policies such as quota system and the tax exemption for the promotion of RE technology. Furthermore, a feed-in tariff is cost-efficient enough to compete with the conventional energy technologies in the long-run.

In like manner, research and development (R&D) is another important component in RE and plays a key role in technological development (ISPRE, 2009; Jones, 1998). Furthermore, R&D matures the technology by the accumulation of knowledge and knowledge spillover. Furthermore, the interest of researchers regarding profit expectations, providing clean energy for consumption, induces them to create new ideas or imitate existing technology, which contributes to technological development (Jones, 1998). According to Garces and Daim (2010), once the technology matured, it secures the RE system and enhances the production of RE. The European Union formed the Strategic Energy Technology Plan (SET-Plan) to increase the R&D subsidy from €3.2 to €5.4 billion per year under the 2020 framework

(European Union, 2014). The EU is enhancing investment close to €6 billion in the energy sector in R&D to promote the RE sector/technology for the period 2014-2020. In addition, the report estimated that technological development would enable a reduction in the cost of production by up to 30-80 per cent (European Commission, 2012).

According to Toman and Jemelkova (2003), energy development, in the broader sense, means the increased provision and use of energy services for domestic as well as industry. Therefore, energy development is considered to be at the core of economic development. The increased energy consumption in domestic and industrial production may contribute to the depletion of conventional energy resources and increased in environmental pollutions. Furthermore, it is conceivable that conventional energy resources will eventually run out one day (Jones, 1998). Contrary to that, RE not only reduces pollution but are also undeleted energy sources, which may contribute to help stimulate green growth (Smulders, Toman, & Withagen, 2014). According to the Organisation for Economic Cooperation and Development (OECD) (2011), "Green growth is about fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. It is also about fostering investment and innovation which will underpin sustained growth and give rise to new economic opportunities".

According to Apergis and Danuletiu (2014), the causality relationship between RE and economic development indicates that the economy is energy based and that policymakers should design suitable policies to promote energy. There are two hypotheses likely used for explaining the causality relationship of RE conservation policies and economic development. For example, the bidirectional hypothesis contends that energy and economic growth associated with each other, which implies that the relationship is interdependent and complement. Conversely, the neutral hypothesis stipulates that there is no causal relationship between energy consumption and economic growth. The inference is that economic development has an insignificant impact on the energy conservation policies (Apergis & Payne, 2010b; Armeanu, Vintila, & Gherghina, 2017).

Although several studies have produced estimates concerning the production of RE such as quota system, tradable certificates, feed-in tariff and research and development, however, this thesis is different in a number of ways. Firstly, this thesis studies the effect of investment subsidy in supporting schemes and R&D in contribution to technological development, which finally leads to enhance the production of RE. Furthermore, the thesis studies the magnitude and direction of the effects on the production of RE whether production of RE benefits from substituting supporting schemes for R&D. Secondly, the thesis investigates the effect of economic development on the production of RE. Thirdly, the Cobb-Douglas production function is used for modelling and to determine the relationship between the dependent variables and independent variable. Finally, the study applies dynamic pooled mean group (PMG) technique for empirical analysis. The reason for choosing such technique over other alternatives discussed in Section 5.

1.1 Objectives of the Study

The main objective of the study is to investigate the effect of technological development (i.e. supporting schemes and R&D) on the production of RE. In addition, this thesis also intends to investigate the relationship between the economic development and the production of RE in twelve EU countries from 1990 to 2013.

1.2 Hypotheses

Hypothesis 1: An increase investment subsidy in supporting schemes (SS) increases production of RE.

Hypothesis 2: An increase investment subsidy in research and development enhances the production of RE.

Hypothesis 3: The production of RE and economic development has bidirectional causality.

The remainder of the study is as follows: Chapter 2 contains the literature review related to, supporting schemes, and research and development and economic development. Chapter 3 explains the theoretical framework used in the study; basic Solow growth model augmented with natural energy sources and technological development. Chapter 4 discusses the methodology. Chapter 5 explains the empirical model based on the panel data analysis used for estimation purposes. Chapter 6 and 7 discuss the results and provides the conclusion, respectively.

2. Literature review

A government-provided supporting schemes encourages the production of RE through technology. A study on wind capacity in OECD, by Jaraite, Karimu, Kažukauskas and Kazukauskas (2015), shows that renewable energy schemes promote the production of RE and impact on the economic growth in the short-run. In contrast, the study finds no support for the long-run and considers that this is due to insufficient development of the wind and solar technology. A study by Lam, Woo, Kahrl and Yu (2013) provides supporting arguments regarding supporting schemes to promote wind technology. The study focuses on the role of the government of China to promote investment in wind energy development. The data were collected through a survey in Mainland China and the Hong Kong Special Administration Region. The study found that wind energy developers are more interested in cash flow supporting schemes, such as high feed-in tariff, government financial assistance, and inexpensive transmission access. These schemes enable wind energy developers to reduce cost. As a result, the government provided supporting schemes encourage to enhance production of RE. Johnstone, Hascic and Popp (2008a) studied the role of supporting schemes to promote technological development with special reference to renewable energy (RE). The study uses the fixed effects model to analyse the data. The data contain a panel of twenty-five OECD countries over the period 1978-2003. The empirical results confirm the positive role of supporting schemes regarding developing new technologies, except for biomass. Furthermore, the study adds that different types of supporting schemes are helpful for the promotion of RE. For example, investment incentives encourage technological development in solar and waste-to-energy technologies. Similarly, feed-in tariff encourages biomass and trade certificates to support wind technology. According to the International Science Panel on Renewable Energy (ISPRE, 2009), the improvement in technology has a causality relationship with research and development (R&D) in RE technology. A study by Garces and Daim (2010) examines the investment in R&D to promote RE technology in the US economy. The study uses 33 years of data for the estimation. The cointegration technique is used to analyse the dynamic relationship of the variables in the short-run as well as the long-run. The study finds that investment in R&D to promote RE technology has a positive impact on the economy in the short-run and the long-run.

In like manner, a study by Popp, Newell and Jaffe (2010) finds that investment in R&D to promote RE technology has a positive role in energy production. Furthermore, the study confirms that investment in R&D reduces the cost of output as well as environmental pollution. In addition, the study shows the significant role of R&D in terms of reducing innovation costs for wind turbine farms in Denmark, Germany, and the United Kingdom (UK). The study finds that investment in R&D reduces the cost related to technological development and converts the technology into carbon-free wind turbines. The study uses time series data for the countries organised as a panel dataset. The study uses two techniques to investigate the R&D impact on innovation for wind energy in Denmark: firstly, the study uses a survey of the literature, and, secondly, the study uses the two-factor learning curve (2FLC) model based on knowledge stock. The study finds that, in Denmark, the role of R&D to reduce the cost of wind energy is more successful compared to the other two countries – Germany and the United Kingdom (UK). A study by Armeanu, Vintila and Gherghina, (2017) include research and development expenditure as a control variable in renewable energy in EU-28 countries. For econometric model, the study uses panel cointegration test, unit root test and panel error correction model for the period 2003-2014. The study concludes that R&D consumption in renewable energy has a positive effect in the short-run as well as in the long-run. However, a study by Lam et al. (2013) finds that international R&D cooperation is less important for RE technology to generate wind energy output. A study by Doner (2007) suggests that among the available options for encouraging the development of renewable energy technology, the correct policy decision might be helpful to achieve sustainable growth as well as RE technologies in the US. The bottom line is that EU countries should be rational in the allocation of investment subsidy between supporting schemes and R&D to promote renewable technologies effectively.

A study by Van (2016) shows the impact of energy on the economic development and RE. According to him, the strong correlation exists between energy with economic development. Later, he divides the energy into two separate inputs, i.e. RE and conventional energy. Hence, the study concludes that RE is weakly correlated with economic development when conventional energy used as a control variable. In respect to finding the relationship of production of RE with economic development, a study by Armeanu et al. (2017) finds the contribution of RE in economic development. The study used cointegration regression set on panel fully modified and dynamic ordinary least square regression technique for 28 EU countries. Based on the techniques, the results confirm the positive influence related to the production of RE on GDP. According to them, a 1 per cent increase in RE increases GDP per capita by 0.05 - 0.06 per cent. However, the result based on Granger causality (panel vector error correction model) confirms the unidirectional causal relationship exists in both the short run and the long run from economic growth to the production of RE. Contrary to that, a study by Shafiei, Salim and Cabalu (2014) finds the bidirectional causality relationship between the production of renewable energy (RE) on economic activities. Further, the study investigates whether economic growth stimulates from RE sources. According to them, RE energy stimulates economic growth in OECD countries. Moreover, the study confirms that there is bidirectional causality between economic activities and RE consumption in short- and long-run. The study confirms that high level of economic growth leads to high level of RE consumption and vice versa.

