The effect of the global financial crisis on the emission of carbon dioxide

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Abstract

The effects of the global financial crisis 2008-2009 (GFC) were widespread around the globe and discussed extensively. A sphere that was affected but did not get the attention it deserves is the environment. Especially carbon dioxide, the major greenhouse gas, fluctuates with economic situations and is highly correlated with GDP and energy consumption. In this study the effect of the global financial crisis on carbon dioxide emissions is examined by literature and empirical research. A panel dataset for 55 countries over 39 years is used to make OLS estimations for fixed effects models. The fixed effects allow for individual heterogeneity of the countries. The aim is to detect the effect of the GFC using a crisis dummy. This effect is not found to be significant. There are several explanations. There is large regional diversity in carbon dioxide emissions, GDP and their relationship. The emerging economies have growing carbon dioxide emissions and are counteracting the reductions in emissions from developed countries. These reductions were only partly caused by policies and investments. The rest of the reductions can be explained by the reduced economic activity due to the GFC. This is a positive effect for environmental quality, although overruled largely by the emissions from emerging economies. The crisis also reduced incentives for environmental investments, which should have a negative effect on environmental quality. The exact consequences of this will only be observable in the long term. Other explanations for the small impact of the GFC on emissions are the fast recovery of energy prices and widespread government support to recover from the crisis.

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List of abbreviations

AN	Percentage of alternative and nuclear energy consumption in a country (variable)
BLUE	Best linear unbiased estimator
CO_2	Carbon Dioxide
CO2	CO_2 emissions in metric tons per capita (variable)
EKC	Environmental Kuznets Curve
EU ETS	European Emission Trading Scheme
EU	Energy use per capita (variable)
FF	Percentage of fossil fuel energy consumption in a country (variable)
GDP	Gross Domestic Product
GDP	Gross Domestic Product per capita (variable)
GFC	Global financial crisis
IPCC	Intergovernmental Panel on Climate Change
LSDV	Least Squares Dummy Variables
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
OP	Oil price (variable)
SRES	Special Report on Emissions Scenarios
WDI	World Development Indicators

1. Introduction

The effects of the global financial crisis 2008-2009 (GFC) were widespread around the globe and discussed extensively. Many countries, sectors and households were affected. A sphere that was affected as well but did not get the attention it deserves is the environment. More specifically the greenhouse effect, which leads to global warming and extreme weather, is closely related to the global economic situation. Carbon dioxide, the major greenhouse gas, fluctuates with economic situations and is highly correlated with GDP and energy consumption[1].

The exact effect of the economic crisis on the environment is a complicated effect to measure. The global financial crisis spread itself through the world in many ways while the environment changed as well. Some changes might have occurred in the same way if the global financial crisis did not occur. The aim of this study is to analyse this effect by using carbon dioxide emissions as the indicator of environmental quality. Intuitively it is expected for economic crisis to have a positive effect on the environment. CO_2 emissions are reduced because of a decline in economic activity. It would be the silver lining of the cloud called global financial crisis. Unfortunately it is not this simple.

The drop in economic activity due to the crisis did reduce energy consumption and thus carbon dioxide emissions. It did not lead to a structural change in the growth path that emissions were following before the crisis. After a modest decrease of 1.4% in 2009, in 2010 there was already a 5.9% growth observed in global CO_2 emissions[2]. In 2011 global carbon dioxide emissions reached an all-time high[3]. There are several reasons why this crisis seems to have little impact on CO_2 emissions and why economic crises in general are not simply good for the environment. The latter can be understood by the deferment and postponement of environmental projects and investments. Governments and companies have to cut on their budgets and shift their priorities. Surviving the crisis and recovering becomes the aim, rather than becoming a ‘green’ company or economy. It has been suggested that in fact these two might go hand in hand[4]. The reasons why the global financial crisis (GFC) in particular has little impact on carbon dioxide emissions are

[1] See (Gierdraitis, Girdenas, & Rovas, 2010) and (Lane, 2011)
[2] See (Peters, Marland, Le Quéré, Boden, Canadell, & Raupach, 2011)
[3] See (Olivier, Janssens-Maenhout, & Peters, 2012)
[4] See (Grossman & Krueger, 1991), (Porter & Linde, 1995) and (Leichenko, O'Brien, & Solecki, 2010)

elaborated in this paper. The most important reason is the development of emerging economies, which counteracts reductions in emissions made by the developed countries.

