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The Finance of Environmental Investments

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Abstract

The aim of this dissertation is to highlight the importance of the environmental finance and the inextricable relationship between the economic development, finance and investments with the environment. The economic growth, the finance of environmental investments and the emissions price dynamics are analysed. Having used a panel data analysis to four groups of countries, several empirical findings have been raised concerning the CO_2 emissions; (i) an N-shape relationship is evident between CO_2 emissions and economic growth in the presence of R&D and Renewable Energy Consumption in all cases except America, where we have an inverted U-shape relationship; (ii) a negative relationship is evident between R&D and CO_2 emissions; (iii) the same negative relationship is evident in the case of Renewable Energy Consumption and CO_2 emissions.

Key Words: Environmental Finance; Environmental Investments; Economic Growth and Environment; Emission Price Dynamics; CO_2 emissions; Energy Consumption.

1. Introduction

Without any doubt, the environmental finance nowadays constitutes a subject undergoing intense study, especially for the governments and the policy planners. Developed thoroughly throughout the years, it analyses and links, above else, the economic development, finance and investments with the environment. Globally, societies are facing a number of interrelated environmental, economic and social crises, challenges that are to be solved with the use of various financial instruments, after taking into account the studies concerning climate change and resources management.

The present thesis is about this topic of broad and current interest, and elaborates, most of all, the connection of the environment with the economic growth, the finance of the environmental investments and the emissions price dynamic. Even more, it tries to answer the research question regarding the effect of Gross Domestic Product (GDP), the number of the researchers in Research and Development and the renewable energy consumption on CO_2 emissions.

In more detail, this thesis follows a specific outline, which is presented below.

First, a literature review is presented in Section 2, which relates to the studies carried out up until recently. In the existing literature, most of the attention has been drawn to the relationship between economic development and environmental pollution (Panayotou, 1997; Halkos, 2003, 2013). The differences between developing and developed countries are also pointed out, as the evident need for technology transfer in order to help developing countries achieve sustainability, is a repetitive pattern to many of the papers published in the academic world. Transaction costs, as well as socioeconomic and political factors are also taken into account (Nilsson, 2009). Economic growth and environmental quality in terms of macroeconomic policy occupy a large part of the academic studies as well (Malthus, 1798, 1820; Brock, 1973; Daly, 1990; Hollander, 1997), and importance of exploring the relationship between fiscal policy and pollution (Halkos and Paizanos, 2015) and between fiscal spending and the environment (Lopez et al., 2010) are questioned and examined. A special part of the studies carried out is dedicated to interrelated environmental, economic and social crises, and examines which economic sub-systems should be in focus for sustainability transitions (Røpke, 2016).

In Section 3, the relationship between economic growth and the environment is shown. Arguably, the deterioration of the environment begins to have direct impact on the quality of human life, while a variety of options concerning the organization of the economic activity exists indeed, each with different levels of efficiency. In this section it is also explained that, although positive economic growth accounts for improvements, global economy has not been equally developed as a result of the uneven pace of growth. In addition, there is a close connection between rapid economic growth and human activity, but it is often damaging for the environment. The problems regarding the negative environmental consequences of the policies or methods used up until now are also analysed, and more specifically, exploitation of natural resources, resource scarcity and deterioration of the environment are examined. Moreover, the evident need for sustainable development is elaborated, and various model specifications of economic growth are presented, trying to incorporate the impact of economic growth on the environment. Finally, given that the link between GDP and economic growth, and the developing and developed countries' distribution, Section 3 underlines the need for long-term economic and social goals to be set when designing and implementing environmental policies.

Section 4 deals with the finance of environmental investments, and therefore the characteristics of investment projects are presented. Furthermore, the real options approach is pointed out, as the investment opportunities are perceived as such. Options price with the binomial tree are also elaborated, as well as the Black and Scholes model. In this section, the environmental regulations' compliance with the EU Emissions Trading System is presented and the emission rights trading is investigated. Finally, Section 4 demarcates the NPV criterion and real options pricing.

In Section 5, the emission price dynamics are elaborated, and specifically, the substitution principle between emission allowances and abatement technology. The switch from coal-fired power to gas-fired power generation is denoted, and the CO_2 allowance prices regarding the European Union's Emissions Allowances are mentioned. This section also provides information about the deterministic and stochastic equilibrium allowance price models, which were developed and are essential for the comprehension and the analysis of the emission price dynamics.

Section 6 investigates the relationship of CO_2 emissions, GDP, number of researchers in R&D and renewable energy consumption with the help of a balanced panel data. The empirical research performed in this chapter brings out several interesting finding regarding the relationship under investigation. The research has been applied to several countries so that the conclusions drawn can cover a global range.

Last but not least, Section 7 discusses the overall conclusions of this dissertation.

2. Literature Review

In the existing literature, much attention has been given to the relationship between economic development and environmental pollution. Empirical formulation consists of various forms of pollution that stem from economic development, as well as economic development being represented by the polynomial forms of income levels. A key example of the mentioned variables would be an environmental damage indicator, which is the dependent variable and the economic development variable (represented by GDP per capita), which is an independent variable. Other variables could include air and water pollutants, as well as environmental indicators that have to do with deforestation and energy use, or socioeconomic variables like population density, industrialization etc.

Studies carried by Halkos (2003, 2013) suggested that the relationship between the economy and the environment in the case of sulphur has been clarified by using a large database to test the Environmental Kuznets Curve (EKC) hypothesis and applying homogeneous and heterogeneous methods in such a way that environmental degradation tends to become worse before it becomes better during a country's development. The results in Halkos (2013) indicated that using a fixed model and a random effect model produces inverted U-shaped curves within the sample turning points in both cases, as well as using a random coefficients method does not support an EKC hypothesis in the case of the full sample. While the opposite result is found in the case of the EU countries where an EKC is evident, it is implied that their parameters are homogeneous across countries. Previously, Grossman and Krueger (1995), based on the Global Environmental Monitoring System (GEMS), found that at high-income levels material use increases in such a way that the EKC is N-shaped in the cases of SO_2, dark matter and suspended particles.

Panayotou (1997) examined the economic growth, which increases pollution levels due to scale and industrialization, but ignores the abatement effect of richer countries, a conclusion that comes after decomposing the EKC into its main determinants.

When it comes to the demarcation between developed and developing countries, there is an evident need for technology transfer in order to help developing countries achieve sustainability, as sulphur abatement methods in developed countries are more advanced. Nilsson (2009) investigated the transaction costs involved in this transfer, as well as their reliance on technical and political factors, given that developing countries not only lack the financial resources to import these technologies, but also are in shortage of the means to modify them in order to fit at each country's environment.

As far as the intersection between macroeconomics and environmental economics is concerned, and more specifically the relationship of economic growth and environmental quality, it is a subject of study for numerous academics.

Malthus (1798, 1820), through his studies, dismissed the effectiveness of several possible solutions to the problem of increasing growth harming the environment, stating that population growth would intensively consume natural resources, making the problem of source scarcity more intense. His solutions revolve around two types of stabilizers that might assist in holding population within sustainable limits: one being raising the death rate (positive checks) and the other being lowering the birth rate (preventing checks). Those stabilizers were also examined by Hollander (1997).

Recent studies have stopped focusing on the macroeconomic theory's hypothesis of continuous growth in GDP, and focus to the relationship between economic growth and environmental degradation instead, giving special attention to exhaustible resources, as well as their replacement. Brock (1973) took into account the environmental costs of economic growth, while Daly (1990) indicated the failure of the environmental macroeconomics. Hence the importance of physical constraints (Harris, 2009).

On the empirical framework examined by Halkos and Paizanos (2015), the importance of exploring the relationship between fiscal policy and pollution was highlighted and several results had been elaborated. Specifically, Halkos and Paizanos (2015) pointed out that environmental macroeconomics introduces the importance of physical constraints to economic growth and examines how decision makers can implement appropriate policies to promote sustainable economic growth within these limits. This sustainability, has to do with the recent events concerning the failure of the markets and the financial crisis occurring globally, as well as the partial incapability of the policy makers to introduce sustainable solutions to those problems. Moreover, their study indicated that, in the framework of endogenous growth models with an environmental dimension, growth rates can be affected by government policies[1] that internalize the negative externalities linked with pollution and positive externalities associated with the knowledge accumulation and human capital. This is explained by the existence of sustained growth without pollution accumulation, because the accumulation of knowledge (public good) consists a fundamental factor for growth. Technological progress is considered endogenous and caused by investing in R&D, in expectation of future monopolistic profits. The empirical framework concerning this relies on testing the relationship between per capita income and the environment via the EKC. In this light, Bithas (2006, 2011) emphasized both market-based and regulatory instruments of environmental policies so as sustainability is ensured.

The studies of Lopez et al. (2010) regarding the fiscal spending and the environment, showed that the size of government expenditure and its composition are associated with the quality of growth, such as income inequality and environmental sustainability, as in the presence of externalities, there is a significant role for

[1] Key examples of these policies consist of expenditure in education, R&D and health, environmental taxes, maintenance of public order, regulations of international trade and environmental protection etc.

government policies and intervention. This happens as fiscal policy determines the allocation of resources to human, physical and natural capital through expenditure and tax policies and might lead to lowering environmental quality. Studies carried by Halkos and Paizanos (2015) found that the size of government increases as a percentage of GDP, thus progressively the structure of production in the economy may change from the industrial to the service sector, which is less pollution intensive. Furthermore, government spending on public order and safety is a way of protecting the property rights. As a result, environmental externalities such as the overexploitation of natural resources can be smoothed out. Finally, Frederik and Lundström (2001) examined the effect of public spending in education and health, which can increase public awareness when it comes to the effects of environmental pollution. Therefore, there is increased demand for improved environmental quality.

Another fact is that, arguably, the societies nowadays are facing a number of interrelated environmental, economic and social crises. As a result, the development of an ecological macroeconomics has been massive, as it addresses these multiple crises in combination. Studies by Røpke (2016) examined which economic sub-systems should be in focus for sustainability transitions, and whether relevant guides for sustainability can be formulated for these systems. While much work in ecological economics, carried by Kennedy et al. (2007), focused on ways to transform the concept of global sustainable scale into criteria and methods for managing the systems at the boundaries of the metabolic organism[2], Røpke (2016) identified three types of economic systems within this organism and argues that the interplay between them is important in relation to sustainability transformations. Moreover, he focused on the first type, known as the provision systems, which explore the relationship between the extraction of resources and the emission of waste through processes that transform resources into useful products and services, and emphasized their interplay with macroeconomic and distribution systems.

Last but not least, Røpke's (2016) empirical framework included a key example, which concerns investments in sustainability transitions of provision systems and demonstrates the complexities of implementing such transformations during the economic crisis. More specifically, it illustrates that the effective implementation of sustainability transitions of provision systems depends on the interplay with both macroeconomic policies and distribution systems. With the provision of public funding being difficult due to austerity policies, private funding can hold only if economic and institutional instruments reform increase their relative profitability. If these austerity policies shift to more expansionary fiscal policies, in combination with stricter regulation of the financial sector, it may become easier to fund sustainability transitions, but, according to Røpke (2016), not without consequences. As a result, attempts to improve the modeling of the macroeconomic system have been made (Fontana & Sawyer, 2016), in order to better include the workings of the financial

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[2] Given that global human economy can be seen as a metabolic organism within the biosphere (Schramski, 2015; Røpke 2016).

sector and to develop options for changing the key mechanisms and functioning of the macroeconomic system.

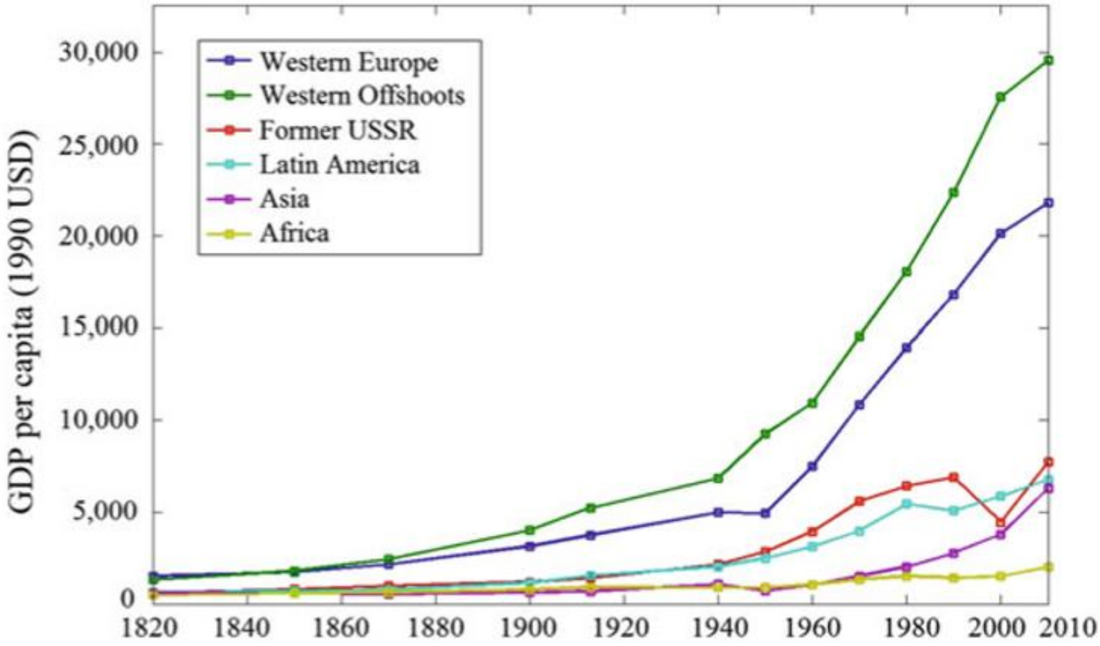
3. Economic Growth and the Environment

Undoubtedly, climate change constitutes a controversial issue; economic activity is deeply connected to the changes of climate, given that this activity is planned accordingly in order to face the challenges of temperature increase and its various consequences. In the light of this planning, negative externalities are internalized and tax schemes are studied, especially when it comes to their advantages and disadvantages. As a result, it is obvious that there is a variety of options concerning the organization of the economic activity; however, because of the constant evolution of variables included, the efficiency of each solution is not clear. The socioeconomic system plays a major part as well, as it is considered the source of the climate change related problems. Thus, it is important to study the economics of growth.

Positive economic growth accounts for improvements in health of the population, better standards of living, higher education, hence the political motivation for governments to make economic growth a priority.

Health of the population is deeply associated with the standard of living and the extended life spans, thus some might say that the economic growth and the rise in wealth have global benefits. While this is not false, it must become clear that the global economy has not been equally developed; for example, the pace is unequal, during the recent years, as well as historically speaking. For instance, it is clear from the graph below (Figure 1) that Africa and South East Asia have developed with an obvious slower pace, compared to Western Europe. Former USSR is also seen to indicate development during the 1950s, before drastically falling in the 2000s, right after its dissolution, due to political and socioeconomic reasons. According to the chart, however, former USSR seems to have higher development the recent years. Latin America shows signs of economic development as well, though not as high as Western countries (Western Europe and Western Offshoots - Australia, New Zealand, Canada, and the US).

Figure 3: History of economic development (Source: Bolt and van Zanden, 2013)



Let us also observe that the inequalities mentioned above apply not only to individual countries, but regions within countries as well.

However, according to Sachs (2015) developing countries could reach the standards of living of developed countries. That is to say, if there is a high increase in the total world output, given the world population and if the mentioned population increases as well, this would be unbearable for the environment, leading to more problems regarding the preservation of this extra population. What might also prove unbearable for the environment is the environmental damage caused by international competition among the countries. This, known as the *Race to Bottom theory*, plays an important role in the relationship between the economy and the environment (Halkos & Psarianos, 2015) and indicates that at first, international competition increases environmental damage. This happens until developed countries begin to decrease their environmental effect, but at the same time they start polluting the developing countries with new activities (Kelly, 2002). So, this inequality in growth leads to further environmental deterioration of the developing countries.

Even more, it is without mentioning that there are several negative environmental consequences regarding the world's up-until-now economic activities. From this fact stem two major problems:

First and foremost, the exploitation of natural resources results in resource scarcity (Perrings et al., 2011). Key examples of this scarcity are water, forests, oil, overfishing and natural gas. While this may seem like a distant consequence, it certainly affects the long-run sustainability of the eco – system, causing many serious problems in the environment and the future generations. Production process is affected as well, given the lower (contracted) labor market supply due to diseases or migration, the water shortage and the forest degradation.

Secondly, there is a deterioration of the environment. For instance, the atmosphere is heavily loaded by the Green House Gases (GHGs) accumulation (nitrogen, phosphorus, ozone depletion, etc), climate change, ocean acidification and the overuse of fresh water resources.

There is an undeniable strong correlation between economic activities and environmental systems, thus all these negative environmental consequences pose as a serious challenge in the economic system, hence the underlying need for a fundamental change in the way resources are used (Chesney et al., 2016). Rapid economic growth is closely linked with human activity, but this vast growth's influence is often damaging for the environment (Meadows et al., 1972).

As a result, there is also an evident need for sustainable development. According to the World Commission on Environment and Development's report "Our Common Future", (1987), sustainable is the Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In order to achieve that, Sachs (2015) proposed three guidelines related to the policies the governments should follow.

First, all those facts that are linked to the environment deterioration, such as the climate change and the ozone depletion, are caused due to us already being close to reach various planetary boundaries. Therefore, economic development should account for those boundaries. This point was specifically underlined by Rockstroem et al. (2009).

Second, economic growth should be socially inclusive, ensuring that the benefits of development reach the entire population, including the most vulnerable members, and supporting the endorsement of gender, race and class equality.

Third, it is of high importance to eliminate extreme poverty around the world. This has to be set as a global goal.

3.1. Models of Economic Growth

In order to understand the benefits and costs of economic development, we need to study several models to analyse optimal production, allocation and consumption decisions. Those models formulate predictions regarding the economic growth and other variables, such as inequality, poverty reduction, education and democracy.

First of all, there is the Neoclassical Growth model, which predicts that economic growth depends on capital accumulation through the population's capacity to save and invest the savings in capital, with positive growth though not being guaranteed in the long-run.