Similarly, to identify the bidirectional relationship between economic development and renewable energy (RE) in the long-run, a study by Apergis and Danuletiu (2014) uses the data from eighty countries. The study uses the causality test of Canning and Pedroni, which confirms the causality relationship between economic growth and RE. Furthermore, the empirical findings confirm the interdependent relationship of RE and economic development, which implies that economic development encourages the use of renewable energy. Another study by Apergis and Payne (2010, 2010b), provides the supporting arguments that economic development encourages the use of RE. The study uses data from 13 Eurasian countries over the period 1992-2007 to confirm the bidirectional (interdependency) causality relationship between RE and economic development by applying panel error correction model (PECM). Besides, their study uses the heterogeneous panel cointegration test to determine the long-run relationships among the variables: RE, real gross fixed capital formation, and labour force. By using the same variables and estimation technique, Apergis and Payne (2010a) identify the relationship between renewable energy consumption and economic development for a panel of twenty OECD countries over the period 1995-2005. The Granger causality test confirms the positive bidirectional causality between RE consumption and economic development in both the short-run and the long-run.

3. Theoretical Framework

3.1 Neoclassical Growth Model

In 1930's, Wassily Leontief presented input-output model (Bjerkholt, Olav, & Heinz, 2006). He raised a question regarding production and demand. According to him, "what is the optimal level of production that satisfies the total demand for the product"? Based on the Leontief production technology, the Roy Harrod (1939) and Evsey Domar (1946) developed the first and simplest economic growth model. According to them, the growth model has two main components: saving-investment ratio and capital-output ratio. The model is positively related to its saving-investment ratio and negatively related to its capital-output ratio. Moreover, the capital factor is a crucial factor in economic development, but since it remains constant in the short-run, the rate of growth of a nation depends largely on the rate of saving. In addition, they focus on the possibility of steady growth through adjustment of supply of demand for capital. They assume that only capital and labour had a perfect substitute and used in the same proportion. Bottom line, the model concludes that the higher the saving-investment ratio and the lower the capital-output ratio, the faster an economy grows.

However, shortly after, the neoclassical growth model explains the major drawbacks of the Harrod-Domar’s growth model. For example, the Harrod-Domar growth model mainly focuses on savings and capital as the main factors of economic growth but ignores the idea of the diminishing returns as being a factor. This idea was criticised on assumption of labour surplus countries that could replaced with capital and vice versa. In addition, the lower growth rate may be the reason of lower productivity of capital rather than the availability of capital (saving), i.e., for the developing countries, it is not easy to increase saving, particularly when they are fighting for enough food to eat. The model explains the boom and bust cycles through the importance of capital. They assume the linear relationship between capital to output ratio and capital to labour ratio. It implies that to reach equilibrium, both capital to output ratio and fixed capital to labour should grow at the same rate, which is not possible.

In summary, following are the very remote assumptions in the long run. Then, Solow-Sawn (1956) published their articles and replaced Leontief production function with the neoclassical growth theory. In neoclassical growth model theory, total production is a function of labour, capital, and technology over a period.

$$\boldsymbol{Y(t) = K(t)^{\beta}(A(t)L(t))^{1-\beta}} \quad \text{Equation 1}$$

Where Y represents output, K is capital and L is labour, and A is a measure of technology at time *t*. Also, Solow discussed the idea of constant returns on capital, labour and technology.

Further, Solow assumed that the rate of saving, population growth rate, and technology progress as exogenous. Solow define that labour force is coming from the population and its growth rate is equal to$\dot{L}(t)/L(t) = n$.

Solow considered technology as the main factor of growth, which ignored in Harrod-Domar growth model. Solow put aside the assumption of a fixed ratio between production factors and introduced a ratio variable. Furthermore, the substitution of labour by capital and, on the other hand, technological progress, which he considered to be a key determinant of growth in the long run. Solow discusses that the technology grows at the same rate as other variables in the model. Due to that, technological development occurs. According to him, 'Technology is like manna from heaven' (Jones, 1998; Romer, 2001). It implies that technology automatically descends from the heaven and benefitted the different sectors of the economy. Solow model does not talk about where the technology comes from. However, he considered that there is technological progress that is growing at a constant rate$\dot{A}(t/A(t) = g$.

Finally, the production assumes a constant return to scale feature, and the output per effective unit of labour *y = Y/L*, and capital per worker, *k=K/L:*

$$y = k^{\boldsymbol{\beta}}$$

This expression defines as, with more capital per labour, firms produce more output per labour. On the other hand, there are diminishing returns to capital per worker; it implies that, an additional unit of capital provided to the labour increase the output of that labour less and less.

Solow also defines how capital accumulated, which can be written as

$$\dot{K}(t) = sY(t) - dK(t)$$

According to the capital accumulated equation, the capital stock, is equal to the sum of investment, *sY(t)*, less the amount of depreciation that occurs during the production process *dk(t)*. Further, Solow assumes that worker/consumers save of their combined wage and rental income.

Furthermore, conventional energy sources (fossil oil, gas and coal) are included into the basic Solow growth model with technological progress.

Hence, Solow growth production function looks like

$$\boldsymbol{Y = AK^{\beta}E^{\varphi}L^{1-\beta-\varphi}} \qquad \text{Equation 2}$$

Where $\boldsymbol{Y}$ represents the total amount of production of the final good, in the continuous time. $\boldsymbol{K}$ is capital stock, $\boldsymbol{L}$ is labour, $\boldsymbol{E}$ represents the energy input into production, and $\boldsymbol{A}$ is exogenous technological progress, which assumes the technology index multiplies the entire production function rather than just labour and/or capital. The study assumes that $\boldsymbol{\varphi}$is between zero and one and that $\boldsymbol{\beta + \varphi}$ are less than 1. Hence, this production function exhibits a constant return to scale in capital, energy, technology, and labour, reflecting the standard replication argument.

The dynamics of capital, labour and the technology are the same as above: $K(\dot{t})$= sY- dK, $L(\dot{t}) = nL(t) and\ A(\dot{t}) = gA(t)$. In-addition, the new assumption concerns energy resources.

Further, the study assumes that $\boldsymbol{R_o}$denotes the initial stock of natural energy resources that depletes when $\boldsymbol{E}$ amount of energy is used in production function. Moreover, it is assumed that the natural resource stock obey the differential equation similar to capital accumulation equation, only it dissipates rather than accumulates:

$$\boldsymbol{\dot{R} = -E} \qquad \text{Equation 3}$$

$\boldsymbol{E}$ can be determined: it is the amount of energy used in production each period. For example, a firm/industry would demand energy until the marginal product of energy fell to the price of energy, and other firm/industry would supply energy based on the market price.

On simple assumption is that in the long-run, a fixed share of the remaining stock of energy is used in production each period[1],$\boldsymbol{s_E = E/R}$. Let$\boldsymbol{s_E}$ is some number falls between zero and one. Dividing the equation 2 by **R,** the total stock of energy remaining in the economy declines over time at the rate $\boldsymbol{s_E}$:

[1] This assumption is parallel to the constant savings-rate assumption of the Solow model.

$$\dot{R}/_{R} = s_E$$ Equation 4

The solution to this differential equation is an equation defining the behaviour of the stock over time:

Equation 5

$$R(t) = R_o e^{-TS_E}$$

The stock exhibits the negative exponential growth at rate s_E. Since $E = s_E$R the amount of energy used in production each period is given by

Equation 6

$$E = s_E R_o e^{-TS_E}$$

Equation 5 explains that the total stock of remaining energy declines over time, the amount of energy used in production also declines over time.

3.2 The Balance Growth Path

Along the balanced growth path, the capital-output ratio **K/Y** will be constant and divide the Equation 1 with ${Y_{it}}^{\beta}$ and then solved for Y. The new equation will look like

Equation 7

$$Y = A^{\frac{1}{1-\beta}} (K/_{Y})^{\frac{\beta}{1-\beta}} E^{\frac{\varphi}{1-\beta}} L^{1-\frac{\rho}{1-\beta}}$$

8Substituting for energy use from equation 5 gives

Equation 8

$$Y_{it} = A^{\frac{1}{1-\beta}} (K/_{Y})^{\frac{\beta}{1-\beta}} (s_E R_o e^{-TS_E})^{\frac{\varphi}{1-\beta}} L^{1-\frac{\rho}{1-\beta}}$$

The term $R_o$is constant by assumption and can’t be re-generated therefore, it exhibits diminishing returns. Further, the other term related, is the negative exponent terms, which measures the depletion of the resources. The last related terms with $R_o$iss_E, which appears two times. At the first time, $s_E$is multiplying with the stocks, and secondly as the rate of depletion. It implies that, the intense use of energy stock raises current output by raising E directly. However, if a resources rate of depletion more rapid, sooner the stock would shrink.