Income appears to be an important determinant for CO_2 emissions. The relationship is examined extensively in the literature but the results are contradicting. The Environmental Kuznets Curve hypothesis for example states that increases in income will initially result in increasing CO_2 emissions. After a certain turning point in income emissions will decrease because of more energy-efficient production, renewable energy use and the ability of people to spend their income on less polluting products. The Porter hypothesis on the other hand states that proper formulated stringent regulations should lead to both economic growth and better environmental quality.

The difficulty of this study is that the effects manifest themselves in ways that are hard to capture. For example the drop in oil prices during the GFC led to the postponement of many shale oil projects, which are said to be risky for the environment, but as well less polluting if no disasters occur[5]. Such effects are almost impossible to distillate from other things occurring. Moreover, the consequences for the environment are uncertain. Lower oil prices can be good for the environment because of the postponement of risky scale oil projects but lower prices can also lead to more wasteful use of oil and the postponement of renewable energy projects.

The effect of the global financial crisis on carbon dioxide emissions has not been assessed yet in detail. Therefore the knowledge about the effects of other crises on CO_2 and the relation between economic indicators and CO_2 in general will be combined with empirical research. This way, the study aims to find the answer to the question: How does the global financial crisis affect the emission of carbon dioxide? In order to answer this question the main variables to explain carbon dioxide emissions are retrieved from literature research. GDP, energy use, population, the ratio of renewable/non-renewable energy use and the oil market are found as the main factors. The panel data on these variables for 55 countries over 39 years is used to conduct an econometric analysis to examine the effect of economic crises and the variables on carbon dioxide emissions. The findings are relevant for the future of the reduction of CO_2 emissions. Policies on national and international level are required to diminish climate change. This study is unique in examining the link between the global financial crisis and carbon dioxide by including both economic activity and innovation in the energy field.

[5] (Oilprice.com, 2012)

The literature review first discusses CO_2 emissions in general and how the concept is related to economic indicators. After discussing the possibilities to reduce emissions the concepts of Kuznets and Porter are discussed that relate economic growth with environmental quality in different ways. The link between carbon dioxide and financial crises and ways to analyse this link are explained. After discussing the data, the models and the methodology, the empirical results are discussed. Carbon dioxide emissions are examined by estimating an OLS regression with fixed effects from the panel dataset. The aim is to detect the effect of the economic crisis on CO_2 emissions by including a crisis dummy-variable. By combining the results of the literature research and the empirical results, conclusions are drawn and recommendations for environmental policy and further research are made.

2. Literature review

The process of carbon dioxide is a long and complex process that cannot even be comprehended entirely by today's science. A brief description is given of what we do know about carbon dioxide emissions and its effects. This makes clear how closely related CO_2 emissions and economic factors are, both in causes and solutions. The two main ways to reduce emissions, government policies and business investments, are discussed. Then, some of the causes of carbon dioxide emission are analysed in more detail. With the help of the economic causes and solutions, carbon dioxide emissions can be related to financial crisis. In the final section of this chapter the statistical methods that have been used in the literature to examine these phenomena are discussed.

2.1 The emission of carbon dioxide

The climate is changing due to the greenhouse effect. Greenhouse gases accumulate in the atmosphere and then contribute to the process of absorption and re-emission of heat in the atmosphere that is being radiated from the earth, trapping warmth. This process is called the greenhouse effect and causes amongst other effects changes in regional temperatures and extreme weather. This process on its own is a natural process but it is strengthened by the emission of greenhouse gases due to human activities.

Carbon dioxide, also known as CO_2, accounts for the largest part of the global anthropogenic greenhouse gas emissions, about 94%. The other greenhouse gases strengthening the greenhouse effect are methane and nitrous oxide. These are mainly produced by agriculture and industrial processes whereas carbon dioxide stems for the most part, 80%, from the use of energy[6]. The second largest factor for carbon dioxide emissions is deforestation, which accounts for approximately 12%[7].

On its turn the energy sector consists mainly of the use of fossil fuels, which have large emissions of CO_2 with its combustion. The International Energy Agency (2009) divides fossil fuels in the combustion of coal, oil, gas and other. Coal, which is the most polluting of the four, is used for the growing energy demand in developing countries in energy-intensive industrial production.

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[6] (International Energy Agency, 2009)
[7] (van der Werf, et al., 2009)

Important to note when analysing the emissions of carbon dioxide is the high variety in trends and sources over the different regions.