Furthermore, there is the AK model, where the final production of goods is distributed between consumption and savings. The capital stock grows over time, as savings end up to be the investments in capital. Human capital cumulates technological progress, accumulating physical capital and creating a learning-by-doing effect. In contrast to the Neoclassical Growth model, the AK model indicates possible positive long-term growth, which can be sustained through the accumulation of capital supported by savings.

Moreover, there is the product – variety model, which, according to Romer (1990), is an innovation-based model. Productivity growth, as well as technological innovation, happens in the appearance of quantity improvements. Thus, intermediary goods are produced by a monopolist who develops Research and Development (R&D) techniques and therefore makes profits. Growth models that have to do with either technological progress (Romer, 1990) or human capital accumulation (Lucas, 1988) are endogenous growth models.

Finally, there is the Schumpeterian model, which was developed by Aghion and Howitt (1992, 1998), and is about quality rather than quantity. More specifically, the economic growth cases quality improvements to the intermediary goods. The innovations that occur in this specific model are closely linked with the replacement process, since they drive old products out of the market. The said replacement process consists of the most advanced technology and newest products taking the place of older ones. The result of the process above is producers competing, with the one with the highest quantity earning the monopoly market. However, this is not a permanent position, since another innovation might take place and drive the now-older good out of the market. Taking every step of the process described above into account, it is obvious that increased competition boosts the economic growth.

All the previous models are modified depending on the type of resources that someone is referring to. First, there are the exhaustible resources. When we talk about exhaustible resources, we mean non-renewable resources, such as minerals and fossil fuels. Those resources face the problem of scarcity (Halkos & Managi, 2016). Then, there are the renewable resources, such as timber, air, etc**.** According to Chesney et al. (2016), the results indicate that, in the presence of a renewable source, positive economic growth appears to be feasible in the long-run.

However, all the previous models lack the ability to incorporate the environment. Taking the basic form of neoclassical growth theory as an example, the contribution of national resources in production is completely missing. More specifically, in the model developed independently by Solow and Swan (1956), only labor, capital and production methods were used as inputs, while the exhaustion of non-renewable resources (Meadows, 1972) was not predicted. This omission means that the results of this exhaustion (i.e. the fall of the global economy) were not forecasted.

3.1.1. Models of Economic Growth: New Growth Theories and Resources

As it is already mentioned, observing the models presented briefly in the previous section, none of them mentions the environment's role in economic growth. It is important for the analysis that this role of the environment in economic growth is mentioned, as it constitutes a vital input, as well as a negative factor. For example, a negative factor would be pollution, while a vital input would be exhaustible and renewable resources. As a result, new growth theories are developed, describing the production decision, while taking into account the environmental dimension. At this point, the role of green technological improvements and governmental policies is important.

Before exploring the role of the natural resources, it is important to understand the relationship between economic growth and the quality of the environment, which constitutes a controversial issue. Some people, who are radical and conditional supporters of the economic growth, believe that it is beneficial, as it instigates technological innovation and motivates the R&D and therefore the environmental quality is improving. On the other hand, there is another group of people who claim that economic growth is a mean to raise funds which are needed for the adoption of environment – friendly policies (Simon, 1981). Other than being a mean, economic growth for them is environmentally harmful because of the damaging output that is produced, that is pollution. Studying the relationship between the economy and the environment, *the limits theory*, as well as *the new toxic view*, brings forward the environmental damage because of the economy. The former points out the irreversible damage that the environment is enduring, causing the economy to shrink, while the latter deals with the pollutants emissions being reduced with additional economic growth only to be increased again via new pollutants' emissions. As a result, environmental damage increases as the economy develops (Everett et al., 2010).

When talking about economic growth, except for the presence of renewable resources, the economy grows more if we save and contribute more to the accumulation of capital. This growth is highly linked with natural resources, since vast growing requires large amount of resources, and natural resources contribute significantly to production (Halkos & Psarianos, 2015). However, when the resources are non-renewable, the large amount of them used mean great depletion of their stock. This brings economy to a halt, consequently stopping the economic growth.

In order to avoid, or even to overcome, this lack of natural resources, we should find ways to substitute natural capital. This may be succeeded via the usage of another form of abundant capital, such as the human capital.

What plays a critical role in all the substitution process is the endogenous technological advances, which occur due to the undertaken R&D. Hence, there is innovation, but only a proportion of the R&D is effective in delivering actual innovations. It is without saying though, that the technological innovations should be able to substitute the non-renewable inputs (Romer, 1990). Also, effective environmental policies may increase R&D into more resource efficient processes, which results in higher competitiveness and profitability (Everett et al., 2010). This is supported by the *Porter's Hypothesis*, a theory exploring the relationship between economy and the environment (Halkos & Psarianos, 2015).

About the exhaustible resources, it is clear that it will not be feasible to sustain positive economic growth in the long-term. This long-term positive growth is ensured regardless of the kinds of inputs and achieves weak sustainability[3]. That requires two things, the first being the research becoming a continuous process of improvement; this is not a certain fact, though, as the continuity is not guaranteed. The second limitation presents an ethical dilemma, which relies on nature being replaced slowly and, ultimately, completely, by man-made products (Chesney et al., 2016). Although some argue that man-made products are an excellent replica of what nature gives, natural products should not be eliminated and should remain an option.

As far as the protection and the recovery of the environment's quality, a reduction in growth is needed, and more specifically in the growth of economic sectors that cause harmful effects (Daly, 1991; Arrow et al., 1995).

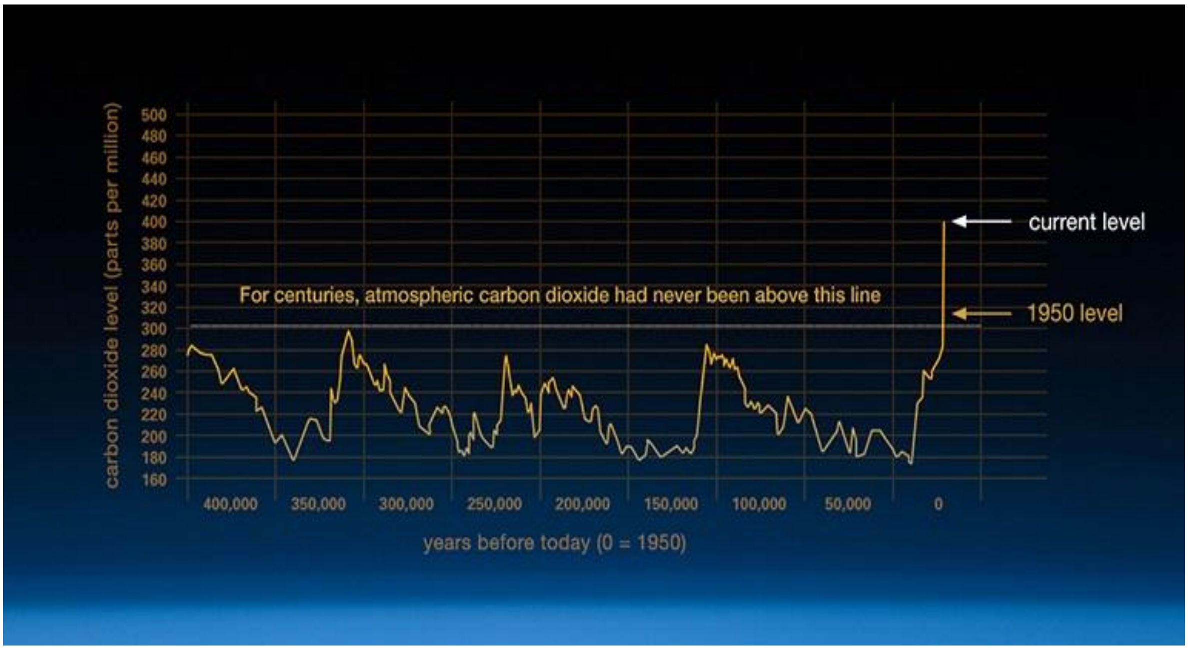
3.1.2. Models of Economic Growth: New Growth Theories and Deterioration of the Environment

Since the evolution of mass-production, there is a large increase in atmospheric GHGs, the most important of them being the carbon dioxide (CO_2). These GHGs are result of human (economic) activity, and are responsible for significant weather alternations and changes in the oceanic chemistry (Falkowski et al., 2000). According to recent research and studies, the current atmospheric CO_2 levels exceed expectations (see Figure 2), resulting to climate change and constituting an obstacle for the sustainable development (Halkos & Managi, 2016). The consequences of this very fact have already started to show and be felt, making the change in temperatures

[3] Weak sustainability states that human capital can substitute natural capital (Solow, 1993). As long as future generations achieve the same production capacity as the present generation, the conditions of sustainable development are satisfied, even if this is done at the expense of drawing down the stocks of natural capital (Gowdy and McDaniel, 1999).

levels a certainty. It has already reached and currently surpassing the 2°C change, alarming world leaders and making World Environmental Conferences a necessity.[4]

Figure 3.1.2: The historical rise of atmospheric carbon dioxide (Source: NASA, 2016)



Hence the evident need for lower emission levels. For this to happen though, there should be a fundamental change in the current economic system, which can be better understood by analysing GHG emissions from the production process, in regards of a growth model. Since the GHGs that remain in the atmosphere are the ones that pose as a threat to the environment, the estimation of the remaining gases should be computed and, after international negotiations, reach a limit which should not be surpassed. In other words, in order to help the climate change problem, the amounts of GHGs should be reduced (Halkos & Psarianos, 2015). Of course, production, consumption and allocation decisions should be taken into account.

More specifically, when it comes to production, there is the type of production that releases GHGs (dirty technology), and the type that does not pollute (clean technology). In that way, final goods are produced, after deciding on the optimal type of production and analysing the long-term impact of the choice made. In order to discourage the former type of production, governments have implemented various tax policies. As a result, according to their production technology, goods are classified as "dirty" or "clean". It is to say, though, that, as far as labor is concerned, it is allocated

[4] A key example of that is the Kyoto Protocol (1997), an international treaty which extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that commits State Parties to reduce greenhouse gas emissions, based on the premise that global warming exists and human-made CO_2 emissions have caused it. The Kyoto Protocol implemented the objective of the UNFCCC to fight global warming by reducing greenhouse gas concentrations in the atmosphere to a level that would prevent dangerous anthropogenic interference with the climate system.

either on the clean or the dirty sector, if all workers are paid equally, i.e. all labor is homogenous. In the case of heterogeneity, the labor allocation is divided between the sectors.

At this point, it is useful to talk about the governmental policies that could ensure the productivity of dirty production being below that of the clean production. This could be obtained via a price mechanism, for example a targeted tax, to which producers would be subjected to for each unit of dirty output produced. That way, clean technologies would be preferred over polluting ones and there would be space for positive economic development. Also, better governance with credible property rights are factors able to raise public awareness when it comes to environmental issues (Lopez, 1994; Stockey, 1998). It is worth mentioning as well that, when governments use environmental policies, such an emissions standard or a tax, to control pollution, pollution taxes are preferred when the policy instrument in use is emission standards. This happens because if the latter is implemented, then pollution, profits and welfare are higher compared to the case of taxes (Antoniou & Hatzipanayotou, 2011). However, it has to be noted that the magnitude of the beneficial effect of a policy or reform depends on the scope of the reform (Hatzipanayotou, Lahiri and Michael, 2005).

Given that the main target is to develop completely environmental neutral technologies, it not easy to be achieved, since all the technologies available for producing renewable energy are not fully environmentally harmless. What is more, producers still use natural resources, thus being neutral is still the case. After all, due to technological improvement and the large increase in world population, the available limited natural resources are being used in a very intensive way (Perrings et al., 2011). In order to ensure the sustainability of economic activities and the neutrality to the environment, R&D should continue to evolve, along with technological progress, structural changes and per capita income levels (Dinda et al., 2000). In that way, energy availability and independence lead to economic growth and creativity or innovative efforts may permit firms to compete quicker and in the direction they prefer (Halkos & Managi, 2016).

The conclusion of the new growth attempting to account for environmental externalities indicates that, since natural resources are limited, economy will come to a halt in the long-run. This can be solved by putting a limit on resource extraction and allocating labor to R&D, or by using environmental friendly technologies instead of pollution – inclined ones.

3.2. Economic Growth and Gross Domestic Product

Without any doubt, this thesis takes into account economic growth, for it is regarded as a political and economic goal by the government. Other factors should be taken into account as well, such as wealth distribution, since economic growth is measured as the change in Gross Domestic Product (GDP) over time. Considering that an increase in GDP expands the total of goods and services, one might think that it may also result in an increase in the general well-being of society (see Figure 3, where Western Offshoots and Western Europe seem to have the highest GDP per capita for the year 2014). That is not the case according to Jackson (2009), since GDP measures the monetary value of the goods. Hence the need to study alternatives to GDP, such as the Human Development Index (HDI)[5] and throughput[6].

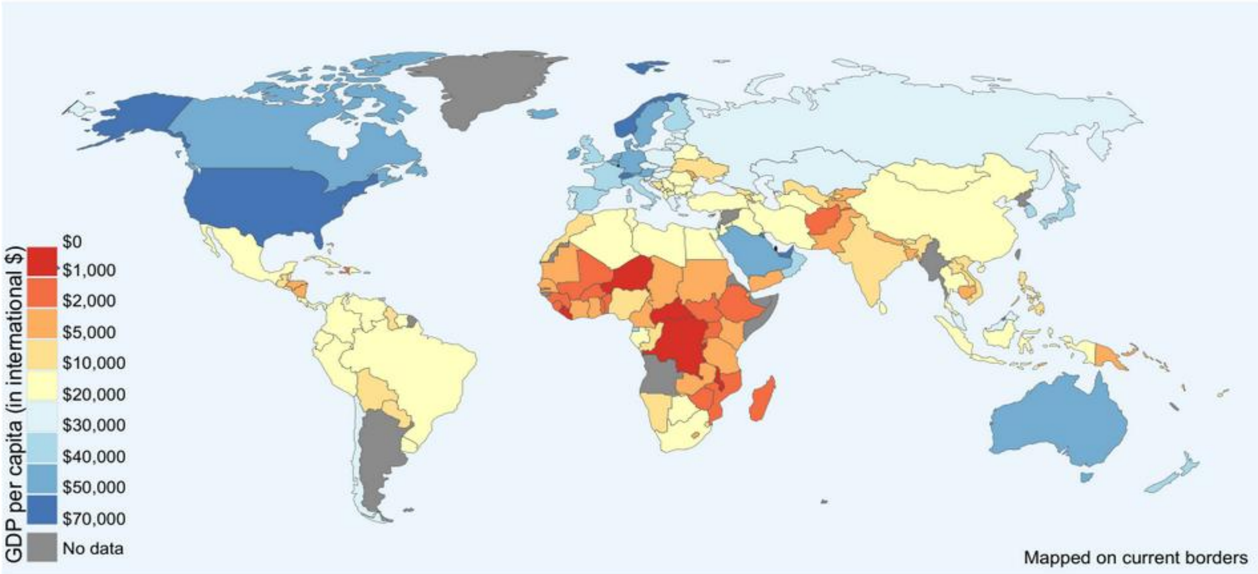
As a result of the analysis above, long-term economic and social goals need to be set when designing and implementing governmental policies. The key to this is the distribution of the remaining resources and growth possibilities among the world's nations (Rockstroem et al., 2009). The dilemma lies between developing and developed countries' distribution, as well as their emission and consumption levels. Regularly, economic growth is considered a priority of developing countries rather than a priority of the developed ones, and many academics, such as Daly (1996), claim that growth in developing countries causes growth in developed ones. This is based on the fact that the latter ones invest in the former ones, and also import goods from them.

However, Chesney (2016) insists that, given the planetary boundaries, increasing quantitative growth is not a target, and further development should be a result of stable population size maintenance, redistribution of wealth, income and technical improvements in resource productivity.

[5] The HDI was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone (United Nations Development Programme, 2016). It indicated that GDP should include social goals, thus it based on health status, education level and income per capita (Chesney et al., 2016).

[6] Throughput takes into account the possible environmental consequences and refers to the total amount of matter and energy involved at every stage of the economic cycle (Jackson, 2009). The result of throughput is that the ecosystem is very small compared to the economic subsystem.

Figure 3.2: Global distribution of GDP growth for 2014, GDP per capita for 2014 (Source: Our World In Data, 2016)



4. The Finance of Environmental Investments

4.1. Characteristics of investment projects

When dealing with finance, either environmental finance, cost – benefit analysis, derivatives or investments, then risk, globalization of economy, competition, technological changes, information asymmetry and environmental constraints have to be taken into account.

According to Chesney et al. (2016), what is needed for the valuation and selection of investment projects is real options[7]. The key is to connect real options with investment decisions in the setting of an emission allowance market (Loubergé et al., 2002). What is important, however, is to firstly examine the characteristics of investment projects.

Chesney recognizes six features, which characterize the investment projects.

1. Price uncertainties, which rely on price dynamics being modeled as stochastic rather than constant processes.
2. Irreversibility of the investment decisions, given an irreversible project, the investment decision will be taken with more caution, thus it will be more time consuming. This works vice versa, meaning that the more possible to reverse the project, the more incentives there are to invest sooner.
3. Time dimension that characterizes investment projects, and it is connected with risk. A project might need more time to be undertaken, thus gathering more information in order to reduce the risks linked with the investment.
4. The implementation delay, since the decision to invest is not implemented instantaneously, the whole process of the investment projects is affected.
5. Sequential decision, which has to do with whether the company wants the process to be taken step-by-step, or as a one-shot decision. The former limits the chance of the risk inherent, as the process stops at any point that the risk would be considered too high.

[7] A real option is a choice made available with business investment opportunities, referred to as "real" because it typically references a tangible asset instead of financial instrument. Real options are choices a company's management makes to expand, change or curtail projects based on changing economic, technological or market conditions (Hull, 2013).

6. Presence (or absence) of competition, where the decision making process is influenced by the first mover advantage. Incentives to invest sooner in order to preempt the competition would be generated in the danger of losing the market. Similarly, in the absence of competition, more flexibility in decision making process would be observed, and it might also lead to monopoly.

4.2. Net Present Value (NPV)

It is of high importance for the companies to take strategic decisions, and the decision making tool is the Net Present Value (NPV) approach. The NPV uses the given cash flows and outflows of an investment.