Referring back, along with the balanced growth path, **K/Y** is constant. Therefore, taking logs and derivate of the equation 7, the growth rate of total output along a balanced growth path is

$$g_Y = g - \bar{\varphi} s_E + (1 + \bar{\varphi}) n \qquad \text{Equation 9}$$

Where the condensed notation by defining $g = g_t/(1-\beta)$ and $\bar{\varphi} = \varphi/(1-\beta)$. Finally, the growth rate of output per worker along the balanced growth path is

$$g_y = g - \bar{\varphi}(s_E + n) \qquad \text{Equation 10}$$

The final expression gives rise to several remarks. Firstly, in the long run, the faster population growth leads the pressure on the finite resources to generate energy. In response, the depletion rate s_E reduces the long run growth rate of the economy. Secondly, in order to combat with the reduction in economic development, one can argue to put $s_E = 0$, to achieve optimal policy benefits. In that case, the analysis contaminated with zero production output, since this situation ($s_E = 0$) shows that economy use no energy in production process. Thirdly, let assume that there is no technological development in the model $g = 0$. In that situation the production function exhibits diminishing returns to energy, capital and labour. This mean that as economy get larger it becomes less productive at the margin. The population growth would put more pressure on energy resources and reducing per capita growth. Finally, however, the presence of technological development g, has a potential to offset these effects. Due to technological development the labour, capital and energy will produce more output with same input. The RE technology has decisively introduced a new source of energy such as RE sources (Stern, 2010). The government promoting RE technology through investment subsidy in supporting schemes (competitive bidding, the tax levied and green certificates) and R&D may have positive effect on the production of RE and as well as on the economy. Referring to the twelve-EU countries, it is considered that the investment subsidy in supporting schemes and R&D will enable them to improve RE technology, even though, they are experiencing the different investment subsidy on supporting schemes and R&D.

4. Methodology

4.1 Estimated Model

The above theory allows us to specify the growth model as follows, in continuous time. The energy augmented into the Cobb-Douglas production function in addition to capital, labour and technology. The regression model of this study is close to that used in other studies such as (Jaraite et al., 2015; Romer, 2001; Romer, 1994; Shafiei et al., 2014; Solow, 1956).

$$Y_{it} = f(K_{it}^{\beta}, L_{it}^{€}, E_{it}^{\psi}, A_{it}^{\alpha}) \qquad \text{Equation 11}$$

$\boldsymbol{Y_{it}}$ represents the total final output yield from the energy, supporting schemes, research and development and other goods of the country *i* at time *t*, $K_{it}^{\beta}$is capital, $L_{it}^{€}$is labour, $\boldsymbol{E_{it}^{\psi}}$ is the total energy production. The study considered capital and labour as a constant and growing at a constant rate. The production of energy is mainly categories between RE and conventional energy (e.g. coal, gas, and fossil fuel). Since this study is about the RE thereon this thesis considered the production of RE as a main source of energy and considered any other sources of energy as a constant and growing at a constant rate. $\boldsymbol{A_{it}^{\alpha}}$ is the state of technology, which is available at a time and assumed to be the function of two variables.

$$A_{it} = f(SS_{it}, RD_{it}) \qquad \text{Equation 11*}$$

Where, SS_{it}^{α}, which denotes the supporting schemes to promote RE technology, and RD_{it}^{β}, which represents the R&D to promote RE technology. Moreover, the control variables *(z)* included are RDnonRE and NonRE. The variables of the state of technology are substituted into Equation 11, taking natural logs on both sides and including error terme_{it}. Hence, the above equation is converted from a deterministic relationship to a statistical one.

$$\mathrm{lnY_{it}} = ln\mathrm{E} + \alpha \ln SS + \beta \mathrm{lnRD} + 6 \ln z + e_{it} \qquad \text{Equation 12}$$

Consequently, the following log-linear in reduced-form of the aggregate Cobb-Douglas production function is used to investigate the long-run and short-run relationships among the production of RE, economic growth, supporting schemes and R&D, and the control variables, i.e. RDnonRE and NonRE:

$$PRE = \alpha_1 GDP + \alpha_2 SS + \alpha_3 NonRE + \alpha_4 RDnonRE + \alpha_5 \mathrm{RDRE} + e_{it} \qquad \text{Equation 13}$$

Where $\alpha_1 \ldots \alpha_5$ are the elasticities of the aggregate output with respect to economic development, supporting schemes and R&D and e_{it} is composed of both unobserved common factors and a random error term. The production function in Equation 13 exhibits a constant return to scale.

4.2 Data

In order to estimate the effect of economic development, supporting schemes and R&D on the production of RE in twelve EU countries, this study utilises data from the OECD iLibrary (Organisation for Economic Co-Operation and Development). The sample includes twelve EU countries for the years 1990-2013. Data for 23 years are used in this study; firstly, due to the accessibility of the data, and, secondly, in this period, the EU countries introduced investment subsidy program to boost the production of RE in total energy consumption (European Commission, 2014; Haas et al., 2011).

The following variables are used in this thesis as dependent and independent variables. The dependent variable is the total final supply and consume energy in 1000 tonnes of oil equivalent, which is assumed to be a proxy for the production of renewable energy (PRE). In addition, the independent variables are as follows. The data of total net-capacity of RE in megawatts used as a proxy variable for supporting schemes (SS) and the total net-capacity of NonRE in megawatts used as a control variable. The data for Gross Domestic Product (GDP); millions measured in USD, constant prices, at 2010 exchange rates PPPs (Unit: US Dollar, Million).

All the variables are converted into log form, as it changes the interpretation of the variables. Instead of comparing millions of dollars as an absolute number, the variables measured as a per cent. For example, the per cent increase in RE has an impact on the per cent increase of PRE. This is more meaningful than using 1 million dollars, 10 million dollar or even 1000 million dollar increments because there are variations in the data that these numbers do not address. A 1 per cent increase in RE is more relevant because of the large variation in RE.

In addition, the data for both variables: investment in research and development in renewable energy sources; RDRE, and non-renewable energy sources; RDnonRE, measured in total RD in millions of NC (nominal). Further, these variables considered proxy variables for the investment subsidy in research and development to promote RE technology and NonRE technology accordingly.

The thesis considers RDnonRE and NonRE as the set of controls, as the omission of these variables leads to bias in the resulting estimates. Therefore, the panel data approach is used to estimate the model. One of the benefits of this approach is that it is the most appropriate for the control variables and reduces the risk of biased results (Baltagi, 2013). Furthermore, the fixed effects model within and random model GLS regression, PMG and MG estimation techniques are the most prominent techniques used for panel data (Apergis & Payne, 2010a; Armeanu et al., 2017; Jaraite et al., 2015; Johnstone et al., 2008b; Shafiei et al., 2014).

The student package (software) Stata 12 is used to estimate all the calculations.

5. Panel data

Panel data are a set of the number of observations of the same unit (individuals, firms) over a number of periods (Verbeek, 2004). In order to deal with the repetition of a unit's observation and time, the panel data approach is considered more reasonable. Firstly, the approach allows the identification of certain parameters and/or questions, without imposing restrictive assumptions. Secondly, panel data allow for possible changes at the individual level. For example, consider a case in which development in RE technology is noted as 2 per cent from one year to another. The panel data can, for example, identify whether this development is due to an increase of 2 per cent for all countries or whether it is 4 per cent for one-half of the country and no development for the other half. Hence, panel data are suitable to study the behaviour of individual units as well over different time periods. Finally, the panel approach is considered more accurate. In addition, the panel datasets are typically larger than cross-sectional data or time series datasets. Also, it allows explanatory variables to vary across time and individuals. In the case of control variables, panel data are the most suitable choice when compared to OLS or time series, because panel data suggest that countries or states are heterogeneous. However, time series or OLS do not control for such heterogeneity; hence, the risk of obtaining biased results increases (Baltagi, 2013). Moreover, according to Baltagi (2013) panel data provides the better understanding and dynamic of adjustment, when the relationships are dynamic in nature; large cross-sectional observation *(N)* and large time-series observation *(T)*.

Equation 13 is an empirical representation of the growth model presented in the estimated model section. In particular, firstly, the study restricted the vectors of the coefficient to be homogenous; constant across the country. Secondly, the study considered the vectors of the coefficient to be heterogeneous; allow it to vary across countries. Thereby, the study applies two variants of estimators: homogeneous estimators; (1) fixed-effect model within and (2) random effects model GLS regression, and two dynamic heterogeneous estimators; (1) the pooled mean group (PMG) estimator of Pesaran, Shin and Smith (1999) and (2) the mean-group (MG) estimator of Pesaran and Smith (1995).