The exact costs and benefits of the climate change are not known. This is partly because the speed and the magnitude of the change are uncertain. It appears to be a slow change. However, as Solomon et al. (2009) conclude, this does not mean that there is the possibility at any moment to reverse changes. Once the concentration of carbon dioxide in the atmosphere has increased and changed global temperature, this change will be irreversible for the most part for the next 1.000 years because of the longevity of CO_2. It is certain that the magnitude of the change will depend on the level of CO_2. This gives enough reason to be concerned with the emissions of CO_2 and possible ways to reduce it.

The emission of carbon dioxide and its consequences are a global problem. Countries prefer to adopt the same measures as other countries to prevent competitive disadvantages for the country because of individual measures. In the early nineties the awareness of the need for international joint action already existed. In 1988 the scientific body of the UN, the International Panel on Climate Change (IPCC), was established. This body is still the most important institution in this field for policy-relevant scientific research. In 1992 the UN Framework Convention on Climate Change was signed in order to stabilize greenhouse gases in the atmosphere to prevent human interference with the climate system[8]. Soon after the treaty entered into force in 1994 it became clear that the measures would not be sufficient in order to achieve the targets. Therefore, the Kyoto Protocol was adopted in 1997 but it only entered into force in 2005. It legally binds developed countries to CO_2 emission reduction targets. These targets are set to prevent the global temperature from increasing more than 2 degrees Celsius.

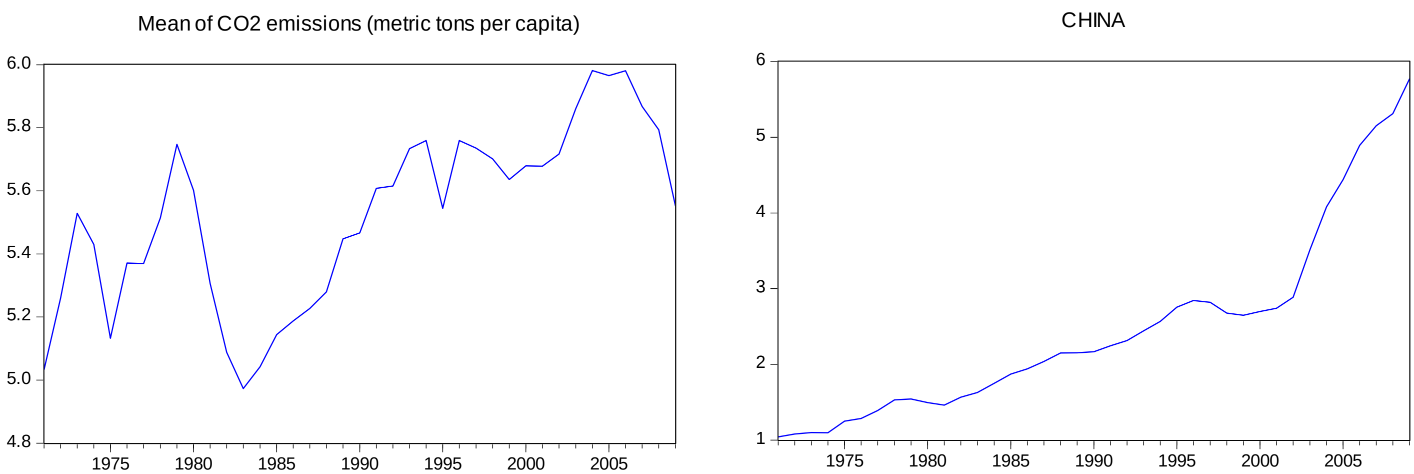
Setting reduction targets asks for analysis of developments and means to achieve these targets. The IPCC generates future scenarios, so called SRES scenarios[9] in which it tries to predict the future greenhouse gas emissions. These scenarios have proven to be overoptimistic more than once[10]. By now it is generally accepted that developed countries, as bound by the Kyoto Protocol, cannot realize the reduction on their own. As mentioned before, developing countries with

[8] Intergovernmental Negotiating Committee for a Framework Convention on Climate Change, 5th session, 2nd part, New York, 30 April-9 May, 1992.
[9] (Nakicenovic & Swart, 2000)
[10] See (Schmalensee, Stoker, & Judson, 1998) and (Raupach, et al., 2007)

increasing energy demand are using the most polluting fossil fuels to satisfy the increasing demand. The developing and least-developed countries account for 80% of the world population. If these countries would reach the same level of emissions per capita as the developed countries this would mean a huge increase in global emissions. The more positive scenario would be that developing countries will develop directly into more energy-efficient and less emission-intensive economies. Government policies and innovations are the key to make this happen.