While this tool is recommended by the corporate finance theory, it has certain limitations, which affect the three basic steps of the investment analysis. Those steps consist of the valuation of the possible investment projects, selection and timing of the chosen projects, and require financial approaches related to the environment.

The formula of the NPV is the following:

$$NPV = F_0 + \frac{F_1}{(1+r)} + \frac{F_2}{(1+r)^2} + \cdots + \frac{F_n}{(1+r)^n}$$

where, n: the lifetime of the investment
r: the discount rate
F_i: The expected cash flaws

When the NPV is positive, then the investment should be undertaken, whereas when it is negative, the project gets rejected.

However, the NPV approach has several limitations (Xepapadeas, 2016). First of all, it is difficult to estimate the values of the cash flows and the outflows over the life of an investment, as well as forecasting future cash flows. Secondly, and more seriously, it is only possible to accept all investments with a positive NPV in a perfect capital market, since only in such a market is there no restriction on the amount of finance available. In reality though, capital is restricted and this can limit the applicability of the NPV decision rule.

While the NPV approaches assumes a reliable estimation of earnings and costs, an explicit derivation of the discount rates, and a static investment rule, stating that the investment is to be undertaken now or never, in reality, this is not the case.

It has to be highlighted that investments undertaken always carry a risk, making the reliable estimation referred above rather questionable. The uncertainty that is linked to the future cash flows is inappropriately considered, because there is a tendency to assume that only the discount rate will take into account this uncertainty.

What is more, an investment rule is not static, given that various investment decisions need to be delayed on purpose, in order to determine their undertaking or not. This delay is related to the information gathered. As a result, a dynamic setting is important, as investing opportunities can be evaluated and compared. Finally, the NPV does not include opportunity costs associated with the decision to invest, because as soon as the decision is taken, the opportunity to invest later vanishes. Given that investing at a later, more suitable stage might be the optimal move, the opportunity costs being present, is essential.

4.3. Investment opportunities and real options

Due to those limitations, the real options approach is used. The financial options developed by Black and Scholes (1973) and Merton (1973) are call[8] and put[9] options.

By perceiving the investment opportunities as real options, one is given the right of undertaking the investment for a given cost (which corresponds to the strike price of the financial option) and takes into account options such as the option to delay, expand, to grow or to abandon. Costs associated with the possibility to reverse the project are taken into account as well.

It is to say, though, while that many scientists and academics believe that the introduction of the real options approach always generates incentives to wait longer before investing than with the NPV criteria, Chesney (2016) argues that this is not the case. More specifically, this conclusion implies a static framework, without interaction between the decisions of the companies. In reality, the dynamic and competitive setting makes the profit generated by the potential investment dependent on the investment decisions of the other companies, thus the real option criteria might generate incentives to invest sooner than with the static NPV approach.

The statement above can be taken into consideration when studying the European Union Emissions Trading System (EU ETS). To be more precise, regulated companies can either invest in a new technology with the intention to reduce their

[8] Call option is an agreement that gives an investor the right, but not the obligation, to buy a stock, bond, commodity or other instrument at a specified price (strike price) within a specific time period.

[9] Put option is an option contract giving the owner the right, but not the obligation, to sell a specified amount of an underlying security at a specified price within a specified time. This is the opposite of a call option, which gives the holder the right to buy shares (Black & Scholes, 1973).

CO_2 emissions, or buy emission rights. If the price of the emission rights is smaller than the marginal cost of technology changes, the NPV approach implies buying them instead of investing in technology. However, when it comes to the NPV approach being static, it neglects the other regulated firms' decisions to invest or not on the price of the emission right. The low price discussed above will push the other regulated companies to buy right as well, and it will not motivate them to reduce their emissions. All buying rights might lead to a market price increase, which in turn leads to a growing interest for a technology switch, as not all companies will be able (or fast enough) to buy rights. In a dynamic environment, Chesney (2016) claims that investing in a new technology and selling rights in surplus is what companies should sought. This investment process is analysed via option pricing with the Binomial Model, known as the binomial tree.

4.4. Option Pricing with the Binomial Model

This option pricing model is obtained via the following formulas:

$p = \frac{e^{r\Delta t} - d}{u-d}$ and $V_t = (1+r) \cdot \Delta t = p \cdot u \cdot V_t + (1-p) \cdot V_t$

where p: probability of an upward improvement, $0 \leq p \leq 1$

Δt: T – t, where t is current time and T time of maturity

V_t: underlying value at time t and $V_T = u \cdot V_t$, $V_T = d \cdot V_T$

u: upwards movement and d: downwards movement

When talking about multi-period Binomial Model, the formula changes to:

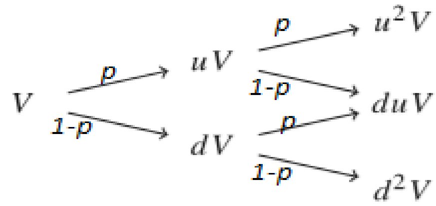
$$P \cdot \left(V_{n\cdot\Delta t} = u^j \cdot d^{n-j} \cdot V_0\right) = \left(\frac{n!}{j! \cdot (n-j)!}\right) \cdot p^j \, (1-p)^{n-j}$$

Where p: probability

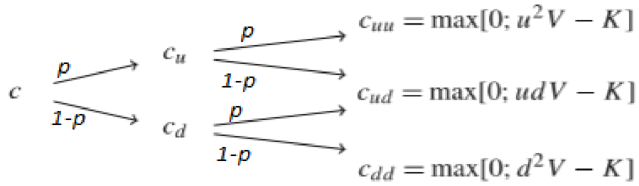
$\left(\frac{n!}{j! \cdot (n-j)!}\right)$: the number of possible paths to reach given node $u^j \cdot d^n \cdot V_0$

$p^j \, (1-p)^{n-j}$: the probability to reach the node

As a result, the options' prices obtained are seen below:



Thus, call value is:



where

$$c_u = [p \cdot c_{uu} + (1-p) \cdot c_{du}]\, e^{-r\Delta t}$$
$$c_d = [p \cdot c_{ud} + (1-p) \cdot c_{dd}]\, e^{-r\Delta t}$$

and eventually

$$c = (p \cdot c_u + (1-p) \cdot c_d) e^{-r\Delta t}$$

where r represents the risk-free rate.

4.5. The Black – Scholes Model (1973)

In order to obtain call *c* and put *p* (European) options, the Black and Scholes Model (1973) is used. The model was also developed by Merton (1973). The Black and Scholes Model works under certain assumptions:

First and foremost, constant, known risk-free interest rates and constant volatility. More specifically, in the real world, there is no such thing as a risk-free rate. As far as the volatility is concerned, it is the most significant assumption, a measure of how much a stock can be expected to move in the near-term, is a constant over time. While volatility can be relatively constant in very short term, it is never constant in longer term. Its estimation consists of two alternative methods: The first approach is based on computing the historical volatility which corresponds to the variance of historical terms. The alternative to this is based on computing the implied volatility[10].

[10] Implied is the volatility that, when used in a specific option pricing model (e.g. the Black – Scholes model), yields a theoretical value for the option equal to the current market price of the option (Chesney et al., 2016; McDonald, 2013). It is the estimated volatility of a security's price. In general, implied volatility increases when investors believe that the asset's price will decline over time, and decreases when investors believe that the price will rise over time. Implied volatility is a way of estimating the future fluctuations of a security's worth based on certain predictive factors (Black & Scholes, 1973).

Furthermore, there are no commissions and transaction costs or taxes. The Black-Scholes model assumes that there are no fees for buying and selling options and stocks and no barriers to trading. There are no riskless arbitrage opportunities as well, whereas the securities trading is continuous.

Another assumption is that the underlying stock does not pay dividends during the option's life. In the real world, most companies pay dividends to their share holders. A common way of adjusting the Black – Scholes model for dividends is to subtract the discounted value of a future dividend from the stock price. The Black-Scholes model also assumes that returns on the underlying stock are normally distributed and all securities are perfectly divisible.

Finally, the final two assumptions of the Black – Scholes are that the short selling of securities with full use of proceeds is permitted and that the market is efficient. The latter assumption of the model suggests that people cannot *consistently* predict the direction of the market or an individual stock. The Black – Scholes model assumes stocks move in a manner referred to as a random walk. Random walk means that at any given moment in time, the price of the underlying stock can go up or down with the same probability. The price of a stock in time t+1 is independent from the price in time t.

According to the Black – Scholes model, call and put options derive from the following formulas in Table 4.5 (Black & Scholes, 1973 and Hull, 2013):

Figure 4.5: Options formulas, with and without dividend yield

Without dividend payments	**Providing Dividend Yield**
$c = S_0\, N(d_1) - K\, e^{-rT} N(d_2)$	$c = S_0 e^{-qT} N(d_1) - K e^{-rT} N(d_2)$
$p = K\, e^{-rT}\, N(-d_2) - S_0\, N(-d_1)$	$p = K e^{-rT}\, N(-d_2) - S_0 e^{-qT} N(-d_1)$
where $d_1 = \dfrac{\ln(S_0/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$	where $d_1 = \dfrac{\ln(S_0/K) + (r - q + \sigma^2/2)T}{\sigma\sqrt{T}}$
$d_2 = \dfrac{\ln(S_0/K) + (r - \sigma^2/2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$	$d_2 = \dfrac{\ln(S_0/K) + (r - q - \sigma^2/2)T}{\sigma\sqrt{T}}$

where c: call price | p: put price

S_0: stock price at t = 0 | r: riskless interest rate

K: exercise price | q: dividend yield

T: time to maturity | σ: annualized volatility of the stock price returns

$N(d_1)$, $N(d_2)$: the cumulative distribution function of the standard normal distribution

4.6. Real options and Environmental Regulation

It is undeniable that environmental regulations and more specifically carbon regulations are something worth considering by the firms. These regulations have to comply with EU ETS, so as the firms think up strategic investments in order to possibly reduce their emissions and the trade of emission allowances. Comparing to the NPV approach, the real options one is more considerate. As a result, the optimal investment decision will be taken with the help of a (dynamic) multi-period binomial tree.

4.7. Emission Rights Trading – Optimal Decision

Imagine having a one-period model, where instantaneous emissions level and emission permits are both exogenous and independent processes.

According to Chesney et al. (2016), there are trading opportunities, but only at initial time. By the end of the period, each company must possess enough permits. However, if it fails, there is a penalty, which equals to an amount plus the price of the permits, which is related to the tons of uncovered pollution. In the end of said period (where the emissions might have a redemption value equal to zero), the emission allowances are either at a surplus or at a shortage. The company has to therefore face two risks:

First, being on a surplus, the company holds (worthless) emission allowances. This means that the company purchased more allowances than needed at the initial time, thus the firm now has incurred costs. Second, being on a shortage, the company is uncovered, hence the costs that occur due to possessing too few emission rights.

The result of the above means that the company's net final position can be positive when on shortage, or negative when on surplus. The goal is to have a net final position as close to zero as possible. The ideal would be such a position equal to zero.

At time zero, the firm minimizes its expected discount costs and, as a result, the total cost is:

TOTAL COST = COSTS INCURRED AT TIME ZERO + POTENTIAL COSTS = PEALTY + PRICE OF THE PERMITS PER UNIT OF UNCOVERED POLLUTION

It is worth mentioning that each cost function mentioned in this section, is a variation of the relationship above.

The initial cost is the one from the purchase of the emission allowances, which can be reduced later by selling some of the allowances. The companies have the two following objectives: First and foremost, to trade a number of emission rights, so as to have net final position equal to zero. In addition, the company wants to avoid the surplus, because it generates costs at the initial time, as well as shortages, as it causes costs at maturity.

What comes out of the above risks is that the firm wants, at initial time, to choose the exercise price, so that the call option has the same initial and exercise price (at-the-money).

Similarly to the one-period model, in the case of a two-period model, there are instantaneous emissions level and emission permits are both exogenous and independent processes, evolving with the help of a binomial tree. In this model, trading opportunities exist at initial time and after one year.

What remains unknown during the course of the two-period model is the optimal quantity of permits that the company should buy and sell at initial time, and the quantity of permits that the company should sell after one year.

At the end of the second period, at time T comes (maturity), the companies should be in a position to have enough permits. If it fails to do so, it must pay a penalty, plus the price of the permits for each ton of uncovered pollution.

The cost of this process is consisted of the costs incurred at time zero (which corresponds to the trade of allowances), the expected discounted costs (resulting from the trade of permits at the end of the first period) and the expected discounts costs at maturity (which equal to the penalty[11] and the price of the permits per unit of uncovered pollution). The cost can be reduced later by selling some of the allowances.

After the year one, the company has to make another choice, this time concerning the number of allowances that it should buy or sell. At this point, this choice corresponds to the one-period binomial tree, which, as it is stated above, results to the company's net final position.

Hence, the need to solve the problem using a backwards solution, starting from the end of the first period, finding the optimal quantity of traded emission and finally resolving at initial time and deriving the initial optimal traded quantity.

As it would be quite obvious, if the initial traded quantity is negative, then the optimal choice would be to buy the largest number emission permits possible.

[11] It is worth mentioning that if, after solving the model, the emissions after year one decrease, then the company is most likely to avoid penalties at maturity, because after one year, it will hedge against the worst case scenario.

Depending on how the emissions move, the result is obviously going to be different, while it largely depends on the price dynamics for the permits. More specifically, if the emissions increase after one year, then the regulated company will have to sell as many permits as to be able to keep the number of allowances that correspond to the hedge in the worst case scenario. On the other hand, if the emissions decrease after one year, the regulated company will have to sell as many permits as to be able to hold the number of allowances that allow the firm to be hedged if emissions increase during the second period. This is justified in the light of benefiting from the increase in value between the two periods, since under the initial assumptions, the discounted expected future price is higher than its initial value.

When the company no longer benefits from the positive evolution of the price, the buying strategies at the beginning are eliminated.

Finally, it is worth mentioning that, as far as the regional control of pollution is concerned, each region uses public pollution abatement and issues either intra-regionally or inter-regionally tradable emission permits.

4.8. NPV criterion and real options pricing

Comparing the NPV criterion with the real options pricing, there are some fundamental differences. Most importantly, according to the NPV, the first decision that the company should take is whether or not it is preferable to wait one period before trading emission permits.

If the company decides not to trade immediately and wait, the initial number of emission permits is equal to zero, and the second decision will be how many optimal permits should be traded to avoid paying a penalty at the second period. If, however, the company decides to trade immediately, the second decision will be whether to purchase or sell emission permits at period one.

Taking some collected data as an example (Chesney et al., 2016), it can be seen from the cost functions (Figure 4.8a and Figure 4.8b) that, under the NPV procedure, the minimized costs are bigger than under the real option setting. To be more specific, the lowest cost in the NPV approach is 2000, while the possible initial traded quantity is a curve (Figure 4.8a), on contrast to the real option setting, where the former is 1500 and the latter is a straight line (Figure 4.8b). The difference in the minimized costs occurs due to the fact that the dynamic strategy of the second date is not to be taken into account.

A similarity between the two figures is that both cost function start from negative points, meaning that a purchase of permits is a cost.

Figure 4.8a: NPV criterion – Cost function (Source: Chesney et al., 2016)

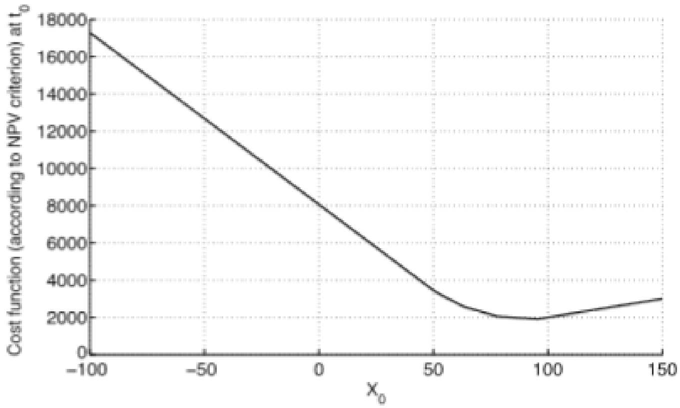
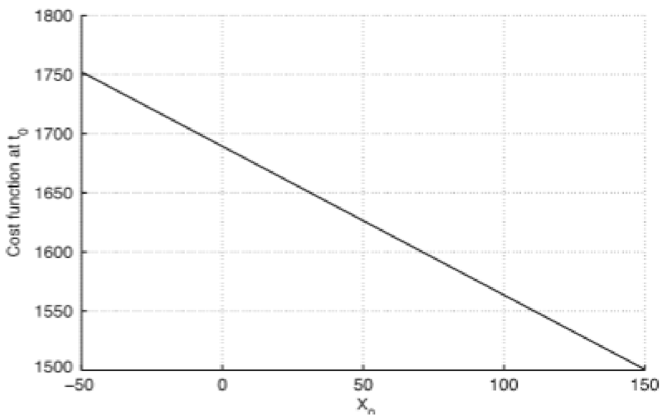


Figure 4.8b: Real option setting – Cost function (Source: Chesney et al., 2016)



What is more in the NPV, if the company increases its emissions during the first year (i.e. wait one period before trading), the company should not trade permits, as a hedge will be generated in the case that emissions increase further in year 2. Of course, the optimal solution depends on whether emissions increased or not. Say the emissions increase, the company should buy permits to avoid having to pay penalties in the worst case, whereas if they decrease, the company needs to buy less permits to hedge its worst case scenario. As a result, waiting for one year causes the company to keep the same amount of permits but will still have to pay to get them. Hence, we conclude that the best NPV strategy is not to wait for one period before trading, given that taking a decision at initial time restricts the possibility of taking a decision on the next period.

In addition, a sequence of static decisions are implemented in the NPV setting, in contrast to the real options framework, where the decision making process is dynamic. Those static decisions on the NPV result into cost at the initial time, and the company can either sell permits if the emissions decrease, or do nothing if the emissions increase.

Furthermore, when it come to the NPV approach, the full hedge is recommended, while the real options framework indicates the over hedge[12]. The over hedging creates a time value, which is absent from the NPV approach. This time value is created due to the fact that over hedging includes extra emission permits, which generate the option to sell the rights at a higher price. So, the real options approach yields lower costs, because the company is able to resell the permits after a year.