With panel data, firstly, this thesis applies for homogeneous estimators, i.e. fixed-effects model within and random-effects model GLS regression and secondly dynamic heterogeneous estimators. At the first stage, the Equation 13 considered as an empirical representation of the regression model. The study applies fixed-effect within the model as the effect of a change in explanatory variables is the same for all the units and all periods but where the average level of unit *i* may be different from unit *j*. In addition, α_i captures the effects of *i-th* EU countries and is considered constant over time and country. In the standard case, ϵ_{it} is assumed to be independent and identically distributed over country and time, with zero mean and variance (6^2). In Equation 13, we consider α_i as *N* fixed unknown parameters, and, hence, Equation 13 is referred to as the standard fixed effects model and looks likes:

$$PRE = \alpha_{it} + \upsilon SS + \tau\, RDRE + \varphi NonRE + \chi RDNonRE + \psi GDP + \epsilon_{it} \qquad \text{Equation 13*}$$

However, an alternative approach (random effects model) to estimate Equation 13 is to consider α_i different but treat it as drawings from a distribution with mean μ and variance 6_α^2. In addition, the intercept of the individuals is assumed to be independent of the explanatory variables. This leads to the random effects model allowing the individual effects α_i to be treated as random. The error term in the random effects model depends on the time invariant component α_i and a remainder component ϵ_{it}, which are uncorrelated over time. In the case of the random effects model, Equation 13 will look like:

$$PRE = \mu + \alpha_{it} + \upsilon SS + \tau\, RDRE + \varphi NonRE + \chi RDNonRE + \psi GDP + \epsilon_{it} \qquad \text{Equation 13**}$$

Whereas μ stands for the intercept term.

At the second stage, in the case of dynamic heterogeneous estimators, where the asymptotics of large *N* and large *T*, the dynamic model such as pooled mean group (PMG) and mean-group (MG) gives consistent and efficient estimator. The PMG and MG estimators are different from the asymptotics of tradition large *N* and small *T;* such as fixed- or random-effect estimators or combination of fixed-effects estimators and instrumental variable estimators (Baltagi, 2013; Blackburne III & Frank, 2007). In addition, in case of large *N* and large *T* literature, the assumption of homogeneity of slope parameter is often inappropriate. However, it raises concern over nonstationarity. The paper by Pesaran, Shin, and Smith (1999) offers two techniques PMG and MG. These techniques dealt with the nonstationarity dynamic panels in which the parameters are heterogeneous across groups.

Furthermore, the MG estimator based on the estimation of *T* time-series and averaging the coefficient, however, the PMG estimator based on a combination of pooling and average of coefficients (Blackburne III & Frank, 2007). The MG estimator allows to fit separately for each group, and a simple arithmetic average of the coefficients calculated. Further, the MG allows the intercepts, slopes, and error variances to differ across groups. In like manner, the PMG also allows the intercept, coefficient of short-run and error variances to differ across groups, but in case of long-run its constraints for the long-run coefficient to be equal across the group, which is a prominent difference between MG and PMG technique.

The MG and PMG estimators can write as:

Equation 13, assuming as an autoregressive distributive lag (ARDL) (p, $q_1 \dots, q_k$) dynamic panel specification form

$$y_{it} = \sum_{k=1}^{p} \varphi_{ik} y_{i,t-k} + \sum_{k=0}^{q} \beta_{ik} X_{i,t-k} + \mu_{it} + e_{it}$$

Where the number of groups $i = 1,2...N$; the number of periods $t=1,2...N$. $X_{i,t}$ is a $K\times 1$ vector of explanatory variables (GDP, RE, etc); β_{ik} are the $K\times 1$ coefficient vectors; φ_{ik} are scalars and μ_{it} is the group-specific effect.

In order to obtain consistent and efficient dynamic heterogeneous estimator, this study applies the Hausman test to choose between the MG and PMG techniques. In the long-run, the PMG constraints that elasticise to be equal across all panels, and reject the alternative hypothesis of slope homogeneity empirically (i.e. MG). Thus, the pooling across countries yields efficient and consistent estimates when the restrictions are true.

Furthermore, to avoid the bias in the standard errors and less efficiency in the result, this thesis control for some diagnostic test, i.e. cross-section dependence, heteroskedasticity and serial correlation. Hence, by applying these tests, the study enables to apply an appropriate estimation method between the homogeneous and heterogeneous estimators. According to Bhattacharya, Paramati, Ozturk, and Bhattacharya (2016), a proper estimation technique needed to avoid spurious regression arising from the cross-sectional dependence, heteroskedasticity and serial correlation.

Before estimating the four models as discussed, four key steps are performed in our empirical strategy: firstly, this thesis studies the time-series properties of the data by considering unit root test. In the second stage, the diagnostic test (cross-section dependence, heteroskedasticity and serial correlation) applied. Thirdly, a cointegration test to determine the long-run relationship between the dependent and independent variables and lastly causality analysis to determine the causality dynamic and to answer hypothesis as presented in the introduction section.

5.1 Unit Root Test

According to Verback (2004), cross-sectional data contain an additional source of information that should be exploited; therefore, researchers use time series analysis, such as unit roots and co-integration techniques (Bhattacharya et al., 2016; Garces & Daim, 2010; Jaraite et al., 2015). The study examines the causal relationship between dependent and the independent variables presented in the Equation 13. Also, the study identifies each time series variables, and whether the series is stationary or (non)stationary. According to Greene (2009), the unit root test exhibits whether the data are (non)stationary, as well as avoids spurious regression. For stationary time series, the shocks gradually decrease as time progresses; also, there is a possibility that the process reverts to the mean. However, in non-stationary data, the shocks persist over time, and there is no possibility to completely revert to the mean (Intriligator, Bodkin, & Hsiao, 1996).

According to Philips (1987), the unit root test is commonly used to detect the (non)stationarity of the data in the linear regression model. Furthermore, it indicates whether the variable is (non)stationary either at the level or 1st difference. In order to determine whether the variables of Equation 13 are stationary at the level of 1st difference, the study employs the unit root test.

In the Panel data unit root test, consider the autoregressive model:

$$y_{it} = \beta_i + \alpha_i y_{i,t-1} + e_{it} \qquad \text{Equation 13.1.1}$$

Which can be written with a first difference as:

$$\Delta y_{it} = \beta_i + \mu_i y_{i,t-1} + e_{it} \qquad \text{Equation 13.1.2}$$

Where from Equation 13.1.1, $\beta_i$is the intercept, $y_{i,t}$ (production of RE) is the current value of time series variables and is linearly dependent on the constant term β_i plus $y_{i,t-1}(RDRE, RDnoRE, GDP\ etc)$, the previous year value, and error term e_{it}.

To detect whether the equation does contain stationarity or (non)stationarity, the study run the regression and test the hypothesis, that is, $\mu_i = 0$ and alternative $\mu_i < 0$. Whereas, $\mu_i = \alpha_i - 1$. and $\mu_i = 0$, for all i; corresponds to unit root. The null and alternative hypothesis can be written as:

Null hypothesis: $\mu_i = 0$ (series has unit root)

Alternative hypothesis: $\mu_i < 0$ (reject the null hypothesis)

The Levin-Lin-Chu unit-root test is employed, and each variable is tested through the level and 1st difference to confirm the stationarity of the data. Hence, this process prevents spurious regression. Furthermore, after confirmation that there is no unit root or integration of the same-order, say integrated *I(1)*, the next step is to test for co-integration.

5.2 Cross-Sectional Dependence

For cross-sectional dependence, this thesis employed Pesaran's (2004) test of error cross-sectional dependence (CD). This test based on an average of pairwise correlation coefficients between the time series for each of the panel units, which is used to calculate the test statistics. The test statistic general written as

$$CD = \sqrt{2T/_{N(N-1)}}\left\{\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\varphi_{ij}\right\} \qquad \text{Equation 13.2.1}$$

Where φ_{ij} are the pairwise correlation-coefficients for each of the panel units, *N* indicates the number of panel units and *T* is the number of observation from *i=1,...,N.*

The null hypothesis: The test is cross-sectional independence (errors are not correlated) *(CD ~ N (0, 1).*

According to Pesaran (2004), the test is suitable for panel models, including stationary and unit root dynamics heterogeneous; small *T* and large *N*. Above all, the test provides robust results when dealing with raw series and on the estimated residuals. According to Baltiga (2013), Pesaran's test performed well even for small *T* and large *N*, unlike Breusch-Pagan LM test.