In the SRES scenarios from the IPCC and other papers[11] global carbon dioxide emissions from fossil fuel combustion and industrial processes are explained by the global population, world GDP, and global primary energy consumption. Since 2000 there has been a strong growth in the emissions from fossil fuel combustion. The growth was driven by increases in the population, per-capita global GDP and carbon intensity of GDP. The latter increase mainly stems from developing countries, for example in 2004 they accounted for 73% of the emissions growth worldwide.

Graph 1: Chinese and global CO_2 emissions per capita



Source: World Development Indicators, World Databank (2013)

Olivier et al. (2012) note that China's carbon dioxide emissions per capita in 2011 are approaching European levels. This is due to a decline in European emissions and an increase in Chinese emissions. Globally carbon dioxide emissions reached its highest level all-time in 2011. After a decline in 2008 and 2009 due to the global financial crisis, the long-term increasing trend in global carbon dioxide emissions was resumed in 2010. The regional differences are significant.

[11] (Raupach, et al., 2007)

In most OECD countries CO_2 emissions are decreasing. Possible causes are the economic conditions, mild winters and high oil prices. The global increase can be explained by looking at the developing countries. Estimated is that OECD countries are responsible for one third of global emissions and China and India together for another third. Those two countries have increasing emissions. In many other developing countries there is an increasing trend (Olivier, Janssens-Maenhout, & Peters, 2012).

Lane (2011) explains the clear and strong relationship between GDP and CO_2 emission in his research paper *CO_2 emissions and GDP*. The production of output, measured in GDP, requires energy. The most important source of energy is the combustion of fossil fuels, which results in the emission of carbon dioxide. The magnitude of the relationship could change due to developing countries using more polluting sources of energy on the one hand and improving technologies for renewable energy and more energy-efficient processes on the other hand. Per country there is wide variety in the so-called transmission factor, that is, with how much emissions change as a result of a higher GDP.

International agreements have shown to be difficult to close. Even when countries come to agreements it is hard to enforce and monitor the compliance. Therefore, according to Lane, the only ways to stabilize emissions is by reduction of economic growth or reduction of the transmission factor. The first is not desirable, especially considering developing countries. That leaves us with the latter; policies should give incentives to produce output with less pollution. Investments can also contribute by improving technologies for more energy-efficient production and alternatives such as renewable energy (Lane, 2011).

2.2 Policies and investment

One policy instrument that is used increasingly as a means for the reduction of carbon dioxide emissions is the design of CO_2 markets, such as the European Emission Trading Scheme (EU ETS). Markets are designed to facilitate the trade in emission rights. This way the total cost of reduction is minimized. Unfortunately with the implementation of such markets there are many discrepancies between the design and the practice of the markets. Veal and Mouzas (2012) find such discrepancies in their analysis of the EU ETS. They find that there are many aspects of the markets that the regulators do not take into account. The main observation is that the market does not actually give incentives to participants to reduce their emissions. This can be explained by the lack of political independency of market regulators. Common to find is that the sectors that are to be restricted in their carbon dioxide emissions have a large influence on the market regulators. By lobbying organizations they have the power to affect the policies that will be conducted in the market. Also there is large uncertainty in the market regarding economic and technological developments. This creates difficulties for participants to estimate the costs of emissions.

Other policy instruments are taxation of carbon dioxide emissions or fossil fuels, subsidising clean energy sources or setting portfolio standards for carbon emission intensity of production or non-fossil share in total energy supply. Setting these portfolio standards can be done by using the taxes on carbon dioxide or on fossil fuels as subsidies for non-fossil energy. The most cost-effective way is to make a portfolio standard for the CO_2 emission intensity of production and achieving this by taxing carbon dioxide emissions and use the proceeds as subsidies for non-fossil energy. Depending on technological advance it will be feasible to apply carbon dioxide capture and storage on a large scale. Research learns that this will not make other policies redundant (Gerlagh & van der Zwaan, 2006).