4.9. Emission Rights Trading and Technology Changes – Optimal Decision

4.9.1. Emission and Price Processes – One-period model

By further comparing the real options setting and the NPV criteria, it has become obvious that the one-period model does not indicate a distinction between those two approaches. This happens because the investment decision should be taken later on.

The company's objective is to choose the exercise price at initial time, subjected to the technology factor, so as to have an at-the-money call option at maturity, i.e. the optimal choice of exercise price. Its objective is also to determine the optimal quantity of tons of GHG (something that is achieved via minimizing the cost function of each company). If at maturity, the emissions have increased, the company is fully hedged and has to purchase more emission rights, in order to avoid being given a penalty, which is a cost for the company. However, if the hedge is partial, then emissions will decrease in the next period, and the emission rights that have to be purchased in order to avoid the penalty should be less than before. As a result, there is a risk of higher a penalty if the emissions increase. On the other hand, this risk is compensated via the risk of abating too much, which occurs when companies reduce their emissions to a partial hedge.

[12] Over-hedging is a term used in trading to refer to when a position has been hedged so much that there is no (or very little) opportunity for profit, i.e. your hedge cancels out your main position. This does also mean you cannot lose money, but not being able to make money defeats the purpose of investing (Jorion, 2009).

There is also a more realistic set, in which price dynamics are endogenously derived. This means that the emission permits price derives from the supply and demand balance and constitutes the equilibrium price. In that case, there is a second company as well, which interacts with the first company. Since the gas reduction target is settled according to EU ETS, the supply of permits (and thus their total number) is fixed. The first company is not aware of the level of emission of the second company (asymmetric information), something that will be revealed at the end of the first period. At the end of the period, a surplus or a shortage between the issued emission allowances and the realized pollution level is expected, meaning that each company will either be holding worthless emission allowances, or paying the price for being uncovered.

Given that each company must have enough permits, a failure to achieve compliance at maturity (shortage) means that the firm will have to pay a penalty. In order to avoid it, the firm can buy allowances for each ton of uncovered pollution at maturity. As Chesney (2016) assumes, the price of the penalty is equal to the price of the extra permits, so the two possible solutions are financially equivalent.

On the other hand, if the company is at a surplus at maturity, it can sell some allowances, whose number is constrained by how many of them the other firm wants to buy. To find the number of emissions, one should minimize each companies cost function, which equals to the total costs of each company plus the potential penalty.

4.9.2. Emission and Price Processes – Two-period model

As it is already mentioned, a two-period model means that companies should take two decisions. This time, it is not about waiting for one period, but about trading emission rights and changing their technology.

At the beginning (t = 0), a company has only trading opportunities. At period one, the company has a choice: either to switch to new technology that reduces the firm's emissions for a lump-cost, or keep the old technology. Solving the problem backwards (through the function cost of each company), eventually the optimal choice for the company would be to indeed change the technology, but only if the initial purchase of emission allowances is too limited. If the company has enough emission allowances, developing/purchasing new technology is too expensive, thus it corresponds to an over-hedge at maturity.

What is more, an increase in the emissions or price during period one means that in case of shortage, the costs are at the maturity, thus the need for a technology switch. The more the emissions and the price increase, the more the need for new technology.

When comparing the NPV approach to the real options setting, the dynamic environment in the two-period model benefits the latter. The former is a sequence of static decisions, the first one being the purchase of emission permits without accounting for technology, and the second one being the acquirement of new technology. All in all, when a technological change happens (dynamic environment), the real options approach benefits from under-hedging, while the NPV approach is better for perfect hedging, albeit keeping the old technology.

5. Emission price dynamics

Price of emission allowances have always been closely linked with the observed market – price behavior. Investigating the asymmetrical responses to different shocks in the allowances market, according to Paolella and Taschini (2008), the weight falls on recent, as well as negative returns.

What has really been under the microscope the past decades is the substitution principle between emission allowances and abatement technology[13] (Montgomery, 1972b), as well as the relationship of the allowance price and the marginal cost of abatement. More specifically, this price corresponds to the cheapest marginal cost (Tietenberg, 1985; Rubin, 1996).

When it comes to the EU ETS in the short-run, the cheapest abatement technology referred above is fuel switching, that is, the option to switch from coal-fired power to gas-fired power generation (Chesney et al., 2016). This switch is considered more environmentally beneficial, because a fuel switch from coal to gas lowers emissions per *Megawatt hours (*MWh) of electricity, making the gas-fired power production more appealing. The lower emissions rates originate from the different relative carbon intensities that coal and gas have. As a result of that, and given that the CO_2 allowance prices keep rising as seen in the section about the Economic Growth and the Environment, gas-fired power generation turns out to be more competitive than the coal.

Moreover, the CO_2 allowance prices may be rising, but the CO_2 emissions per MWh of produced electricity are benefited from the switch to that extent that they get reduced. Therefore, fewer emissions have to be covered with the European Union's Emissions Allowances (EUAs). [14]

[13] It refers to technology applied or measure taken to reduce pollution and/or its impacts on the environment. The most commonly used technologies are scrubbers, noise mufflers, filters, incinerators, waste—water treatment facilities and composting of wastes (OECD, 2016).

[14] For a closer, comparative look at the emissions indicative performance for the years 2005 – 2009, see Figures 5a and 5b.

Figure 5a: EU ETS Covered CO_2 Emissions and EUA prices 2005 – 2007. The verified CO_2 emissions between 2005 and 2007 and the average monthly price of the European Emissions Allowances (EUA) traded under that scheme. (Source: European Commission, 2008)

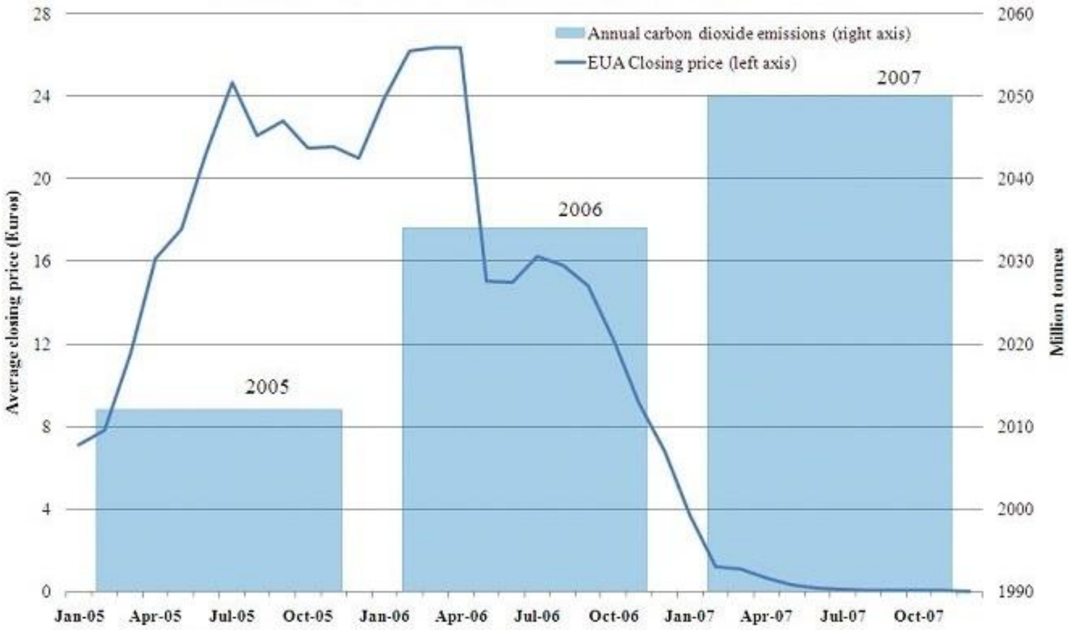
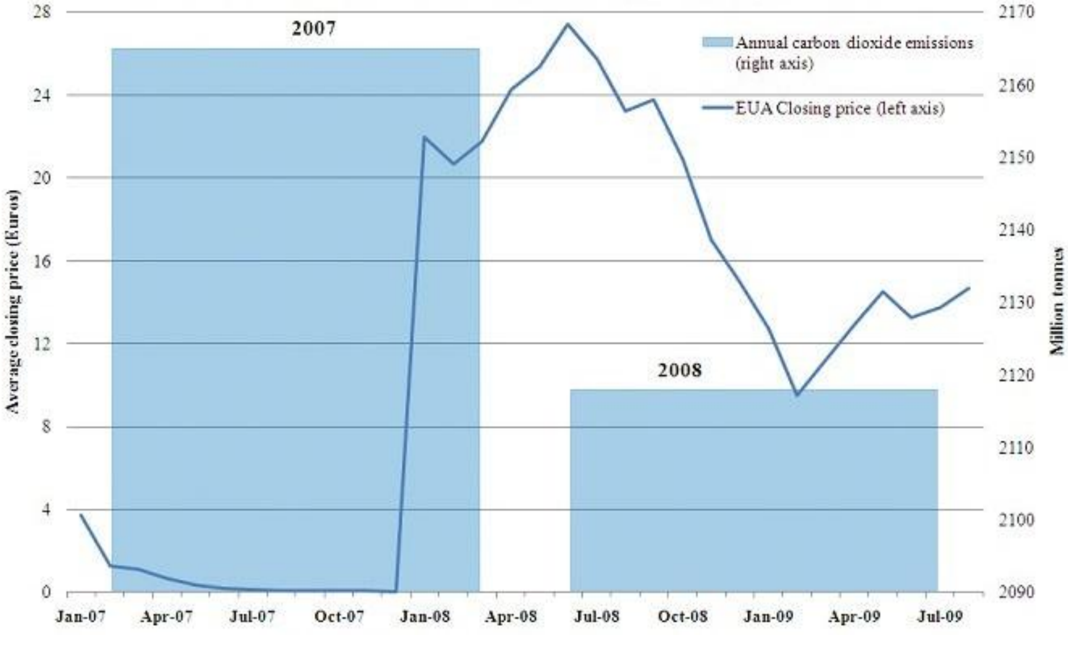


Figure 5b: EU ETS Covered CO_2 Emissions 2007 – 2008 and EUA Spot Prices 2007 – 2009. The verified CO_2 emissions in 2007 and 2008 and the average monthly price of the EUA traded under that scheme between January 2008 and August 2009. (Source: European Commission, 2008)



But what does really affect the operating choices for the power generation industry? According to Hynes (2009), it is all about the price of the coal versus the price of the gas. Assuming that gas is cheaper compared to coal, gas will be preferred over coal. Given that gas has lower carbon emission in order to produce one MWh of electricity than coal, the demand of EUAs will decrease. On the other hand, if coal is cheaper compared to gas, the installations will probably switch to coal, which has higher carbon emission levels. As a result, the demand of EUAs will increase.

Taking a closer look at the prices for gas, a dependence on the season is observed. More specifically, winter prices for gas are generally higher than the summer ones, due to the gas heating demand that occurs during the winter months. In addition, generally, winter is not indicated for production and supply of gas, as the weather is colder and makes the whole process more difficult. From these facts, it is easy to understand that the possibility for a switch from coal to gas has fewer possibilities to happen, making the opposite switch more attractive.

In order to face the seasonality problem described above, fuel switch price has to be de-seasonalised via a procedure, which is called Seasonal Trend with Local Regression Smoothing or Loess (STL)[15] (Cleveland et al., 1990).

As far as the industry is concerned, it makes the fuel switch according to relative prices or allowance shortages. Fuel switching is a medium-term abatement option, and as a result it could be used as a proxy for the allowance price, for hedging, as well as pricing purposes (Fusai & Roncoroni, 2008).

As a way to understand the switch better, Figure 3 shows the carbon prices necessary for US and EU power production to switch from coal to gas. Although natural gas prices in the EU have dropped in the last two years of the graph (significantly reducing the carbon price required for switching), coal prices have also fallen. This means that for natural gas to drive out coal in EU electricity production, either gas price would have to drop further, or the carbon price would have to increase.

[15] The specific procedure, developed by Cleveland et al. in 1990, provides trend and seasonal components that are robust to outliers. The full potential of the procedure are more obvious using time series.

Figure 5c: Carbon price needed for switching from coal to gas in power generation (Source: Zachmann, 2015)

In order to view into action the analysis of the emission price dynamics, deterministic and stochastic equilibrium allowance price models have been developed. Studying those models, it should be mentioned that their prime assumption is that they are profit maximizers who want to minimize total compliance costs and that they have to choose an optimal production strategy and an optimal allowance trading strategy. Furthermore, all models, except cited otherwise, hold under the symmetric information in the market for allowances assumption. The models studied below give various conclusions that are equally important to the academic community about the emissions price dynamics.

5.1. Equilibrium Allowance Price Models

The Montgomery model (1972)

Given that the pollution – abatement problems are highly connected to the property rights (Crocker, 1966; Dales, 2002), in the light of an economic, cost-benefit framework, transferable emission allowances lead to an efficient allocation of abatement costs across various sources of pollution (Montgomery, 1972b). Since the problem is focused on regulating the GHG emissions, which affects the global community[16], the Montgomery model is slightly differentiated. While the original Montgomery model includes and estimates the location – dependent concentration of pollution by multiplying the dispersion factor with the emission quantities, Chesney et al. (2016) reduce their study in only one location. As a result, they are under one extra assumption, i.e. the dispersion factor does not differ from one location to another.

The target of the firm being to find the optimal emission level so that it maximizes its profits under that fixed level of emission, Montgomery imposed a set of definitions, so that his model works. First of all, he defines necessary and sufficient conditions for the existence of a market equilibrium that corresponds to the initial allocation of allowances. At the same time, he defines a joint cost minimum, i.e. a subsidiary construction, that its conditions are satisfied via the emission vector and shadow prices for given totals of allowances. The emission vector and shadow prices (or price vector) satisfy the conditions of competitive equilibrium relative to any initial allocation of allowances in which the given totals are distributed among firm completely, as well. As a result, the joint cost minimum is achieved by a competitive equilibrium. That statement is proved by showing that when allowances totals are equal to desired air qualities, then the emission and price vectors that satisfy the equilibrium conditions satisfy the efficiency conditions as well.

Montgomery comes to the conclusion that, when pollution emissions are positive, the equilibrium allowance price is equal to the marginal abatement costs. What is more, transferable allowance systems are cost optimal, because, as Montgomery points out, the market equilibrium is equivalent to the joint cost minimum.

The Rubin model (1996) and Kling and Rubin (1997)

Another academic, Rubin (1996), solves the deterministic problem by maximizing profit and minimizing compliance costs of firms, while adding an extent to Montgomery's work. More specifically, Rubin analyses the allowance price over time and investigates the effect of banking and borrowing on the allowance price.

[16] The level of pollution of global pollutants (such as CO_2) is not influenced by the location of the polluting activity. Only if we are talking about local pollutants, the location does matter (Chesney et al., 2016).

Furthermore, Rubin proves that there is cost optimality of transferable allowance systems in a continuous – time setting with finite horizon.

Since the Rubin model follows the steps of the Montgomery model, necessary and sufficient conditions for the existence of a market equilibrium that corresponds to the initial allocation of allowances are defined, as well as the joint custom minimum. Of course, as previously, market equilibrium is equivalent to the joint cost minimum.

Certain conclusions are reached, the prime of them being the same as Montgomery's, i.e. the allowance price equals the marginal abatement costs. What is more, the shadow price, or the marginal value of a banked emission allowance, equals the discounted marginal abatement costs. A really interesting finding on Rubin's behalf is that, under the condition that there are no restrictions on banking and borrowing, the allowance price is growing at the risk – free interest rate. Also, banked allowances are worthless at a specific time T[17]. Note that, in this model, a firm has to hand in one allowance per unit of emission independent of when emissions take place.

In addition, marginal abatement costs are the same for all the firms causing pollution, thus the discounted marginal abatement costs equal to the marginal cost of banking allowances. Finally, Rubin concludes, as in the Montgomery model, that the equilibrium allowance price is equal to the marginal abatement costs and that the market equilibrium is equivalent to the joint cost minimum.

Rubin extended his study, this time with Kling, and includes cost and social optimality. This way, Kling and Rubin (1997) incorporate the damage function associated to pollution emissions and analyse the socially optimal solution, contrary to the two previous models, where it is shown that a system of transferable allowances leads to the low – cost solution. In order to do that, they adopt a regulated firm and they solve its profit maximization problem. Then, they solve the central planner's optimization problem.

After solving the model they created, Kling and Rubin conclude that the equilibrium allowance price is equal to the marginal abatement costs. When it comes to the firms incentives to bank or borrow emission allowances, under constrained provisions, in the early periods they choose excessive damage and output levels, although that is not the optimal choice for them. In later periods, they choose too few of those levels. Assuming linear social damages, they introduce modified banking rules that penalize borrowing by discounting borrowed alliances, thus showing that a social optimum could be achieved.

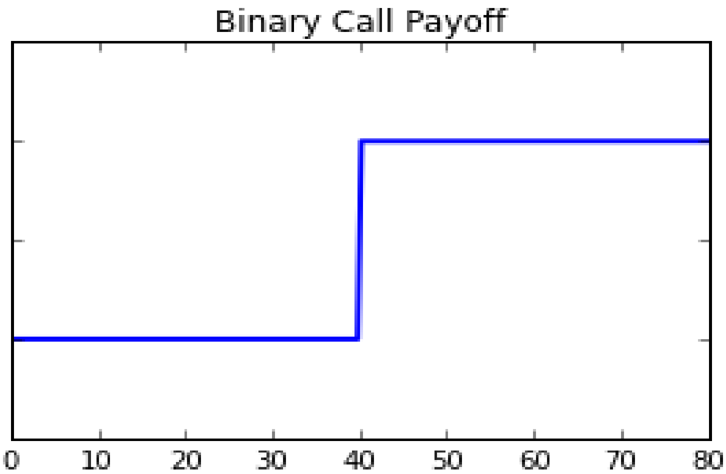
[17] This is the transversality condition (which is for an infinite horizon dynamic optimization problem), i.e. the boundary condition determining a solution to the problem's first-order conditions together with the initial condition. The first-order and transversality conditions are sufficient to identify an optimum in a concave optimization problem. Given an optimal path, the necessity of the transversality condition reflects the impossibility of finding an alternative feasible path for which each state variable deviates from the optimum at each time and increases discounted utility (Craven and Islam, 2005).