5.3 Heteroskedasticity and Autocorrelation

Equation 13 given in estimated model section used to check for the heteroskedasticity and autocorrelation. Previous studies found that assuming homoskedastic disturbance and ignoring serial correlation when heteroskedasticity and autocorrelation are present provide result in consistent estimates of the regression coefficient, however; these estimates are inefficient. Further, the standard errors of these estimates are also biased (Baltagi, 2013; Greene, 2009; Verbeek, 2004; Wooldridge, 1960).

Firstly, this thesis dealt with the heteroskedasticity and assumes that the regression disturbances are homoskedastic with the same variance across time and country; given in Equation 13.3.1 and 13.3.2.

$$PRE = \alpha_1 GDP + \alpha_2 SS + \alpha_3 NonRE + \alpha_4 RDnonRE + \alpha_5 \text{RDRE} + e_{it} \quad \text{Equation 13.3.1}$$

$$e_{it} = \varphi_i + v_{it} \quad \text{Equation 13.3.2}$$

Where $\varphi_i$denotes the unobservable country-specific effect and v_{it} denotes the remainder disturbance. This thesis generalized the homoskedastic disturbance model to the case where $\varphi_i$are heteroskedastic, i.e $\varphi_i \sim (0,\omega^2)$ for *i*= *1*,.., *N* but v_{it}~ IID $(0,6^2)$. In vector form, φ ~ $(0,\Sigma_\varphi)$ where Σ_φ = *diag* $[\omega^2]$ is a diagonal matrix of dimension $N \times N$ and v_{it}~ IID$(0,6^2 I_{NT})$. Therefore, the equation can be written as

$$\Omega = \mathrm{E}(U\acute{U}) = \mathrm{Z}_\varphi \mathrm{Z}_\varphi \acute{Z}_\varphi + 6^2 I_{NT} \quad \text{Equation 13.3.3}$$

or

$$\Omega = \text{diag}\,[\omega^2] \otimes J_t + diag[6^2] \otimes I_{NT} \quad \text{Equation 13.3.4}$$

Furthermore, the modified wald statistic test used for the GroupWise heteroskedasticity in the residuals, under the null hypothesis; the constant variance or homoskedasticity; $\varphi_i = \varphi$ for all *i* = *1*,..,*N_g*, where *N_g* is the number of cross-sectional units. The resulting test statistic is distributed by Chi-square *(N_g)*.

Secondly, this thesis applies the Wooldridge's test for serial correlation. The Equation 13, in general, can write as follows:

$$y_{it} = \alpha + \beta_i X_{it} + \beta_2 Z_i + \mu_i + e_{it}$$

Where y_{it} represents dependent variable; X_{it} is a $(1 \times K_1)$ vector of time-varying covariates; Z_i is a $(1 \times K_2)$ time invariant covariates; $\alpha, \mu_i, and\, \beta_2$ are $1 + K_1 + K_2$parameter; μ_i is the country-level effect and e_{it} is the idiosyncratic error. Furthermore, this test further classified for the fixed- and random-effects model as follow: The fixed effect model or first differenced provides consistently estimated coefficients on the time-varying covariatesX_{it}, when μ_i are correlated with the X_{it} and the Z_i. In contrast, the feasible generalized least squares method provides consistently and efficiently estimated coefficients on the time-varying and time-invariant covariates, when μ_i are uncorrelated with the X_{it} and the Z_i.

Null hypothesis: These estimators assume that $E[e_{it}e_{is}]$ = 0 for all $s \neq t$; i.e., that there is no serial correlation in the idiosyncratic errors.

5.4 Co-integration Test

In the third step, the co-integration test is used to investigate whether there is a long-run equilibrium relationship between variables. The co-integration test is used to test the hypothesis that linear combinations of the variables are stationary. Hence, all the stationary variables can move together to achieve long-run equilibrium. The study applies test whether a long-run relationship exists among the variables in Equation 13. Furthermore, the study uses the latest test developed by Wasterlund and Persyn (2007) for calculating the error-correction model (ECM) panel cointegration test.

According to Westerlund and Persyn (2007), the ECM panel cointegration test helps the researcher to decide whether the null hypothesis is rejected or accepted. However, many studies reject the hypothesis of no-cointegration, even theories that strongly suggest cointegration among the variables. Westerlund and Persyn (2007) have developed a four-panel cointegration test that based on structural rather than the residual dynamic.

Wasterlund and Persyn (2007) consider the following equation for testing for cointegration:

$$\Delta e_{it} = \acute{\psi}_i d_t + +\acute{\rho}_i x_{i,t-1} + \sum_{j=1}^{m_i} \psi_{ij} \Delta e_{i,t-1} + \sum_{j=-q}^{m_i} \rho_{ij} \Delta x_{i,t-j} + u_{it}$$

Where *t=1,..., T* index the time-series and *i=1,..., N* individual index units, while d_t denotes the deterministic component. The index *j=1,...,m* is the lag term of the model, whereas *j=-q,...,m* is the leading term. The vector x_{it} as a pure random walk such that Δx_{it} is independent of u_{it}, and it is further assumed that these errors are independent across both *i* and *t* (In this study, the repressors' are Production of RE, GDP, Supporting Schemes, NonRE, RDNonRE, RDRE and $u_{it}$is the random error term). Testing for cointegration thus implies testing for error correction in the model, if $\rho_i < 0$.

Null hypothesis: $\rho_i < 0$, results in an error correction and implies a cointegration relationship between $e_i \; and \; x_i$.

Alternative hypothesis: $\rho_i = 0$, no cointegration relationship.

Westerlund (2007) proposes four test statistics and groups them into two, namely, the group-mean statistics $G_T \, and \, G_\alpha$ and panel statistics $(P_T \, and \, P_\alpha)$. $G_T \, and \, G_\alpha$ denote the test statistics for the group panel cointegration test, while α is the conventional stand error. Similarly, $P_T \, and \, P_\alpha$ and $P_\alpha$are the computed formulas for the panel statistics (see Westerlund and Persyn (2007).

5.5 Estimation Technique

Lastly, this thesis employed a test for causality based on Granger methodology, which investigates the linkage between the dependent variable and independent variables given in Equation 13. In addition, the thesis accounts for both the short-run causality and the long-run causality via panel vector error correction model (PVECM) by following the procedure describe in previous studies (Apergis & Danuletiu, 2014; Apergis & Payne, 2010b, 2010a; Armeanu et al., 2017; Jaraite et al., 2015; Shafiei et al., 2014). In addition, the PVECM provide efficient estimates of the long-run relationship in the case of heteroskedasticity and serial correlation. Furthermore, This model involves regressing the dependent variable on a constant and independent variable on levels, leads and logs of the first difference of all $I(1)$ independent variables. Also, the PVECM can applied to the system of variables with different orders of lags. The PVECM include leads and lags of the differenced explanatory variables correct for simultaneity, endogeneity, and serial correlation among the independent variables (Baltagi, 2013; Blackburne III & Frank, 2007))

The final PVECM can expressed as follows:

Equation 13.5.1

$$\begin{aligned}\Delta PRE_{it}^{s} = \tau_{1i}^{s} &+ \sum_{k=1}^{q} \beta_{11ik}^{s} \, \Delta PRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{12ik}^{s} \, \Delta ss_{it-k}^{s} \\ &+ \sum_{k=1}^{q} \beta_{13ik}^{s} \, \Delta NonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{14ik}^{s} \, \Delta RDNonRE_{it-k}^{s} \\ &+ \sum_{k=1}^{q} \beta_{15ik}^{s} \, \Delta RDRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{16ik}^{s} \, \Delta GDP_{it-k}^{s} \\ &+ \psi_{1i}^{s} e_{it-1}^{s} + v_{1it}^{s}\end{aligned}$$

$$\Delta ss_{it}^{s} = \tau_{2i}^{s} + \sum_{k=1}^{q} \beta_{21ik}^{s}\ \Delta ss_{it-k}^{s} + \sum_{k=1}^{q} \beta_{22ik}^{s}\ \Delta PRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{23ik}^{s}\ \Delta NonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{24ik}^{s}\ \Delta RDNonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{25ik}^{s}\ \Delta RDRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{26ik}^{s}\ \Delta GDP_{it-k}^{s} + \psi_{2i}^{s} e_{it-1}^{s} + v_{2it}^{s}$$

Equation 13.5.2

$$\Delta NonRE_{it}^{s} = \tau_{3i}^{s} + \sum_{k=1}^{q} \beta_{33ik}^{s}\ \Delta NonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{31ik}^{s}\ \Delta PRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{32ik}^{s}\ \Delta SS_{it-k}^{s} + \sum_{k=1}^{q} \beta_{34ik}^{s}\ \Delta RDNonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{35ik}^{s}\ \Delta RDRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{36ik}^{s}\ \Delta GDP_{it-k}^{s} + \psi_{3i}^{s} e_{it-1}^{s} + v_{3it}^{s}$$