Seifert et al. (2008)

The problem Seifert et al. (2008) solve is the representative agent's cost minimization problem, whose framework is justified by the market equilibrium being equal to the joint cost optimum. In the model discussed in this section, each regulated firm can buy and sell allowances and it minimizes its expected costs by choosing an optimal abatement strategy, while buying and selling an optimal number of allowances.

With the help of the Brownian motion[18] as far as the emission rate is concerned, Seifert reaches the conclusion that although it is impossible to have a closed – form solution, it highly resembles the trend of a binary call option payoff (see Figure 5.3).

Figure 5.3: Binary call option payoff (Source: Copeland, 2005)



Carmona et al. (2009)

In this particular model, there is stochastic equilibrium, which resembles the ordinary allowance scheme. Assuming there is a specific number of firms in the economy and an in time-T currency expressing profits and costs, no discount factors are in sight. What firms do is maximize their profits in order to choose an optimal allowance trading strategy and an optimal production strategy. With marginal costs being exogenous, the certain constraints must hold:

[18] The Brownian motion model is an extension to the one-period market model (Markowitz, 1952; Sharpe, 1964) and defines the concepts of financial assets and markets, portfolios, gains and wealth in terms of continuous-time stochastic processes. Under this model, these assets have continuous prices evolving continuously in time and are driven by Brownian motion processes. This model requires an assumption of perfectly divisible assets and a frictionless market (i.e. that no transaction costs occur either for buying or selling) of no surprises in the market (Merton, 1970).

First and foremost, production can be less or equal to the capacity, but it cannot exceed it. Moreover, demand is always smaller compared to the total production capacity. The demand is stochastic, while the firm's capacity to produce goods with a certain technology is constant. Last but not least, the sum of all uncontrollable emissions must have a continuous distribution (technical condition), so that there are no pathological situations about the equilibrium prices.

When each firm buys or sells an optimal number of allowances and produces an optimal quality of goods, it maximizes its expected terminal wealth, making it the firm's optimization problem. As far as the global optimization problem is concerned, expected total costs are minimized when an optimal quantity of goods is produced.

What is needed in order for the market equilibrium to be understood is to structure the emission allowances under certain limitations and make them correspond to certain associated strategies. To be more specific, if there is a given one-dimensional process for forward price on allowance, as well as a given multi-dimensional stochastic process for the prices of the products, then the associated optimal strategies[19] lead to a situation where all the firms that have maximized their profits are satisfied by their strategies. At this case, there two conditions that take place:

First of all, the market cleaning condition on allowance must hold, and secondly, for each good, the supply should meet demand. Depending on the presence or the absence of a penalty, there are two possible scenarios: One, given that there is no penalty, the equilibrium prices are a merit – order type of equilibrium. The production means contributing to this equilibrium are ranked by increasing production costs, while producing with the cheapest production means meets demand. Furthermore, the resulting equilibrium price of goods equals to the marginal cost of production, while the demand is met when firms use the most expensive production meets. Two, assuming that there is a penalty involved, the equilibrium prices are a merit – order type of equilibrium as in scenario one, and the costs are adjusted for the emissions associated to the production.

The results given by the Carmona et al. model are quite interesting. For one, as in the models mentioned before this, the market equilibrium is equal to the joint cost optimum. As far as prices of the produced goods are concerned, they correspond to a merit – order type equilibrium with adjusted costs. This means that, the presence of an emissions trading scheme, products become more expensive, and their price increase equals to the value of allowances needed for the good's production.

What is more, the future allowance price equals the penalty, multiplied by the probability of allowance shortage[20] at the end of the compliance period.

[19] The first is the multi-dimensional stochastic process of optimal trading strategies and the other, the multi-dimensional stochastic process of optimal production strategies (Carmona et al., 2009).

[20] The allowance shortage happens after abatement activities, when all the regulated companies' the net cumulative emissions exceed the total number of allocated allowances.

The Chesney and Taschini model (2012)

Chesney and Taschini (2012) used the assumption of asymmetric information to their model. This derives from the fact that, the market for allowances is not only about transferring them from the firms with a surplus (in allowances) to the firms with a deficit (Kijima et al., 2010). Consequently, the Chesney and Taschini model deals with this asymmetry by developing an equilibrium model that is able to detect the excess or scarcity of allowances in the market while studying the price dynamics of emission allowances in the short-term.

More specifically, in this model the allowance price is equal to the penalty multiplied by the probability of allowance shortage, i.e. the expected non – compliance cost. As in Seifert et al. model (2008) and in the Carmona et al. model (2009), following a Brownian motion and a cumulative emission process respectively, the results of the Chesney ad Taschini study are the following:

Firstly, working in a multi-firm framework, in the short run, firms eventually comply with the regulations imposed and adjust their allowance portfolios. For this to happen, an optimal amount of allowance is purchased on the behalf of the firms, and is sold. Although this is also stated by Hintermann (2010), Chesney and Tachini extended it by equating the equilibrium allowance price with the net accumulated pollution of one company and the expected net accumulated pollution of the remaining companies (since the number of the companies is a finite number).

Moreover, the equilibrium allowance price follows the same pattern as the previous model, here being specifically sensitive to the characterizations of the pollution processes. However, the asymmetric information introduced means that the firms are not aware if each others' net accumulated pollution. The only complete knowledge they have is of their own, hence the expected net emissions that are often computed. Hence, the probability of each firm being in shortage by the end of the trading period depends on the expected pollution growths, and the allowance price will be set accordingly. To be more precise, the higher the expected pollution growths are, the higher the said probability, thus the higher the allowance price, and vice versa. As for the uncertainty about each single net allowance position before the compliance date, the higher it gets, the higher the uncertainty for each probability of shortage. This will result to the allowance price to be higher once more.

6. Empirical Research

In order to examine the effect of GDP, number of the researchers in R&D and renewable energy consumption on CO_2 emissions, a panel data analysis is used, so as to have is a dataset in which the behavior of entities is observed across time. In this panel data, several countries are examined, using the same variables on those countries.

Using STATA, the fixed and random effects are examined together with the Hausman test, in order to decide between fixed or random effects. Before the model specifications, panel unit root and cointegration tests were applied. On this dissertation, four groups are examined and analysed, each group including specific countries according to their geographical dispersion or level of development. Further details are elaborated, as each group is presented, while final conclusions are also drawn.

First and foremost, however, a brief description of the use of random and fixed effects should be mentioned. Note that, on the fixed and random effects models run on STATA, the dependent variable is CO_2 emissions, while the independent variables are GDP (as well as GDP^2 and GDP^3), number of the researchers in R&D and renewable energy consumption.

6.1. Data

All data collected for the countries, and all the values the variables acquire, were collected from the World Bank. The countries used in the panel dataset were carefully selected, so as to cover a global range. To be more precise, 44 countries were examined for the period 1996 – 2014, which were later divided into smaller groups, depending on their geographical region. Thus, the groups are formed as follows:

Group 1 – Total of countries: Argentina, Australia, Austria, Belgium, Bulgaria, Brazil, Canada, China, Colombia, Czech Republic, Germany, Denmark, Ecuador, Spain, Estonia, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland, Italy, Japan, South Korea, Lithuania, Latvia, Mexico, Netherlands, Norway, Panama, Poland, Portugal, Romania, Russian Federation, Singapore, Russian Republic, Slovenia, Sweden, Thailand, Turkey, United States of America, South Africa.

Group 2 – Europe: Austria, Belgium, Bulgaria, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland, Italy, Lithuania, Latvia, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Sweden.

Group 3 – America: Argentina, Brazil, Canada, Colombia, Ecuador, Mexico, Panama, United States of America.

Group 4 – Asia, Australia and Africa: Australia, China, Japan, South Korea, Russian Federation, Singapore, Thailand, Turkey, South Africa

Tables 1 and 2 present the descriptive statistics of the variables used for the geographical regions considered. Table 3 presents the correlation coefficients of the variables considered.

Table 1: Summary statistics for the variables used in: Total of countries and Europe

	Total of countries				Europe			
Summary Statistics	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
CO_2 emissions	7.680412	4.005703	1.28899	20.20761	7.725984	2.505466	2.682623	15.11041
GDP	22032.92	18268.35	707.0298	102910.4	25983.22	18481.31	1208.85	102910.4
R&D researchers	2656.924	1843.98	37.92977	8002.608	2969.8	1659.999	799.536	8002.608
Renewable energy consumption	16.7539	15.01431	0.3251189	78.13932	17.52924	16.64249	0.8731176	78.13932

Table 2: Summary statistics for the variables used in: America and Asia, Australia, S. Africa

	America				Asia, Australia, S.Africa			
Summary Statistics	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
CO_2 emissions	6.323155	6.563124	1.28899	20.20761	8.750149	4.342671	2.648649	18.24015
GDP	14421.95	15596.78	1451.291	54398.46	16947.36	16418.02	707.0298	67652.68
R&D researchers	1336.009	1623.674	37.92977	4785.521	2467.148	2095.756	72.82194	6899.003
Renewable energy consumption	20.97101	12.4818	4.51426	49.11435	10.67931	8.947847	0.3251189	30.31531

Table 3: Correlation coefficients of the variables considered. The correlation coefficients between the variables with no indication of any possible multicollinearity problems, except in the case of GDP and RD, are presented.

	CO_2	GDP	RD	REN
CO_2	1	0.47818	0.531568	-0.309887
GDP	0.478181	1	0.77257	0.138673
RD	0.531568	0.77257	1	0.144167
REN	-0.309887	0.138673	0.144167	1

6.2. Fixed and Random Effects

Fixed effects are used only when the impact of variables that vary over time is to be analysed, and they explore the relationship between predictor and outcome variables within an entity, i.e. a country in the specific case, given that there might be some characteristics of each country that affect the GDP, political or socioeconomic crisis for instance.

The fixed effects model has two basic assumptions; first, assuming that there might be something that might impact or bias the predictor or outcome variable, there is a need to control those actions in order to assess the net effect of the predictors on the outcome variable. The key to this is the correlation between entity's error term and predictor variables. Fixed effects are able to remove the effect of those time-invariant characteristics. Second, those time-invariant characteristics are unique to and should not be correlated with the other characteristics. Each country is different therefore the country's error term and the constant should not be correlated with the others.

Similarly, the random effects model is used when the variation across countries is assumed to be random and uncorrelated with the predictor or independent variables included in the model. Furthermore, when differences across countries have some influence on your dependent variable, then random effects should be used as well.

The random effects model has two basic assumptions; first, it assumes that the country's error term is not correlated with the predictors which allows for time-invariant variables to play a role as explanatory variables. In addition, in random effects, those individual characteristics that may influence the predictor variables need to be specified. This model allows researchers to generalize the inferences beyond the sample used in the model.

To decide between fixed or random effects, a Hausman test is used, where the null hypothesis (H_0) is that the preferred model is random effect, whereas the alternative (H_1) is following the fixed effects. It basically tests whether the unique errors (u_i) are correlated with the regressors; the null hypothesis indicates they are not.

6.3. The Unit Root Tests

What is in need for examination as well is the stochastic nature and properties of the variables; hence unit root tests are applied in each group. In this thesis, the Fisher-type test is used, after having created lag(1) variables; its assumptions are the following:

Firstly, the panels are not required to be strongly balanced and it is generally assumed that the cross-section dimension, N, is fixed, in which case tests performed are consistent against the alternative that at least one panel is stationary. Fisher-type tests do not allow for cross-sectional dependence across units.

As far as the Fisher-type test is concerned, it has as the null hypothesis (H_0) that all the panels contain a unit root, while the alternative (H_a) is that at least one panel is stationary. As N tends to infinity, the number of panels that do not have a unit root should grow at the same rate as N under the alternative hypothesis. Apart from the Fisher tests, we have applied the Levin-Lin-Chu, the Breitung, and the Im-Peseran-Chin tests. In all cases, the tests indicate that our variables are I(1). While the tests were applied on the total of countries, similar picture is for all the groups considered.

Similarly, Table 4 presents the Pedroni Co-integration tests. According to these tests, in the majority of the cases (seven out of the eleven), we reject the null hypothesis of no co-integration at the chosen statistical significance level of 0.05[21].

Table 4: Pedroni Cointegration Tests

Null Hypothesis: No cointegration

Alternative hypothesis: common AR coefs. (within-dimension)

	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	-3.500348	0.9998	-8.012331	1.0000
Panel rho-Statistic	-1.773983	0.0705	0.429178	0.6661
Panel PP-Statistic	-6.382368	0.0000	-21.74162	0.0000
Panel ADF-Statistic	-1.568574	0.0584	-3.585820	0.0002

Alternative hypothesis: individual AR coefs. (between-dimension)

	Statistic	Prob.
Group rho-Statistic	2.915779	0.9982
Group PP-Statistic	-10.80116	0.0000
Group ADF-Statistic	-2.828911	0.0023

[21] An alternative co-integration test is the Westerlund co-integration test.

6.4. Empirical Findings

The empirical findings are show in Table 5, and are given in more detail in the Appendix, as each group is examined separately. Table 5 presents the main estimates for our panel data model specifications[22].

Table 5: Parameter estimates for the panel data models. FE represents the Fixed Effects model, while RE represents the Random Effects model; p-values in parentheses.

	Total of countries	Europe	America	Asia, Australia, S.Africa
Model	FE	FE	FE	RE
Constant	9.557238	9.731093	6.483435	9.809373
	(0.000)	(0.000)	(0.000)	(0.000)
GDP	0.0001497	0.0001127	0.0000886	0.0004199
	(0.000)	(0.000)	(0.002)	(0.000)
GDP^2	-3.23e-09	-2.20e-09	-3.02e-09	-1.37e-08
	(0.000)	(0.000)	(0.000)	(0.009)
GDP^3	2.14e-14	1.40e-14	-	1.33e-13
	(0.000)	(0.000)	-	(0.049)
R&D researchers	-0.0004667	-0.0002298	0.0010852	-0.0006712
	(0.000)	(0.002)	(0.001)	(0.005)
Renewable energy consumption	-0.1326365	-0.1641081	-0,0475876	-0.1800642
	(0.000)	(0.000)	(0.005)	(0.003)
Hausman test	116.2	3.49	2925.73	1.48
	(0.0000)	(0.0000)	(0.0000)	(0.6873)
Turning points	\$ 36,188	\$ 44,607	\$ 14,669	\$ 23,086
	& \$ 64,435	& \$ 60,155	-	& \$ 45,586

6.4.1. Total of countries

Running the data from the World Bank on STATA, the results acquired can be seen in the Appendix on Table 6.4.1.1, Table 6.4.1.2 and Tables 6.4.1.3.i-vi.

On Table 6.4.1.1, the fixed effects regression is shown. The errors u_i are correlated with the regressors in the fixed effects model. This is apparent from the fact that corr(u_i, Xb) = -0.2887.

As far as the t-values are concerned, t-values test the hypothesis that each coefficient is different from 0. To reject this, the t-value has to be higher than 1.96 (for a 95%

[22] We have also calculated the cross dependence Pesaran test with no indication of problems and in the cases of full record of the data.

confidence)[23]. This is the case here, so the variables have a significant influence on the dependent variable, which is CO_2 emissions. The higher the t-value, the higher the relevance of the variable, thus the independent variable with the highest relevance is the renewable energy consumption, symbolized with “rencon” on the figures.

When it comes to the p-values, two-tail p-values test the hypothesis that each coefficient is different from 0. To reject this, the p-value has to be lower than 0.05 (again for a 95% confidence). As all p-values equal to zero on this specific regression, all variables have a significant influence on CO_2 emissions.

The coefficients are interpreted in the traditional econometric way, i.e. when the GPD per capita (symbolized as “gdpc”) increases by 1 dollar, the CO_2 emissions increase by 0.0001497 metric tons per capita. When it comes to the R&D researchers (symbolized as “rdreasearchers”), if they increase by 1 million of people, the CO_2 emissions decrease by 0.0004667 metric tons per capita. Finally, when the renewable energy consumption increases by 1% of the total energy consumption, the CO_2 emissions are lower by 0.1326365 metric tons per capita. The latter two coefficients naturally make the CO_2 emissions drop, as, according to the literature mentioned on previous section of this dissertation, are a step towards reduction of the CO_2 emissions. So, the minus sign on the regression is reasonably and expectedly present.

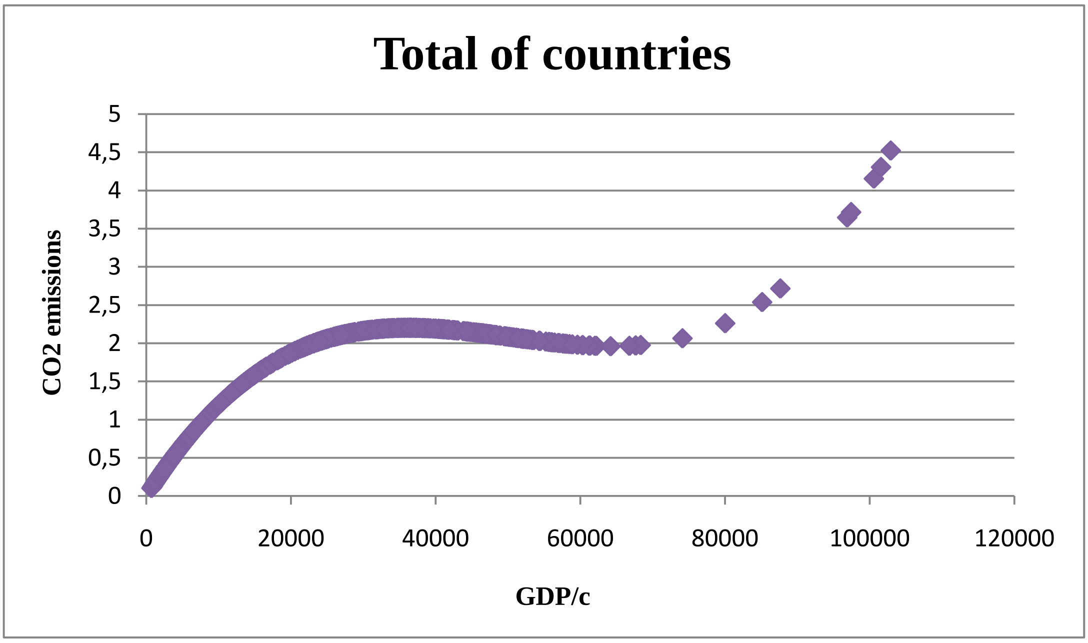
When it comes to choosing between random and fixed effects, the Hausman test is conducted. The null hypothesis is that the preferred model is random effects, while the alternative is that the preferred model is the fixed effects, meaning that the unique errors are correlated with the regressors. Since Prob>chi2 = 0.0000, so it lower than 0.05 (i.e. significant), thus we use the fixed effects model.