Equation 13.5.3

$$\Delta RDnonRE_{it}^{s} = \tau_{4i}^{s} + \sum_{k=1}^{q} \beta_{44ik}^{s}\ \Delta NonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{41ik}^{s}\ \Delta PRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{42ik}^{s}\ \Delta SS_{it-k}^{s} \sum_{k=1}^{q} \beta_{43ik}^{s}\ \Delta RDNonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{45ik}^{s}\ \Delta RDRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{46ik}^{s}\ \Delta GDP_{it-k}^{s} + +\psi_{4i}^{s} e_{it-1}^{s} + v_{4it}^{s}$$

Equation 13.5.4

$$\Delta RDRE_{it}^{s} = \tau_{5i}^{s} + \sum_{k=1}^{q} \beta_{55}^{s}\ \Delta RDRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{51ik}^{s}\ \Delta PRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{52ik}^{s}\ \Delta SS_{it-k}^{s} + \sum_{k=1}^{q} \beta_{53ik}^{s}\ \Delta NonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{54ik}^{s}\ \Delta RDnonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{56ik}^{s}\ \Delta GDP_{it-k}^{s} + \psi_{5i}^{s} e_{it-1}^{s} v_{5it}^{s}$$

Equation 13.5.5

Equation 13.5.6

$$\Delta GDP_{it}^{s} = \tau_{6i}^{s} + \sum_{k=1}^{q} \beta_{66}^{s}\ \Delta GDP_{it-k}^{s} + \sum_{k=1}^{q} \beta_{61ik}^{s}\ \Delta PRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{62ik}^{s}\ \Delta SS_{it-k}^{s} + \sum_{k=1}^{q} \beta_{63ik}^{s}\ \Delta NonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{64ik}^{s}\ \Delta RDnonRE_{it-k}^{s} + \sum_{k=1}^{q} \beta_{65ik}^{s}\ \Delta RDRE_{it-k}^{s} + \psi_{6i}^{s} e_{it-1}^{s} + v_{6it}^{s}$$

Where *s* indicates the level of data aggregation, *k = 1,...,q* is the lag length, *β's* are the short-run coefficients, while the $v_{it}{'s}$ denotes the random error terms for the short-run model. $e_{it-1}^{s}{'s}$ are the lagged error terms from the long-run model and therefore represents the error correction term, which are used to panel dynamic error correction terms in the above equations. This thesis test the following hypothesis for each variables, For short-run analysis causality; $H_o\colon \beta_{mnik}^{s} = 0\ \forall\ each\ vairables$ whereas the long-run causality is tested via null hypothesis of $H_o\colon \psi_{mnik}^{s} = 0\ \forall\ each\ variables.$ The parameter ψ_{mnik}^{s}represent the speed of adjustment term, which expected significantly negative under the prior assumption that the variables show a return to a long-run equilibrium. Where, *m* indexes the equation number in the vector of equation and *n* indexes the coefficient for each of the variables in the equation.

Table 1: Descriptive Statistics

Variable		Mean	Std. dev	Min	Max
Id	Overall	96.75	88.9673	11	288
	Between		92.7618	11	288
	Within		0	96.75	96.75
Time	Overall	2001	6.9342	1990	2013
	Between		0	2001	2001
	Within		6.9342	1990	2013
SS	Overall	9.2103	1.0988	5.7333	11.4239
	Between		1.0347	7.2176	10.2615
	Within		.4717	7.5382	10.5522
NonRE	Overall	9.9595	.9658	8.7381	11.7294
	Between		1.0019	8.8878	11.6358
	Within		.0969	9.6903	10.2321
RDnonRE	Overall	2.0404	2.0315	-3.8167	7.7284
	Between		1.9191	-1.5632	5.7024
	Within		.8598	-.813	5.0195
RDRE	Overall	3.3688	1.6822	-1.3704	6.5875
	Between		1.5029	-.2580	5.2778
	Within		.8670	-.1637	5.6575
PRE	Overall	11.7579	.9246	10.1651	13.3703
	Between		.9542	10.5392	13.2787
	Within		.1321	11.3531	12.1076
GDP	Overall	13.2047	.9819	11.7373	15.0345
	Between		1.0115	12.0486	14.8954
	Within		.1520	12.8569	13.4477

Observations: N =288, n=12 and T=24.

Table 1 shows the descriptive statistics of the variables. This panel consists of annual observations for twelve EU countries over the period 1990-2013. The total number of observations used in this thesis is 288. A variable that shows a variation over time or a given individual (Id) called within variation, and a variation across individuals is known as between variation. This distinction is important because estimators differ in their use of within and between variations.

Id shows the cross-sectional dimension of the data and Time shows the time dimension. Both Id and Time show how the panel data are classified. Id (EU countries) shows that a minimum of 11 and a maximum of 288 observations used for analysis. The Time variable shows that the collected data range from 1990 to 2013. The overall production of the renewable energy (PRE) mean is 11.7579 and the minimum a country produces is 10.651 in KT, and the maximum is 13.3703 in KT. The standard deviation shows that the PRE variation Between countries is .9542 more than the within countries variation over time .1321.

The results of supporting schemes (SS) and non-renewable energy (NonRE) show that the overall standard deviation is 1.09 and .96, the Between variation is higher than the within variation. The total net capacity of SS and NonRE shows that the Between variations 1.03 and 1.0 compare to within variations .47 and .09. Hence, the variation across countries is higher amongst the EU countries than the within variation in a country over time. The mean for the total net capacity of SS and NonRE are almost the same, 9.2 and 9.9, respectively. The overall minimum total net capacity of RE is 5.73, and the maximum is 11.42, and the NonRE is 8.73 and 11.72.

The overall mean of total (research and development in non-renewable energy) RDnonRE is 2.04, which is less than (research and development in renewable energy) RDRE 3.36 in millions. The column for standard deviation shows that the Between variation amongst the EU countries is more than the within variation in a country over time for both RDnonRE and RDRE. The total investment in RDnonRE falls in the range of -3.08 to 7.72 compared to RDRE, which is -1.37 to 5.27, respectively.

The overall mean (gross domestic product) GDP is $13.24 in millions and varies Between $11.73 to $15.05. The standard deviation is .98, and the Between variation is 1.01 amongst EU countries, which is higher than the within the variation of a country over time .15.

6. Results and Discussion

The empirical analysis is done by estimating a fixed- and random-models, PMG and MG motivated by different assumptions, as indicated in the empirical approach section. Before presenting the results of the fixed- and random-effects model, PMG and MG estimator, it is important to present the time series properties of the data. Firstly, the unit root tested for each variable. The unit root test is done using the Levin-Lin-Chu variable as mentioned above. The results of the unit root test presented in Table 6 in Appendix A. The result indicates that the variables excluding R&D and the lag of GDP are stationary at level; however, evidence in support of the first difference *I(1)*, noted stationarity for all variables.

With panel data, the fixed- and random-effects models are the most frequently used techniques. Secondly, In order to obtain consistent and efficient estimator, this thesis control for some diagnostic tests such as cross-sectional dependence, heteroskedasticity, and serial correlation. These tests can cause bias in the standard errors and less efficiency in the results. In this thesis, Pesaran's cross-sectional dependence test applied. The result of the diagnostic test provided in Table 2. Further, the Pesaran's test does not reject the null hypothesis of no-cross sectional dependence under fixed-and random-effects estimations. Thus, this study accepts the null hypothesis (i.e. the cross-sectional independence) for both estimations. In addition, Table 2 also provides the result of heteroskedasticity and serial correlation under a fixed-and random-model. The results of heteroskedasticity and serial correlation tests confirm the existence of the problem of heteroskedasticity and serial correlation at a 1 per cent level of significance.

Table 2: Cross-sectional, Heteroskedasticity and Serial Correlation Tests

	FE Estimation	RE Estimation
Model		
Cross-sectional Dependence		
Pesaran (*P-value*)	1.977	1.973
Heteroskedasticity		
Modified Wald (*P-value*)	0.000***	
Serial Correlation		
Wooldridge	0.000***	

In the third stage of estimation, this thesis applies Westerlund and Persyn (2007) cointegration test. According to Westerlund and Persyn (2007), one of the prerequisites for the cointegration is that all the unit roots should integrated of order one. The result of the unit root confirms that the series is stationary and enables the use of the cointegration test. The Westerlund and Persyn panel cointegration approach is implemented to test the hypothesis of no cointegration, using the Alkaline information criterion to determine the lag length for each series and with the Barlet kernel window width. The result showed the lag length *(1)* and bootstrapped robust critical values, *p-values,* to test the significance. The result confirms the strong cointegration relationship among the variables to achieve equilibrium and rejects the null hypothesis at the 5 per cent significance level. The results of the cointegration test presented in Table 7 in Appendix B. The bottom line is that cointegration test specifies that all the variables move either together or not and if a long-run relationship exists between them.