On Tables 6.4.1.3.i-vi, a Fisher-type unit root test is performed in each variable. All p-values equal to 0.000, which is lower than 0.01. Therefore, we reject the null hypothesis at the 1% level of statistical significance and conclude that the series is stationary. Table 5 demonstrates the Pedroni Co-integration test performed on the variables that refer to the total of countries; however, the same results and conclusions hold for every group examined in this dissertation.

Finally, on Figure 6.4.1.a, the turning points for the total of countries when examining the relationship between CO_2 emissions and economic growth are presented. More specifically, GDP, GDP^2 and GDP^3 per capita are significant, implying an N-shape relationship with homogeneous parameters across countries, and the turning points are \$36,188 and \$64,435. In this case, the Environmental Kuznets Curve (EKC) hypothesis is rejected.

[23] Meaning that ItI > 1.96, hence the t-value being either greater than 1.96 or lower than -1.96.

Figure 6.4.1.a: The EKC for the total of countries



6.4.2. Europe

Running the data from the World Bank on STATA, the results acquired can be seen in the Appendix on Table 6.4.2.1, Table 6.4.2.2, Table 6.4.2.3 and Tables 6.4.2.4.i-vi.

In the fixed effects regression on Table 6.4.2.1, the errors u_i are correlated with the regressors in the fixed effects model, as corr(u_i, Xb) = -0.6584.

Furthermore, we reject the hypothesis that each coefficient is different from 0, as t-value is higher than 1.96 for a 95% confidence. Hence the variables having a significant influence on the CO_2 emissions. Since the higher the t-value, the higher the relevance of the variable, the independent variable with the highest relevance is the renewable energy consumption, on which equals to -12.54.

Moreover, we reject the hypothesis that each coefficient is different from 0, because the p-value is lower than 0.05. As a matter of fact, all p-values equal to zero on this specific regression, except for the number of R&D researchers, which equals to 0.002 and is still lower than 0.05. As a result, all variables have a significant influence on CO_2 emissions.

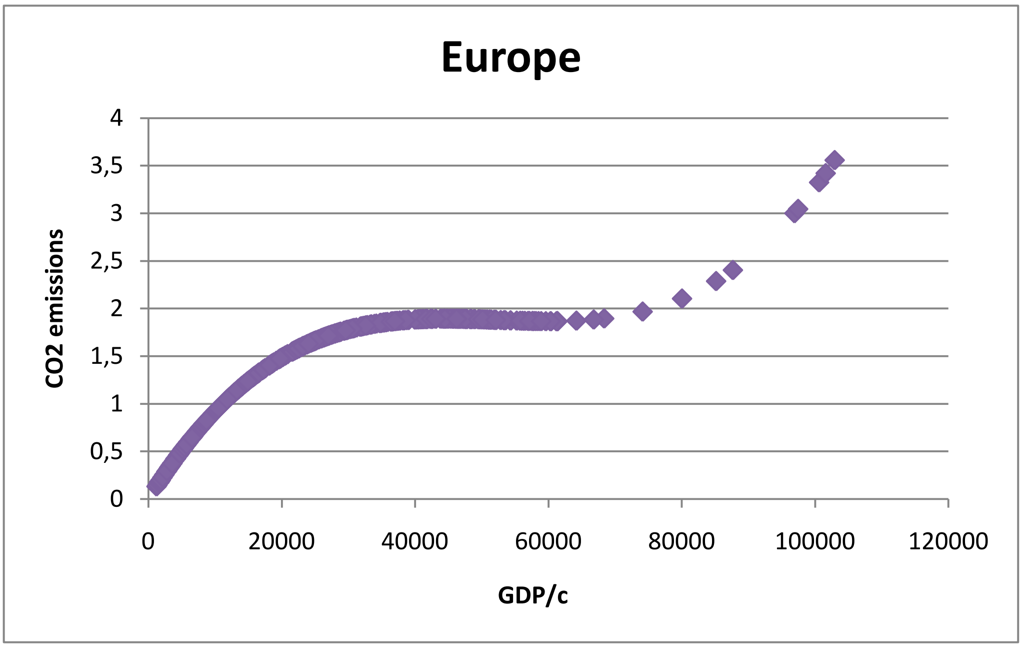
The coefficients are interpreted as follows: If the GPD per capita increases by 1 dollar, the CO_2 emissions increase by 0.0001127 metric tons per capita. Moreover, if the R&D researchers increase by 1 million of people, the CO_2 emissions decrease by 0.0002298 metric tons per capita. Last but not least, when the renewable energy consumption increases by 1% of the total energy consumption, the CO_2 emissions are decreased by 0.1641081 metric tons per capita, so the latter two coefficients naturally make the CO_2 emissions drop; the minus sign on the regression is reasonably and expectedly present.

On Table 6.4.2.3, the Hausman test is conducted. The null hypothesis is that the preferred model is random effects, while the alternative is that the preferred model is the fixed effects, meaning that the unique errors are correlated with the regressors. Since Prob>chi2 = 0.0000, so it lower than 0.05 (i.e. significant), thus we use the fixed effects model.

On Table 6.4.2.4.i-vi, a Fisher-type unit root test is performed in each variable. All p-values equal to 0.000, which is lower than 0.01. Therefore, we reject the null hypothesis at the 1% level of statistical significance and conclude that the series is stationary.

Finally, on Figure 6.4.1.b, the turning points for the European countries when examining the relationship between CO_2 emissions and economic growth are presented. More specifically, GDP, GDP^2 and GDP^3 per capita are significant, implying an N-shape relationship with homogeneous parameters across countries, and the turning points are \$44,607 and \$60,155. In this case, the EKC hypothesis is rejected.

Figure 6.4.1.b: The EKC for Europe



6.4.3. America

Running the data from the World Bank on STATA, the results acquired can be seen in the Appendix on Table 6.4.3.1, Figure 6.4.3.2, Table 6.4.3.3 and Tables 6.4.3.4.i-vi.

In the fixed effects regression on Table 6.4.3.1, the errors u_i are correlated with the regressors in the fixed effects model, as corr(u_i, Xb) = 0.8008.

Furthermore, we reject the hypothesis that each coefficient is different from 0, as t-value is higher than 1.96 for a 95% confidence. Hence the variables having a significant influence on the CO_2 emissions. Since the higher the t-value, the higher the relevance of the variable, the independent variable with the highest relevance is the R&D researchers, which equals to 3.35.

Moreover, we reject the hypothesis that each coefficient is different from 0, because the p-value is lower than 0.05. As a matter of fact, all p-values on this specific regression equal either to zero or to a level lower than 0.05. As a result, all variables have a significant influence on CO_2 emissions.

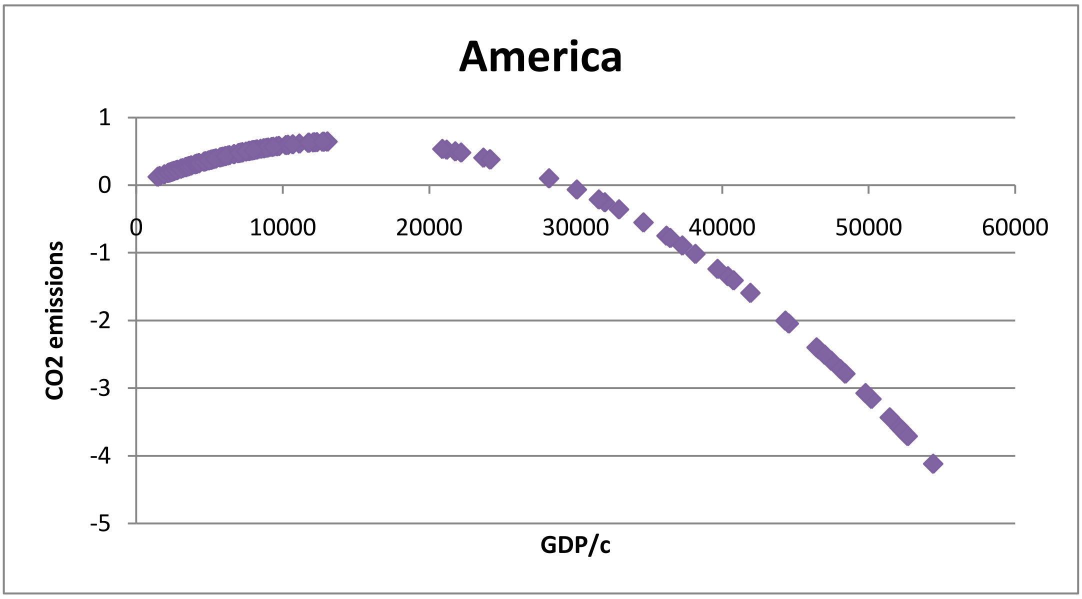
The coefficients are interpreted as follows: If the GPD per capita increases by 1 dollar, the CO_2 emissions increase by 0.0000886 metric tons per capita. If the R&D researchers increase by 1 million of people, the CO_2 emissions increase by 0.0010852 metric tons per capita. Finally, when the renewable energy consumption increases by 1% of the total energy consumption, the CO_2 emissions decrease by 0.0475876 metric tons per capita. As a result, the rise of the renewable energy consumption causes the CO_2 emissions to drop; this is explained by the minus sign on the regression.

On Table 6.4.3.3, the Hausman test is shown. The null hypothesis is that the preferred model is random effects, while the alternative is that the preferred model is the fixed effects, meaning that the unique errors are correlated with the regressors. Since Prob>chi2 = 0.0000, so it lower than 0.05 (i.e. significant), thus we use the fixed effects model.

On Table 6.4.3.4.i-vi, a Fisher-type unit root test is performed in each variable. All p-values equal to 0.000, which is lower than 0.01. Therefore, we reject the null hypothesis at the 1% level of statistical significance and conclude that the series is stationary.

Finally, on Figure 6.4.1.c, the turning points for America when examining the relationship between CO_2 emissions and economic growth are presented in an estimated EKC. More specifically, both GDP and GDP^2 per capita are significant, implying an inverted U-shape relationship with homogeneous parameters across countries, and the turning point is $14,669.

Figure 6.4.1.c: The EKC for America



6.4.4. Asia, Australia and South Africa

Running the data from the World Bank on STATA, the results acquired can be seen in the Appendix on Table 6.4.4.1, Table 6.4.4.2, Table 6.4.4.3 and Tables 6.4.4.4.i-vi.

On Table 6.4.4.2, the random effects regression is shown. From the fact that corr(u_i,Xb) = 0 that the differences across units are uncorrelated with the regressors .

Two-tail p-values test the hypothesis that each coefficient is different from 0, a hypothesis that is rejected for all the values that are lower than 0.05 for a 95% confidence. This is the case here, as all p-values equal to values lower than 0.05, thus all variables have a significant influence on CO_2 emissions.

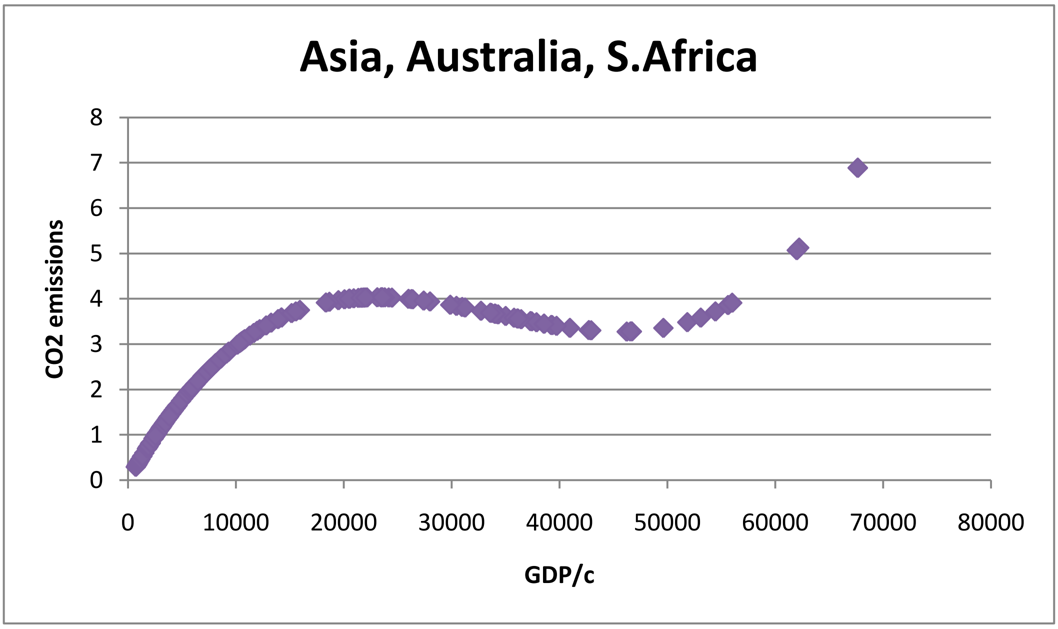
As it is shown on the Table 3.4.2, when the GPD per capita increases by 1 dollar, the CO_2 emissions go up by 0.0004199 metric tons per capita. Moreover, if the R&D researchers increase by 1 million of people, the CO_2 emissions decrease by 0.0006712 metric tons per capita. Last but not least, when the renewable energy consumption increases by 1% of the total energy consumption, the CO_2 emissions drop by 0.1800642 metric tons per capita. The minus sign on the coefficients mean that the higher those coefficients, the lower the price of the CO_2 emissions.

On Table 6.4.4.3, the results of the Hausman test are shown. The null hypothesis is that the preferred model is random effects, while the alternative is that the preferred model is the fixed effects, meaning that the unique errors are correlated with the regressors. Since Prob>chi2 = 0.6873, so it greater than 0.05 (i.e. significant), thus we use the random effects model. A further explanation for the random effects model shown as the preferred model in this case, would be the economic disparity and diversification of this particular group, given that we have used countries from three different continents, each one with different economic, cultural, social and geographical characteristics. For instance, China and South Africa being in the same group leads to the possible interpretation that, due to common sense reasons (Greene, 2009), i.e. their being completely non-related, the fixed effects model would not be the right one for this case.

On Table 6.4.4.4.i-vi, a Fisher-type unit root test is performed in each variable. All p-values equal to 0.000, which is lower than 0.01. Therefore, we reject the null hypothesis at the 1% level of statistical significance and conclude that the series is stationary.

Finally, on Figure 6.4.1.d, the turning points for Asia, Australia and South Africa when examining the relationship between CO_2 emissions and economic growth are presented. More specifically, GDP, GDP^2 and GDP^3 per capita are significant, implying an N-shape relationship with homogeneous parameters across countries, and the turning points are \$23,086 and \$45,586. In this case, the EKC hypothesis is rejected.

Figure 6.4.1.d: The EKC for Asia, Australia and S. Africa



6.5. Overall results

Comparing the four groups, there are several results to be taken into account.

First and foremost, we observe that one change in the GDP has similar effects in each group's CO_2 emissions. Specifically, if GDP increases by 1 dollar, CO_2 emissions go up in the case of all four groups. However, the CO_2 emissions do not increase significantly, given that the higher increase is 0.0005158 metric tons per capita. As a result, no matter the geographical region that we are studying, GDP always makes CO_2 emissions increase, albeit a little. This can be connected with section 3, where it is stated in more detail that economic growth is measured as the change in GDP over time, and economic growth causes environmental issues.

On similar note, the R&D coefficient is slightly different when it comes to the American countries. To be more precise, in all groups examined, minus America, an increase in the R&D researchers means a decrease in the levels of the CO_2 emissions, which is perfectly explained by the literature presented in this dissertation. However, the CO_2 emissions do not decrease significantly, since the most they drop is 0.0006712 metric tons per capita (in the case of Asia, Australia and South Africa), given an increase of 1 million of people in the R&D researchers. In American countries, it is obvious that an increase in the R&D causes an increase as well, in the levels of the CO_2 emissions.

The exception of America could be explained by grand differences of the countries that compose this particular group. Given that there are fewer countries in this group compared to, for instance, Europe, and that the largest country of them is the United States of America, the difference compared to the other groups lies to the fact that those countries included have vital differences, despite their being in the same continent. Those differences could refer to the various geographical areas, social and economic differences. A key point to this would also be the extremely different political regimes that prevail in each of those countries (Kim, 2004). Comparing this heterogeneity of America to the relative geographical and political homogeneity of Europe, such differences are not unjustifiable.

In addition, it is without doubt that one change in the renewable energy consumption has similar effects in each group's CO_2 emissions as the number of researchers in R&D. If we examine the results of the regressions, it is obvious that if the renewable energy consumption increases by 1% of the total energy consumption, the CO_2 emissions decrease by a considerable amount, reaching up to 0.1800642 metric tons per capita in the Asia, Australia and South Africa group. This, of course, is in full line with what has already been said in the previous sections, and is exactly what was expected from all the regressions performed.

Finally, an N-shape relationship is evident between CO_2 emissions and economic growth in the presence of R&D and Renewable Energy Consumption in all groups examined, i.e. the total of countries, Europe and Asia, Australia and South Africa. America constitutes an exception, where there is an inverted U-shape relationship.

7. Conclusions and Future Extensions

7.1. Main Findings

This dissertation shows that that, while economic growth has set a number of targets, the aggregated outcome might not always be the optimal. As the natural environment that we all live in is finite, with the resources reaching crucial level, the inconsiderable extension of the economic activity cannot stay indefinite. Hence there is a need to examine the finance of the environmental investments.

Economic growth is regarded as a political and economic goal by the government, however, what is needed to be understood is the fact that global economy has not been equally developed, neither on recent years nor over time, and these inequalities apply to individual countries, as well as regions, leading to environmental damage caused by international competition among the countries. There is a point where developed countries begin to decrease their environmental effect, but at the same time they start polluting the developing countries with new activities, so the environmental problem due to the economic growth is definitely not solved.