This thesis applies dynamic panel model to obtain efficient estimates of the long-run relationship in the case of heteroskedasticity and serial correlation, i.e. MG and PMG. Furthermore, to choose most suitable estimation technique between MG and PMG estimators, this thesis applies Hausman test.

6.1 The Hausman Test

The results of the Hausman test are given below in Table 3. The study confirms that the PMG is a most suitable choice for the dynamic panel data analysis; as presented in the estimation section Equation 13. The $chi^2(5)$ is 13.69 values are 0.017; the result rejects the null hypothesis, i.e. the preferred model is the MG model and accept the alternative hypothesis

Table 3: Hausman Inspection Result

	no addition option
$chi^2(5)$	13.69
Prob>chi2	0.0177

Author conducted all tests using STATA software edition 12

6.2 Long-run Estimation

This thesis presents the result of long-run elasticities of all estimated modes in Table 4. According to the estimates from the PMG model, the coefficients of production of renewable energy (PRE), supporting schemes (SS), non-renewable energy (NonRE), research and development in non-renewable energy (RDnonRE), and gross domestic product (GDP) are positive and significant at 1 per cent level, except research and development in renewable energy (RDRE), which is insignificant.

The result shows that in the long-run a 1 per cent increase in SS, NonRE, REnonRE, RDRE and GDP will result in 0.3460, 0.6891, 0.0259, 0.0027 and 0.258 per cent increase respectively in the production of renewable energy (PRE). Comparing the coefficient of explanatory variable reflects that NonRE has the largest effect on the PRE in the long-run. Similarly, comparing the coefficients between SS and RDRE indicates that SS has the largest effect on the production of RE in the long-run when controlling for states variable; NonRE and RDnonRE.

In addition, the elasticities of the production of RE with respect to SS and RDRE show that both types of policies stimulate the production of RE in twelve EU countries. Nevertheless, the elasticity of RDRE is insignificant. In line with the common findings such as (Johnstone et al., 2008a; Lam et al., 2013)), this thesis finds the similar result that supporting schemes enhance the production of RE in the long-run. In case of RDRE, this thesis finds similar result as discussed by Popp, Newell and Jaffe (Popp et al., 2010) and Garces and Daim (2010) that in the long-run, research and development in RE have positive relationship with the production of RE.

Furthermore, Table 4 also shows the elasticities of production of RE with respect to GDP, which shows that in the long-run GDP enhance the production of RE in twelve EU countries. This relationship between GDP and production of RE follows the outline of previous studies as pointed out by Apergis and Danuletiu (2014), Apergis and Payne (2010a) and Shafie et al. (2014).

Table 4: Coefficients of Fixed-Random Effects, Pooled Mean Group and Mean Group Estimations

PRE	Fixed effects (within) regression		Random-effects GLS regression		Mean Group Estimation (MG)		Pooled Mean Group (PMG)	
	Coefficient (Std Error)	P>|z|	**Coefficient** (Std Error)	P>|z|	**Coefficient** (Std Error)	P>|z|	**Coefficient** (Std Error)	P>|z|
SS	**.0331*** (.0138)	0.017	**.04151*** (.0138)	0.002	0.1250 (0.1544)	0.42	**0.3460*** (0.0316)	0.000
NonRE	**.4372*** (.0551)	0.000	**.4303*** (.0551)	0.000	0.1619 (0.2987)	0.59	**0.6891*** 0.0516	0.000
RDnonRE	-.0024 (.0066)	0.724	-.0009 (.0066)	0.893	0.0247 (0.0407)	0.54	**0.0259*** (0.0062)	0.000
RDRE	-.0021 (.0087)	0.807	-.0001 (.0087)	0.991	0.0156 (0.0463)	0.73	0.0027 (0.0100)	0.789
GDP	**.4916*** (.0534)	0.000	**.4601*** (.0534)	0.000	**0.6683*** (0.1339)	0.00	**0.258*** (0.0600)	0.000
Const	.6185 (.6575)	0.348	**1.0167**** (.6575)	0.061				
	Sigma_u	.386	Sigma_u	.256				
	Sigma_e	.082	Sigma_e	.082				
	Rho (fraction of variance due to u_i)	.956	Rho (fraction of variance due to u_i)	.906				

The bold values in Table 4 are the coefficient values, and the values in brackets are the standard error. Prob. Significance values at1, 5 and 10 per cent, represents with *, ** and *** respectively.

6.3 Panel Granger Causality

Finally, the results of the short-run and long-run Granger causality tests are presented in this section. The result presented in Table 5 shows that supporting schemes (SS), non-renewable energy (NonRE), research and development in non-renewable energy (RDnonRE), research and development in renewable energy (RDRE) each has a negative effect on the production of RE, and significant at 10 per cent level. Thus, it is concluded that SS, NonRE, RDnonRE and RDRE do not Granger cause production of RE in the short-run. Moreover, the gross domestic product (GDP) has a positive effect on the production of RE and significant at 20 per cent level. The result shows that GDP does Granger cause the production of RE in the short-run. In estimating the Equation 13.5.2 in which SS is the dependent variable, the impacts of the production of RE, NonRE and RDnonRE on SS are negative and significant at 5 per cent and 10 per cent level, respectively. In addition, the effect of RDRE and GDP are positive and significant at 5 per cent and 10 per cent, accordingly. The result shows that unlike production of RE, NonRE and RDnonRE, do not cause the SS in the short-run. However, RDRE and GDP do.

In regards to the Equation 13.5.3, the impacts of PRE, RDnonRE and GDP are positive and significant at 5 per cent and 20 per cent on the NonRE. Regarding the remaining variables of the model such as SS and RDRE are negatively related with NonRE. This result indicates PRE, RDnonRE and GDP are the only factors that Granger cause NonRE in the short-run. With respect to the Equation 13.5.4 for RDnonRE, PRE, NonRE and GDP each have a negative and insignificant effect on the RDnonRE. In addition, the other variables such as SS and RDRE has a positive but insignificant effect on the RDnonRE. According to the Equation 13.5.5 for RDRE, only RDnonRE has a positive and significant effect at 10 per cent on the RDRE. This demonstrates that only RDnonRE Granger cause RDRE in the short-run. Finally, for the last Equation 13.5.6, PRE and RDnonRE positively and significantly influence GDP, implying these variables Granger cause GDP in the short-run.

In sum, the empirical results indicate that there is bidirectional causality between PRE and GDP. In addition, this thesis also found unidirectional causality running from RDRE to SS, from GDP to SS. Moreover, unidirectional causality floating from PRE to NonRE, from RDnonRE to NonRE and GDP to NonRE.

Table 5 Causality Pooled Mean Group Regression (PMG)

Dependent Variable	Source of causation (Independent Variable)						
	Short run						Long run
	Δ PRE	Δ SS	Δ NonRE	Δ RDnonRE	Δ RDRE	Δ GDP	ECT
Δ PRE	-	**-0.0006**** (0.085)	-0.2628 (0.3704)	**-0.0086**** (0.0117)	**-0.0035**** (0.0117)	**0.3750*** (0.1906)	**-0.4182**** (0.099)
Δ SS	**-0.01373***** (0.05724)	-	**-0.1374*** (0.1242)	**-0.0006***** (0.005)	**0.0008***** (0.0064)	**0.0199**** (0.1097)	**-0.0193***** (0.0362)
Δ NonRE	**0.1209***** (0.0479)	**-0.2249**** (0.1134)	-	**0.0004**** (0.0104)	**-0.0032***** (0.0098)	**0.3387*** (0.1651)	**-0.1956***** (0.0582)
Δ RDnonRE	(-.8300) (1.1011)	1.4278 (1.9425)	-1.8867 (1.7108)	-	1.4278 (1.9425)	-0.7543 (2.2248)	**-0.4244**** (0.0932)
Δ RDRE	-0.2258 (0.7167)	-0.1823 (.7243)	0.6830 (1.2627)	**0.2103**** (0.1094)	-	-3.1786 (1.6029)	**-0.3277**** (0.1009)
Δ GDP	**0.0621***** (0.0392)	**-0.0107***** (0.0402)	**-0.1351**** (0.0673)	**0.0020***** (0.0036)	**-0.0078***** (0.0070)	-	**-0.1410**** (0.0625)

The **bold values** in Table 5 are the coefficient values, and the values in brackets are the standard error. Prob. Significance values at5, 10 and 20 per cent, represents with ***, ** and * respectively

The result of bidirectional causality between PRE and GDP is consistent with the study of Apergis and Payne (2014) conducted for eighty countries, Apergis and Payne (2010) for Eurasia countries and Apergis and Payne (2010a) for a panel of twenty OECD countries. The finding of bidirectional causality between the production of renewable energy and economic growth confirms the feedback hypothesis implying that high level of economic growth demand high level of energy consumption and vice versa.