Furthermore, there are two major problems standing out, which need to be limited and eventually eliminated. The exploitation of natural resources that result in resource scarcity, as well as the deterioration of the environment (GHGs, climate change etc), pose a serious challenge to the ecosystem and the economy, and they indicate the essentiality for a fundamental change to the way resources are used. Sustainable development is also required in order to face the environmental threats caused by human activity, and is achieved via socially inclusive economic growth, accounting for planetary boundaries and eliminating extreme poverty. While the lack of natural resources can be overcome by substituting natural capital, what plays a critical role in all the substitution process is the endogenous technological advances, which occur due to the undertaken R&D. However, only a proportion of the R&D is effective in delivering actual innovations. Since natural resources are limited, economy will come to a halt in the long-run, limiting resource extraction and allocating labor to R&D, or by using environmental friendly technologies instead of pollution – inclined ones are fundamental for the issues mentioned.

The controversial issue concerning economic growth and the quality of the environment is also presented, with a number of people claiming it promotes technological innovation and motivates the R&D, and others believing that it is environmentally harmful because of the pollution that it causes. Moreover, sustaining positive economic growth in the long-term is not achievable, due to exhaustible resources. Two solutions are mentioned; research becoming a continuous process of improvement along with technological progress, structural changes and per capita income levels, and nature being replaced by man-made products. While the latter solution is questionable, the former leads to ensuring the sustainability of economic activities.

When it comes to models of economic growth, they lack the ability to incorporate the environment and its deterioration problem, thus the New Growth theories are developed. Most of these studies concentrate on pollution and the GHGs that remain in the atmosphere and threaten the environment, and the limit for these emissions that should be not be surpassed. Their reduction is vital indeed, and governments have implemented policies to ensure this purpose, revolving around taxes and governance with credible property rights to raise public awareness about environmental issues. It is without saying that long-term economic and social goals need to be set when designing and implementing governmental policies by distributing the remaining resources and growth possibilities among the world's nations, while taking into account the dilemma of developing and developed countries' emission and consumption levels and distribution.

Combining the policies implemented and the necessity to expand the R&D and technology, regulated companies can either invest in a new technology with the intention to reduce their CO_2 emissions, or buy emission rights. When deciding between those two, one has to take into consideration the price of the emission rights and the marginal cost of technology changes. This investment process is analysed via option pricing with the Binomial Model.

Thus, it is important for the companies to take strategic decisions, many times using the NPV as a tool. However, this approach has certain limitations, and therefore the real options approach is used by various firms as well. Comparing these two methods, it is believed that the real options approach always generates incentives to wait longer before investing than with the NPV, yet in reality, the real option criteria might generate incentives to invest sooner than with the static NPV approach, because of the dynamic and competitive setting making the profit generated by the potential investment dependent on the investment decisions of the other companies.

Of course, firms need to consider the environmental regulations, which have to comply with EU ETS. The real options approach is more widely used by the companies in order to make strategic investments and reduce their emissions and the trade of emission allowances. Emission permits are also purchased and sold, and depending on how the emissions move, the trading result differs. Using the Emission and Price Processes, several conclusions are offered, mainly that the real options approach yields lower costs, because the company is able to resell the permits after a year, and when a technological change happens (dynamic environment), the real options approach benefits from under-hedging, while the NPV approach is better for perfect hedging.

Another part of this dissertation underlines the emission price dynamics, and, to be more precise, the substitution principle between emission allowances and abatement technology. As it turns out, the allowance price corresponds to the cheapest marginal cost of abatement.

As it is already mentioned, the firms in each country have to comply with the regulations of the EU ETS, therefore, in the short-run, the cheapest abatement technology is fuel switching, i.e. the option to switch from coal-fired power to gas-fired power generation, making the switch more beneficial for the environment, as gas lowers emissions. As a result, gas-fired power generation turns out to be more competitive than the coal, and the CO_2 emissions per MWh decrease. Thus, fewer emissions have to be covered with the EUAs. A factor contributing in the switch from coal to gas is the season dependence, meaning in colder the weather, the less likely to switch due to the gas prices going up and the difficulty in production and supply of gas. To fix this, a procedure must be used, known Seasonal Trend with Local Regression Smoothing or Loess.

As for the question arising, what affects the operating choices for the power generation industry, the answer lies in the price of the coal versus the price of the gas. If gas is cheaper compared to coal, gas will be preferred over coal, and since gas has lower carbon emission, the demand of EUAs will decrease. This works vice versa, however, coal has higher carbon emission levels, so the demand of EUAs will increase. The fuel switch also depends on relative prices or allowance shortages, because fuel switching is a medium-term abatement option and could be used as a proxy for the allowance price, hedging and pricing purposes.

All this analysis had to be studied thoroughly, thus deterministic and stochastic equilibrium allowance price models have been developed for this purpose, mainly the models of Montgomery, Rubin, Kling and Rubin, Seifert et al., Carmona et al., and of Chesney and Taschini.

This thesis also examines the impact of economic activities on the environment, by investigating the influence of the GDP, the number of the researchers in Research and Development and the renewable energy consumption on CO_2 emissions. For this purpose, four different groups of countries were created, each accompanied by a panel with data for the period 1996 – 2014. In order to have a general picture of what influences the CO_2 emissions globally, each group represented a specific geographical region, thus the results offered vary.

More specifically, one change in the GDP has similar effects in each group's CO_2 emissions, i.e. if GDP increases, CO_2 emissions increase as well, no matter the geographical region. Since economic growth is measured as the change in GDP over time, and economic growth causes environmental issues, this outcome is explained thoroughly by the literature gathered. Studying the number of the R&D researchers, the output of STATA showed that an increase in the R&D researchers means a decrease, however not a significant one, in the levels of the CO_2 emissions, which is perfectly explained by the literature presented in this thesis. Minus differences come to surface when it comes to the group with the American countries, but it is explained by the heterogeneity prevailing in those countries, in contrast to the European countries, which have a certain level of homogeneity both geographically and politically. Moreover, if the renewable energy consumption increases, the CO_2 emissions decrease by a considerable amount, coming in full line with the literature presented in the theoretical part of this dissertation.

Finally, an N-shape relationship is evident between CO_2 emissions and economic growth in the presence of R&D and Renewable Energy Consumption in all groups examined, except for America, where there is an inverted U-shape relationship.

7.2. Recommendations for Future Research

Although the study strives to present as accurate and credible information as possible, there are still several unavoidable limitations that may deliver biased or incorrect views of this dissertation. Some of the limitations relate to the number of countries that have been used in our empirical analysis, the criteria of including the countries into specific groups, or to the limited number of indicators used. As a result, several recommendations are made, so that the impact of several indicators on the CO_2 emissions is studied further.

First of all, it would be interesting to include more countries in each sample group. For instance, a number of Asian or African countries not included in the sample due to data limitations can be studied, as they occupy a large percent of the emerging economies. What would be able to give a full glance of the global economy and its effect to the environment, would be to study more thoroughly developing countries. A comparison could be made with the developed ones, regardless of the geographical region that was considered a criterion in this dissertation. Even more, it would be interesting if the already existing groups were divided and studied further; for example, the group including the European countries could be divided in Northern and Southern countries, and studied accordingly. Finally, given the financial and socioeconomic and political crises that infest the world economy, groups of countries including the most crisis-prone countries and the most booming economies could be examined and compared, so as useful results can be offered.

Moreover, several other environmental factors could be used in order to examine the rise or decrease of CO_2 emissions, and more specifically the indicators' impact to the environment. Other indicators, when available in full record for all countries, could be research and development expenditure, renewable electricity output, tax revenues (as it constitutes a macroeconomic policy implicated to reduce and eventually eliminate pollution), invest in energy with private participation, and energy intensity level of primary energy.

Last but not least, it would be interesting to examine a wider time period and include years that several historical events, that have influenced how the world economy is today, have occurred.

For all those reasons above, the issues discussed upon this dissertation will be ongoing topics of research.

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Appendix

Running the data from the World Bank on STATA, the following results are acquired and discussed in detail on Section 7. Those results are used for the empirical findings. In all the groups examined, both fixed and random effects tables are presented, although we choose either the one or the other, with the help of the Hausman test.

A.Total of countries

Table 6.4.1.1: Fixed Effects for all the countries examined (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 gdpc3 rdresearchers rencon, fe

Fixed-effects (within) regression               Number of obs      =       675
Group variable: number                          Number of groups   =        44

R-sq:  within  = 0.2999                         Obs per group: min =         8
       between = 0.0532                                        avg =      15.3
       overall = 0.0623                                        max =        17

                                                F(5,626)           =     53.62
corr(u_i, Xb)  = -0.2887                        Prob > F           =    0.0000

------------------------------------------------------------------------------
co2emissions |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        gdpc |   .0001497   .0000179     8.35   0.000     .0001145    .0001849
       gdpc2 |  -3.23e-09   4.03e-10    -8.02   0.000    -4.03e-09   -2.44e-09
       gdpc3 |   2.14e-14   2.92e-15     7.31   0.000     1.56e-14    2.71e-14
rdresearchers|  -.0004667   .0000802    -5.82   0.000    -.0006242   -.0003092
      rencon |  -.1326365   .0133196    -9.96   0.000     -.158793     -.10648
       _cons |   9.557238   .2454137    38.94   0.000     9.075304    10.03917
-------------+----------------------------------------------------------------
     sigma_u |  4.0784019
     sigma_e |  .79915721
         rho |  .96302387   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(43, 626) =   190.66             Prob > F = 0.0000
```

Table 6.4.1.2: Random Effects for all the countries examined (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 gdpc3 rdresearchers rencon, re

Random-effects GLS regression                   Number of obs      =       675
Group variable: number                          Number of groups   =        44

R-sq:  within  = 0.2977                         Obs per group: min =         8
       between = 0.0748                                        avg =      15.3
       overall = 0.0848                                        max =        17

                                                Wald chi2(3)       =         .
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =         .

------------------------------------------------------------------------------
 co2emissions |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        gdpc |   .0001551   .0000183     8.47   0.000     .0001192     .000191
       gdpc2 |  -3.40e-09   4.14e-10    -8.22   0.000    -4.22e-09   -2.59e-09
       gdpc3 |   2.25e-14   3.00e-15     7.49   0.000     1.66e-14    2.84e-14
rdresearchers |  -.0003839   .0000809    -4.74   0.000    -.0005425   -.0002253
      rencon |  -.1282156   .0125099   -10.25   0.000    -.1527346   -.1036966
       _cons |   9.368783   .5079956    18.44   0.000      8.37313    10.36444
-------------+----------------------------------------------------------------
     sigma_u |   2.843403
     sigma_e |  .79915721
         rho |  .92679023   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Table 6.4.1.3.i.: The Fisher-type unit root test for all the countries examined. Variable: CO_2 emissions (Source: STATA)

```
Fisher-type unit-root test for dco2emissions
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels  =     44
Ha: At least one panel is stationary        Number of periods =     17

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(88)   P       746.0906       0.0000
 Inverse normal            Z       -21.2578       0.0000
 Inverse logit t(224)      L*      -30.8739       0.0000
 Modified inv. chi-squared Pm       49.6054       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
------------------------------------------------------------------------------
```

Table 6.4.1.3.ii.: The Fisher-type unit root test for all the countries examined. Variable: GDP per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =     44
Ha: At least one panel is stationary        Avg. number of periods =  18.98

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(88)    P     1745.2422       0.0000
 Inverse normal             Z      -35.0562       0.0000
 Inverse logit t(224)       L*     -72.6496       0.0000
 Modified inv. chi-squared Pm      124.9193       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
------------------------------------------------------------------------------
```

Table 6.4.1.3.iii.: The Fisher-type unit root test for all the countries examined. Variable: GDP^2 per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc2
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =     44
Ha: At least one panel is stationary        Avg. number of periods =  18.98

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(88)    P     1640.0424       0.0000
 Inverse normal             Z      -33.0787       0.0000
 Inverse logit t(224)       L*     -68.2428       0.0000
 Modified inv. chi-squared Pm      116.9896       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
------------------------------------------------------------------------------
```

Table 6.4.1.3.iv.: The Fisher-type unit root test for all the countries examined. Variable: GDP^3 per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc3
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =     44
Ha: At least one panel is stationary        Avg. number of periods =  18.98

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(88)   P      1578.9432       0.0000
 Inverse normal            Z       -31.8676       0.0000
 Inverse logit t(224)      L*      -65.6309       0.0000
 Modified inv. chi-squared Pm      112.3841       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
------------------------------------------------------------------------------
```

Table 6.4.1.3.v.: The Fisher-type unit root test for all the countries examined. Variable: R&D researchers (Source: STATA)

```
Fisher-type unit-root test for drdresearchers
Based on augmented Dickey-Fuller tests
---------------------------------------------
Ho: All panels contain unit roots           Number of panels       =     44
Ha: At least one panel is stationary        Avg. number of periods =  15.61

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(84)   P      1618.6609       0.0000
 Inverse normal            Z       -32.0278       0.0000
 Inverse logit t(209)      L*      -69.4292       0.0000
 Modified inv. chi-squared Pm      118.4017       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.1.3.vi.: The Fisher-type unit root test for all the countries examined. Variable: renewable energy consumption (Source: STATA)

```
Fisher-type unit-root test for drencon
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels  =     44
Ha: At least one panel is stationary        Number of periods =     16

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(88)   P       557.2803       0.0000
 Inverse normal            Z      -17.1290        0.0000
 Inverse logit t(224)      L*     -22.8641        0.0000
 Modified inv. chi-squared Pm      35.3733        0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

A.1. Panel Unit Root tests: Levin-Lin-Chu, Breitung, Im-Peseran-Shin

Table A.1.1: Panel Unit Root test. Variable: CO_2 emissions

Panel unit root test: Summary
Series: CO2
Date: 01/11/17 Time: 20:40
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel
Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-2.06204	0.0196	44	704
Breitung t-stat	4.73358	1.0000	44	660
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	1.45114	0.9266	44	704
ADF - Fisher Chi-square	82.3166	0.6508	44	704
PP - Fisher Chi-square	139.967	0.0004	44	748

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Table A.1.2: Panel Unit Root test. Variable: D(CO2)

Panel unit root test: Summary
Series: D(CO2)
Date: 01/11/17 Time: 20:41
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel
Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-8.22619	0.0000	44	660
Breitung t-stat	-6.06013	0.0000	44	616
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-8.35441	0.0000	44	660
ADF - Fisher Chi-square	220.854	0.0000	44	660
PP - Fisher Chi-square	583.502	0.0000	44	704

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Table A.1.3: Panel Unit Root test. Variable: GDP

Panel unit root test: Summary
Series: GDP
Date: 01/11/17 Time: 20:39
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel
Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-2.01391	0.0220	44	748
Breitung t-stat	0.89859	0.8156	44	704
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-0.16171	0.4358	44	748
ADF - Fisher Chi-square	83.8990	0.6039	44	748
PP - Fisher Chi-square	71.9384	0.8929	44	792

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Table A.1.4: Panel Unit Root test. Variable: D(GDP)

Panel unit root test: Summary
Series: D(GDP)
Date: 01/11/17 Time: 20:40
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel
Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-11.7550	0.0000	44	704
Breitung t-stat	-9.03606	0.0000	44	660
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-5.68905	0.0000	44	704
ADF - Fisher Chi-square	166.130	0.0000	44	704
PP - Fisher Chi-square	221.898	0.0000	44	748

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Table A.1.5: Panel Unit Root test. Variable: Research and Development (RD)

Panel unit root test: Summary
Series: RD
Date: 01/11/17 Time: 20:41
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-0.79792	0.2125	40	604
Breitung t-stat	1.70838	0.9562	40	564
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	0.68219	0.7524	40	604
ADF - Fisher Chi-square	85.6460	0.3125	40	604
PP - Fisher Chi-square	130.445	0.0003	40	649

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Table A.1.6: Panel Unit Root test. Variable: D(RD)

Panel unit root test: Summary
Series: D(RD)
Date: 01/11/17 Time: 20:41
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-4.85003	0.0000	39	558
Breitung t-stat	-2.54940	0.0054	39	519
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-3.16881	0.0008	39	558
ADF - Fisher Chi-square	136.411	0.0000	39	558
PP - Fisher Chi-square	337.789	0.0000	39	598

** Probabilities for Fisher tests are computed using an asymptotic Chi
-square distribution. All other tests assume asymptotic normality.

Table A.1.7: Panel Unit Root test. Variable: Renewable Energy Consumption (REN)

Panel unit root test: Summary
Series: REN
Date: 01/11/17 Time: 20:42
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel
Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	1.09826	0.8640	44	660
Breitung t-stat	7.81721	1.0000	44	616
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	4.35921	1.0000	44	660
ADF - Fisher Chi-square	54.3686	0.9982	44	660
PP - Fisher Chi-square	67.3614	0.9501	44	704

** Probabilities for Fisher tests are computed using an asymptotic Chi
-square distribution. All other tests assume asymptotic normality.

Table A.1.8: Panel Unit Root test. Variable: D(REN)

Panel unit root test: Summary
Series: D(REN)
Date: 01/11/17 Time: 20:42
Sample: 1996 2014
Exogenous variables: Individual effects, individual linear trends
User-specified lags: 1
Newey-West automatic bandwidth selection and Bartlett kernel
Balanced observations for each test

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-8.32881	0.0000	44	616
Breitung t-stat	-4.05780	0.0000	44	572
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-6.74982	0.0000	44	616
ADF - Fisher Chi-square	198.424	0.0000	44	616
PP - Fisher Chi-square	469.366	0.0000	44	660

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

B. Europe

Table 6.4.2.1: Fixed Effects for the European countries (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 gdpc3 rdresearchers rencon, fe

Fixed-effects (within) regression               Number of obs      =       424
Group variable: number                          Number of groups   =        27

R-sq:  within  = 0.4285                         Obs per group: min =         9
       between = 0.0298                                        avg =      15.7
       overall = 0.0486                                        max =        17

                                                F(5,392)           =     58.78
corr(u_i, Xb)  = -0.6584                        Prob > F           =    0.0000
```

co2emissions	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
gdpc	.0001127	.0000154	7.33	0.000	.0000825	.000143
gdpc2	-2.20e-09	3.29e-10	-6.67	0.000	-2.84e-09	-1.55e-09
gdpc3	1.40e-14	2.30e-15	6.09	0.000	9.50e-15	1.86e-14
rdresearchers	-.0002298	.0000755	-3.04	0.002	-.0003781	-.0000814
rencon	-.1641081	.0130867	-12.54	0.000	-.189837	-.1383791
_cons	9.731093	.2024275	48.07	0.000	9.333114	10.12907
sigma_u	3.4144709					
sigma_e	.56676806					
rho	.97318611	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(26, 392) =   197.19              Prob > F = 0.0000
```

Table 6.4.2.2: Random Effects for the European countries (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 gdpc3 rdresearchers rencon, re

Random-effects GLS regression                   Number of obs      =       424
Group variable: number                          Number of groups   =        27

R-sq:  within  = 0.4262                         Obs per group: min =         9
       between = 0.0288                                        avg =      15.7
       overall = 0.0477                                        max =        17

                                                Wald chi2(3)       =         .
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =         .
```

co2emissions	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gdpc	.000105	.0000159	6.59	0.000	.0000737	.0001362
gdpc2	-2.18e-09	3.45e-10	-6.31	0.000	-2.85e-09	-1.50e-09
gdpc3	1.44e-14	2.42e-15	5.95	0.000	9.66e-15	1.92e-14
rdresearchers	-.000206	.0000782	-2.63	0.008	-.0003592	-.0000527
rencon	-.1361538	.012294	-11.07	0.000	-.1602496	-.112058
_cons	9.567344	.4504223	21.24	0.000	8.684532	10.45016
sigma_u	1.9583799					
sigma_e	.56676806					
rho	.92271677	(fraction of variance due to u_i)				

Table 6.4.2.3: Hausman test for the European countries (Source: STATA)

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
gdpc	.0001127	.000105	7.72e-06	.
gdpc2	-2.20e-09	-2.18e-09	-1.90e-11	.
gdpc3	1.40e-14	1.44e-14	-3.79e-16	.
rdresearch~s	-.0002298	-.000206	-.0000238	.
rencon	-.1641081	-.1361538	-.0279543	.0044855

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

    Test:  Ho:  difference in coefficients not systematic

                 chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                         =       35.49
               Prob>chi2 =      0.0000
               (V_b-V_B is not positive definite)
```

Table 6.4.2.4.i: The Fisher-type unit root test for the European countries. Variable: CO_2 emissions (Source: STATA)

```
Fisher-type unit-root test for dco2emissions
Based on augmented Dickey-Fuller tests
-------------------------------------------
Ho: All panels contain unit roots           Number of panels  =     27
Ha: At least one panel is stationary        Number of periods =     17

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(54)   P       473.0707       0.0000
 Inverse normal            Z       -17.2088       0.0000
 Inverse logit t(139)      L*      -25.0741       0.0000
 Modified inv. chi-squared Pm       40.3251       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.2.4.ii: The Fisher-type unit root test for the European countries. Variable: GDP per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =     27
Ha: At least one panel is stationary        Avg. number of periods =  18.96

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(54)   P       977.9019       0.0000
 Inverse normal            Z       -25.8192       0.0000
 Inverse logit t(139)      L*      -52.0292       0.0000
 Modified inv. chi-squared Pm       88.9025       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.2.4.iii: The Fisher-type unit root test for the European countries. Variable: GDP^2 per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc2
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =     27
Ha: At least one panel is stationary        Avg. number of periods =  18.96

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(54)   P       945.6629       0.0000
 Inverse normal            Z       -25.2536       0.0000
 Inverse logit t(139)      L*      -50.3244       0.0000
 Modified inv. chi-squared Pm       85.8003       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.2.4.iv: The Fisher-type unit root test for the European countries. Variable: GDP^3 per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc3
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =     27
Ha: At least one panel is stationary        Avg. number of periods =  18.96

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(54)   P       948.9663       0.0000
 Inverse normal            Z       -25.4524       0.0000
 Inverse logit t(139)      L*      -50.5080       0.0000
 Modified inv. chi-squared Pm       86.1182       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.2.4.v: The Fisher-type unit root test for the European countries. Variable: R&D researchers (Source: STATA)

```
Fisher-type unit-root test for drdresearchers
Based on augmented Dickey-Fuller tests
---------------------------------------------------------------------------
Ho: All panels contain unit roots          Number of panels       =     27
Ha: At least one panel is stationary       Avg. number of periods =  16.59

AR parameter: Panel-specific               Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                 ADF regressions: 0 lags
---------------------------------------------------------------------------
                                  Statistic      p-value
---------------------------------------------------------------------------
 Inverse chi-squared(54)   P       950.5282       0.0000
 Inverse normal            Z      -24.8312        0.0000
 Inverse logit t(134)      L*     -51.3675        0.0000
 Modified inv. chi-squared Pm      86.2685        0.0000
---------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.2.4.vi: The Fisher-type unit root test for the European countries. Variable: renewable energy consumption (Source: STATA)

```
Fisher-type unit-root test for drencon
Based on augmented Dickey-Fuller tests
---------------------------------------------------------------------------
Ho: All panels contain unit roots          Number of panels  =     27
Ha: At least one panel is stationary       Number of periods =     16

AR parameter: Panel-specific               Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                 ADF regressions: 0 lags
---------------------------------------------------------------------------
                                  Statistic      p-value
---------------------------------------------------------------------------
 Inverse chi-squared(54)   P       326.2458       0.0000
 Inverse normal            Z      -13.0202        0.0000
 Inverse logit t(139)      L*     -17.0895        0.0000
 Modified inv. chi-squared Pm      26.1969        0.0000
---------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

C. America

Table 6.4.3.1: Fixed Effects for the American countries (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 rdresearchers rencon, fe

Fixed-effects (within) regression               Number of obs      =       120
Group variable: number                          Number of groups   =         8

R-sq:  within  = 0.6861                         Obs per group: min =        11
       between = 0.8199                                        avg =      15.0
       overall = 0.7546                                        max =        17

                                                F(4,108)           =     59.01
corr(u_i, Xb)  = 0.8008                         Prob > F           =    0.0000
```

co2emissions	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
gdpc	.0000886	.0000278	3.18	0.002	.0000334	.0001437
gdpc2	-3.02e-09	3.40e-10	-8.87	0.000	-3.69e-09	-2.34e-09
rdresearchers	.0010852	.0003242	3.35	0.001	.0004427	.0017278
rencon	-.0475876	.0166229	-2.86	0.005	-.0805371	-.0146382
_cons	6.483435	.4810362	13.48	0.000	5.529937	7.436932
sigma_u	5.7911954					
sigma_e	.3742869					
rho	.9958403	(fraction of variance due to u_i)				

```
F test that all u_i=0:     F(7, 108) =    244.84             Prob > F = 0.0000
```

Table 6.4.3.2: Random Effects for the American countries (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 rdresearchers rencon, re

Random-effects GLS regression                   Number of obs      =       120
Group variable: number                          Number of groups   =         8

R-sq:  within  = 0.3794                         Obs per group: min =        11
       between = 0.9447                                        avg =      15.0
       overall = 0.9343                                        max =        17

                                                Wald chi2(3)       =         .
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =         .
```

co2emissions	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
gdpc	.0001047	.0000578	1.81	0.070	-8.56e-06	.000218
gdpc2	-4.84e-09	7.02e-10	-6.89	0.000	-6.22e-09	-3.47e-09
rdresearchers	.004668	.0003277	14.24	0.000	.0040257	.0053103
rencon	-.0881994	.0174841	-5.04	0.000	-.1224677	-.0539311
_cons	3.093954	.5954302	5.20	0.000	1.926932	4.260976
sigma_u	.24674318					
sigma_e	.3742869					
rho	.30293738	(fraction of variance due to u_i)				

Table 6.4.3.3: Hausman test for the American countries (Source: STATA)

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
gdpc	.0000886	.0001047	-.0000161	.
gdpc2	-3.02e-09	-4.84e-09	1.82e-09	.
rdresearch~s	.0010852	.004668	-.0035828	.
rencon	-.0475876	-.0881994	.0406118	.

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

    Test:  Ho:  difference in coefficients not systematic

                  chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =      345.94
                Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

Table 6.4.3.4.i: The Fisher-type unit root test for the American countries. Variable: CO_2 emissions (Source: STATA)

```
Fisher-type unit-root test for dco2emissions
Based on augmented Dickey-Fuller tests

Ho: All panels contain unit roots           Number of panels  =      8
Ha: At least one panel is stationary        Number of periods =     17

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
```

		Statistic	p-value
Inverse chi-squared(16)	P	158.1784	0.0000
Inverse normal	Z	-10.0401	0.0000
Inverse logit t(44)	L*	-15.5819	0.0000
Modified inv. chi-squared	Pm	25.1338	0.0000

```
P statistic requires number of panels to be finite.
Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.3.4.ii: The Fisher-type unit root test for the American countries. Variable: GDP per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =      8
Ha: At least one panel is stationary        Avg. number of periods =  18.88

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(16)   P       364.6471       0.0000
 Inverse normal            Z       -16.5385       0.0000
 Inverse logit t(44)       L*      -35.9502       0.0000
 Modified inv. chi-squared Pm       61.6327       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.3.4.iii: The Fisher-type unit root test for the American countries. Variable: GDP^2 per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc2
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =      8
Ha: At least one panel is stationary        Avg. number of periods =  18.88

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(16)   P       317.5614       0.0000
 Inverse normal            Z       -14.9220       0.0000
 Inverse logit t(44)       L*      -31.2818       0.0000
 Modified inv. chi-squared Pm       53.3090       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.3.4.iv: The Fisher-type unit root test for the American countries. Variable: GDP[3] per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc3
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =      8
Ha: At least one panel is stationary        Avg. number of periods =  18.88

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(16)    P      273.2811       0.0000
 Inverse normal             Z      -13.0701       0.0000
 Inverse logit t(44)        L*     -26.8743       0.0000
 Modified inv. chi-squared Pm       45.4813       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.3.4.v: The Fisher-type unit root test for the American countries. Variable: R&D researchers (Source: STATA)

```
Fisher-type unit-root test for drdresearchers
Based on augmented Dickey-Fuller tests
---------------------------------------------
Ho: All panels contain unit roots           Number of panels       =      8
Ha: At least one panel is stationary        Avg. number of periods =  14.13

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(16)    P       74.1967       0.0000
 Inverse normal             Z       -5.2379       0.0000
 Inverse logit t(44)        L*      -6.7383       0.0000
 Modified inv. chi-squared Pm       10.2878       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.3.4.vi: The Fisher-type unit root test for the American countries. Variable: renewable energy consumption (Source: STATA)

```
Fisher-type unit-root test for drencon
Based on augmented Dickey-Fuller tests
------------------------------------------------
Ho: All panels contain unit roots           Number of panels  =      8
Ha: At least one panel is stationary        Number of periods =     16

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
```

		Statistic	p-value
Inverse chi-squared(16)	P	110.8805	0.0000
Inverse normal	Z	-8.0656	0.0000
Inverse logit t(44)	L*	-10.8653	0.0000
Modified inv. chi-squared	Pm	16.7727	0.0000

P statistic requires number of panels to be finite.
Other statistics are suitable for finite or infinite number of panels.

D.Asia, Australia and South Africa

Table 6.4.4.1: Fixed Effects for the Asian countries, Australia and South Africa (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 gdpc3 rdresearchers rencon, fe

Fixed-effects (within) regression               Number of obs      =       131
Group variable: number                          Number of groups   =         9

R-sq:  within  = 0.3288                         Obs per group: min =         8
       between = 0.3662                                        avg =      14.6
       overall = 0.3293                                        max =        17

                                                F(5,117)           =     11.46
corr(u_i, Xb)  = 0.2397                         Prob > F           =    0.0000
```

co2emissions	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
gdpc	.0004276	.0001082	3.95	0.000	.0002133	.000642
gdpc2	-1.44e-08	5.32e-09	-2.71	0.008	-2.49e-08	-3.85e-09
gdpc3	1.43e-13	6.85e-14	2.09	0.039	7.63e-15	2.79e-13
rdresearchers	-.0007003	.0002409	-2.91	0.004	-.0011773	-.0002233
rencon	-.1563995	.0645296	-2.42	0.017	-.284197	-.028602
_cons	9.350359	1.176207	7.95	0.000	7.020943	11.67977
sigma_u	3.7614393					
sigma_e	1.3172997					
rho	.89075102	(fraction of variance due to u_i)				

F test that all u_i=0:   F(8, 117) =   63.88   Prob > F = 0.0000

Table 6.4.4.2: Random Effects for the Asian countries, Australia and South Africa (Source: STATA)

```
. xtreg co2emissions gdpc gdpc2 gdpc3 rdresearchers rencon, re

Random-effects GLS regression                   Number of obs      =       131
Group variable: number                          Number of groups   =         9

R-sq:  within  = 0.3272                         Obs per group: min =         8
       between = 0.4120                                        avg =      14.6
       overall = 0.3820                                        max =        17

                                                Wald chi2(4)       =         .
corr(u_i, X)   = 0 (assumed)                    Prob > chi2        =         .

------------------------------------------------------------------------------
co2emissions |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        gdpc |   .0004199   .0001075     3.91   0.000     .0002091    .0006306
       gdpc2 |  -1.37e-08   5.26e-09    -2.60   0.009    -2.40e-08   -3.36e-09
       gdpc3 |   1.33e-13   6.76e-14     1.97   0.049     5.16e-16    2.66e-13
rdresearchers|  -.0006712   .0002382    -2.82   0.005    -.0011381   -.0002043
      rencon |  -.1800642   .0609886    -2.95   0.003    -.2995998   -.0605287
       _cons |   9.809372   1.701126     5.77   0.000     6.475227    13.14352
-------------+----------------------------------------------------------------
     sigma_u |  3.6717582
     sigma_e |  1.3172997
         rho |  .88596513   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Table 6.4.4.3: Hausman test for the Asian countries, Australia and South Africa. (Source: STATA)

```
                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     fixed        random       Difference          S.E.
-------------+----------------------------------------------------------------
        gdpc |    .0004276     .0004199        7.77e-06        .0000123
       gdpc2 |   -1.44e-08    -1.37e-08       -7.13e-10        7.63e-10
       gdpc3 |    1.43e-13     1.33e-13        1.02e-14        1.09e-14
rdresearch~s |   -.0007003    -.0006712       -.0000291        .0000356
      rencon |   -.1563995    -.1800642        .0236647         .021082
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        1.48
                Prob>chi2 =      0.6873
```

Table 6.4.4.4.i: The Fisher-type unit root test for the Asian countries, Australia and South Africa. Variable: CO_2 emissions (Source: STATA)

```
Fisher-type unit-root test for dco2emissions
Based on augmented Dickey-Fuller tests
------------------------------------------------
Ho: All panels contain unit roots            Number of panels  =      9
Ha: At least one panel is stationary         Number of periods =     17

AR parameter: Panel-specific                 Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                   ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(18)    P       114.8416       0.0000
 Inverse normal             Z        -7.7305       0.0000
 Inverse logit t(49)        L*      -10.4297       0.0000
 Modified inv. chi-squared Pm        16.1403       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.4.4.ii: The Fisher-type unit root test for the Asian countries, Australia and South Africa. Variable: GDP per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc
Based on augmented Dickey-Fuller tests
------------------------------------------
Ho: All panels contain unit roots            Number of panels       =      9
Ha: At least one panel is stationary         Avg. number of periods =  18.89

AR parameter: Panel-specific                 Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                   ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(18)    P       431.8492       0.0000
 Inverse normal             Z       -18.2051       0.0000
 Inverse logit t(49)        L*      -40.0840       0.0000
 Modified inv. chi-squared Pm        68.9749       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.4.4.iii: The Fisher-type unit root test for the Asian countries, Australia and South Africa. Variable: GDP^2 per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc2
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =      9
Ha: At least one panel is stationary        Avg. number of periods =  18.89

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(18)    P       412.1946       0.0000
 Inverse normal             Z       -17.1186       0.0000
 Inverse logit t(49)        L*      -38.2234       0.0000
 Modified inv. chi-squared Pm        65.6991       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.4.4.iv: The Fisher-type unit root test for the Asian countries, Australia and South Africa. Variable: GDP^3 per capita (Source: STATA)

```
Fisher-type unit-root test for dgdpc3
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels       =      9
Ha: At least one panel is stationary        Avg. number of periods =  18.89

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(18)    P       398.2748       0.0000
 Inverse normal             Z       -16.2117       0.0000
 Inverse logit t(49)        L*      -36.8204       0.0000
 Modified inv. chi-squared Pm        63.3791       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.5.4.v: The Fisher-type unit root test for the Asian countries, Australia and South Africa. Variable: R&D researchers (Source: STATA)

```
Fisher-type unit-root test for drdresearchers
Based on augmented Dickey-Fuller tests
---------------------------------------------
Ho: All panels contain unit roots           Number of panels       =      8
Ha: At least one panel is stationary        Avg. number of periods =  15.50

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(14)   P       342.7457       0.0000
 Inverse normal            Z       -16.3407       0.0000
 Inverse logit t(39)       L*      -36.1885       0.0000
 Modified inv. chi-squared Pm       62.1271       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```

Table 6.4.5.4.vi: The Fisher-type unit root test for the Asian countries, Australia and South Africa. Variable: renewable energy consumption (Source: STATA)

```
Fisher-type unit-root test for drencon
Based on augmented Dickey-Fuller tests
--------------------------------------
Ho: All panels contain unit roots           Number of panels  =      9
Ha: At least one panel is stationary        Number of periods =     16

AR parameter: Panel-specific                Asymptotics: T -> Infinity
Panel means:  Included
Time trend:   Included
Drift term:   Not included                  ADF regressions: 0 lags
------------------------------------------------------------------------------
                                  Statistic      p-value
------------------------------------------------------------------------------
 Inverse chi-squared(18)   P       120.1539       0.0000
 Inverse normal            Z        -7.7177       0.0000
 Inverse logit t(49)       L*      -10.9389       0.0000
 Modified inv. chi-squared Pm       17.0257       0.0000
------------------------------------------------------------------------------
 P statistic requires number of panels to be finite.
 Other statistics are suitable for finite or infinite number of panels.
```