The long-run dynamics displayed by the error correction terms confirm the evidence of the presence of bidirectional causality between PRE and GDP. In addition, the coefficient of the error correction term in the Equation 13.5.1 suggests that the deviation of PRE from short-run to long-run is correct by 42 per cent each year, and convergence to equilibrium after a shock to PRE takes about 2.4 years[2] (Table 5)

[2] The number of years is calculated as the inverse of the absolute value of the ECT

7. Conclusion

The goal of the study is to answer the two main questions, firstly, the role of technological development in the production of RE with special reference to investment subsidy in supporting schemes and research and development (R&D). Investment subsidies in supporting schemes and R&D are seemingly more effective to promote RE technology compared to the regulatory system. In general, it seems that RE has encouraged researchers to study more and explore the possible reasons to promote energy by improving RE technology. Particularly, in the context of EU countries, where governments provide investment subsidies at the macro-level through different supporting schemes (quota system, tradable certificates and feed-in tariff) and R&D programmes. The subsidy programme was triggered in the early 90s to initiate the supporting schemes and R&D programmes to promote RE technology. Secondly, the study investigates the bidirectional relationship between the production of RE and the economic development. The bidirectional relationship interpreted as: both the production of RE and economic development are interdependent and complementary for each other.

The thesis uses Solow's growth model embedded with technological development and energy. In-addition, the pooled mean group (PMG) model used for empirical findings. The empirical findings are based on a dataset for twelve EU countries over the period 1990 to 2013. The results of the diagnostic test such as cross-sectional dependence test, heteroskedasticity and serial correlation tests oppose the most commonly estimated models - fixed- and a random-effects model. Therefore, this thesis chooses PMG model based on the result of the Hausman test. The PMG model is the most suitable estimator for determining the long-run relationship between the variables. The result of cointegration shows that, in the long-run, all the variables move together to achieve equilibrium. With respect to long-run estimation, this thesis finds all the explanatory variables are positive and significant at 5 per cent level except RDRE, which is insignificant.

Further, elasticises of production of RE with respect to supporting schemes and research and development in renewable energy indicate that both supporting schemes and R&D stimulate the production of RE in twelve EU countries. In addition, comparing the magnitudes of their coefficients confirms that supporting schemes dominant over the R&D. Therefore, EU countries need to encourage investment subsidies more in supporting schemes than R&D.

In case of economic development and production of RE, the causality result shows that there is bidirectional causality between the production of RE and GDP. The study confirms that an increase in GDP has a positive impact on the production of RE in both the short and the long-run. The bidirectional relationship between Production of RE and GDP shows that an increase in GDP enhances the production of RE, and vice versa.

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Appendix A

Table 6: Unit Root: Levin-Lin-Chu unit-root test

Variable	Level	First difference	Integration order
PRE	**-2.7947**	**-1.0185**	Stationary at level & First difference I(0) & I(1).
	(0.0026)	0.1542	
SS	2.7913	**-2.3464**	Non-Stationary at level I(0) & Stationary at first difference & I(1)
	(0.9974)	(0.0095)	
NonRE	2.0205	**-4.6417**	Unit root at level I(0) & Stationary at first difference & I(1)
	(0.9783)	0.000	
RDnonRE	**-0.9674**	**-8.2587**	Stationary at level & First difference I(0) & I(1)
	(0.1667)	(0.0000)	
RDRE	0.4158	**-5.9659**	Unit root at level I(0) Stationary at First difference I(1)
	(0.6612)	(0.0000)	
GDP	**-3.9744**	**-5.2407**	Stationary at level & First difference I(0) & I(1)
	(0.0000)	(0.0000)	

Author's own calculation. The values without parentheses are coefficients for the first-period lag variable. The values in parentheses are P-Values. Data are in natural log form.

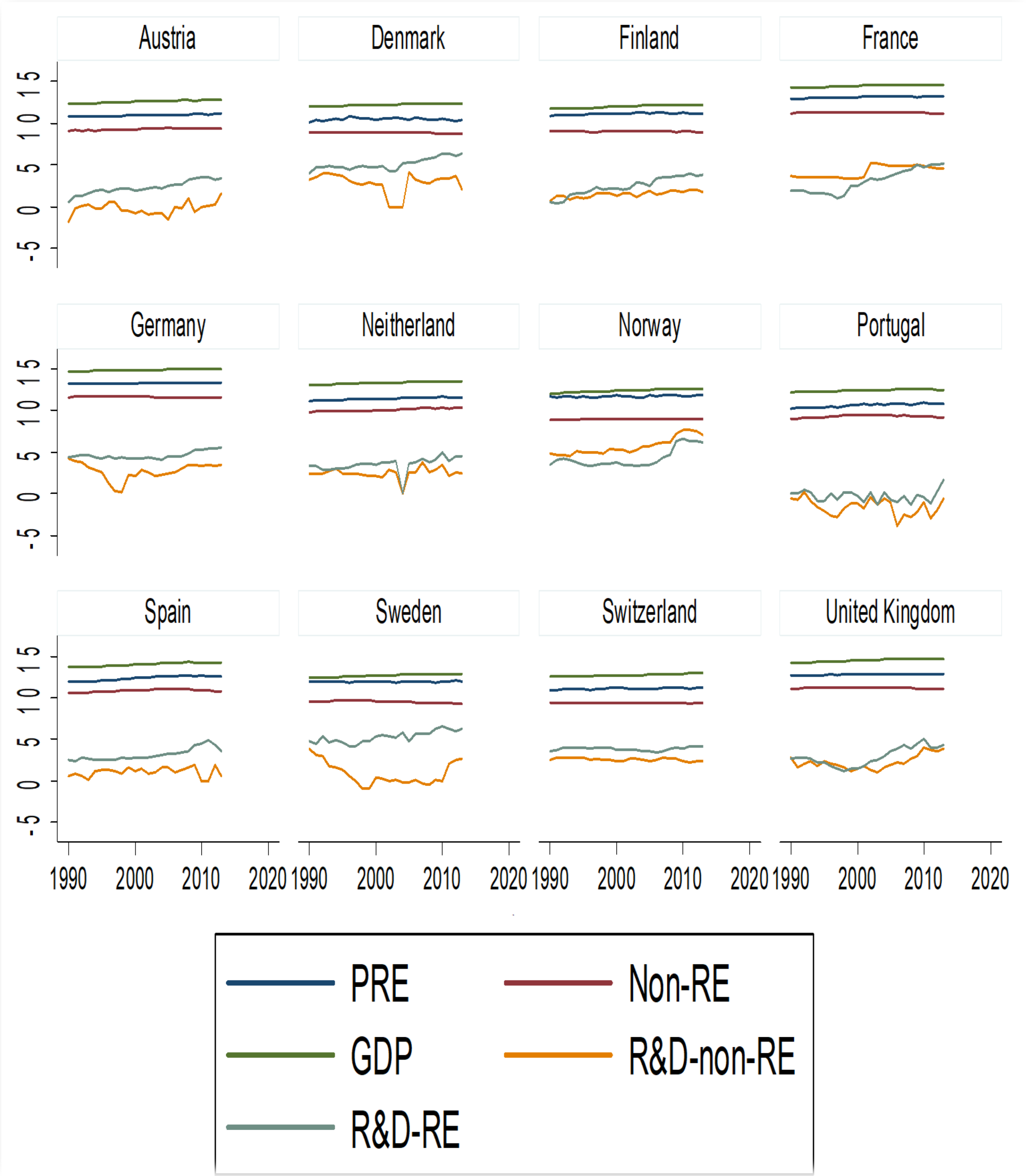
Appendix B

Table 7: Cointegration Test

Dep PRE, Indep SS, NonRE, RDRE, RDnonRE, GDP, lags (1)
With 12 series and five covariates
Null Hypothesis H_o: no cointegration

	Westerlund ECM Panel Cointegration Test		
Statistic	Value	z-value	p-value
G_t	-3.173	-2.930	0.002
G_α	-8.7e+05	-4.2e+05	0.000
p_t	-1.4e+07	-1.6e+07	0.000
P_α	-1.4e+07	-6.4e+06	0.000

Appendix C


Austria
Denmark
Finland
France
Germany
Neitherland
Norway
Portugal
Spain
Sweden
Switzerland
United Kingdom
-5
0
5
10
15
1990
2000
2010
2020
PRE
Non-RE
GDP
R&D-non-RE
R&D-RE