Investments in technology for more energy-efficient and non-emitting production are seen as the main solution for the greenhouse effect. Renewable energy sources or non-fossil sources do not result in the emission of carbon dioxide. Solar and wind power make up the main capacity from renewable energy sources. In 2012 all renewable sources together supplied 16.7% of the global energy consumption. Investment in renewable energy sources is increasingly rewarding. The costs are falling significantly and the use is expanding. In 2009 there was a small decrease in investment due to the global financial crisis. After 2009 the growth continued like before. In the last quarter of 2011 and the first quarter of 2012 the effect of the euro area sovereign debt crisis was already noticeable. Not only banks are decreasing their money flow but also governments are cutting on renewable energy policy expenditure due to the crisis and due to the conviction that the industry has matured enough to be self-sufficient. This is seen as a threat for the continuation of renewable energy expansion (UNEP’s Division of Technology, Industry and Economics, 2012).

2.3 Kuznets and Porter

The relationships between carbon dioxide and its affecting factors have been discussed extensively in the literature. Population, GDP, energy consumption, oil prices and the use of alternative energy appear to be the general accepted factors that affect carbon dioxide emissions. Interestingly, for GDP it is not only the effect of GDP on environmental deterioration that has been suggested but also the reverse. Two conflicting hypotheses are discussed.

The environmental Kuznets curve (EKC) concept was introduced by Grossman and Krueger in 1991. It represents the inverted U-shaped relationship between indicators of economic growth and environmental development. The inverted U-shaped relationship stems from Simon Kuznets, who invented the Kuznets curve to describe the relationship between per capita income and income inequality. When income per capita increases, initially income inequality increases but starts to decline after a turning point. What is expected by the environmental Kuznets hypothesis is that when countries are developing economically there is first an increase of emissions and after a certain point of development a decrease of emissions. Economic growth itself could thus be the solution for environmental degradation. The research on the EKC is very extensive. Empirical proof however, is not unambiguously. Results seem to depend on the country or countries chosen, statistical methods used and the time frame that is tested for. It is common to use panel or cross-section data for empirical analyses but also individual country analyses have been done with time series data. There has been varied with different indicators for as well economic growth as environmental quality. It remains hard to find consistent results (Saboori, Sulaiman, & Mohd, 2012).

The theoretical explanation of the EKC is based on three effects. The scale effect defines the negative effect of economic growth on environmental quality. Higher production levels lead to higher levels of pollution. This is expected to be observed in the early stages of developing economies. By the composition effect is meant the changing structure of economies from agricultural pollution-extensive production to pollution-intensive heavy manufacturing and later to lighter and less-polluting manufacturing and more emphasis on the service sector. The technique effect suggests the technological advance that enables cleaner production. This could be realised by more efficient use of polluting energy or by less polluting production processes. The composition effect and the technique effect would explain the fall in carbon dioxide emissions after a certain level of economic growth (Grossman & Krueger, 1991; Stern, 2004; Saboori, Sulaiman, & Mohd, 2012).

In an empirical study the relationship is examined between the emission of carbon dioxide, economic growth and openness (Choi, Heshmati, & Cho, 2010). Openness to international trade and GDP are used as indicators of economic growth for three countries with different levels of economic development; China, Korea and Japan. There was no straightforward evidence for inverted U-shaped relationships between GDP and CO_2 emissions. For the link between free trade and CO_2 emissions it was found that first a certain level of development in terms of GDP is required in a country before international trade can lead to improvement of environmental quality as opposed to its deterioration. The ratio behind this is that people need a certain level of income before they become concerned with the environment and will spend part of their income on environmental goods. An important difficulty for finding evidence for the EKC is the large diversity between countries for the relationship between CO_2 emissions and economic growth. This is why the EKC is also examined for individual countries.

In other research a different influence from international trade on CO_2 emissions is found, a displacement effect (Jaunky, 2010). This study focuses on 36 rich countries and tests the existence of the environmental Kuznets curve for CO_2 emission and GDP. It finds that international trade leads to the shift of pollution-intensive production in rich environmental-stringent regulating countries to poorer countries. The rich countries import the pollution-intensive products, while the poorer countries at some point have no possibility to displace their polluting industries to other countries. This would mean that the EKC hypothesis would not hold for poor countries. Stern (2004) also mentions this effect and argues further that environmental deterioration inevitably affects economic activity in a way because higher levels of economic activity cannot be sustainable with higher levels of environmental deterioration. Therefore the developed countries export their polluting industries. This leads to the poorest countries with the most polluting industries. For these countries also holds that higher levels of economic activity are not sustainable with higher levels of pollution. They do not have the possibility to export their polluting industries which also refrains them from sustainable economic growth.

Jaunky finds mixed evidence for the EKC hypothesis in rich countries. The hypothesis was tested by differentiating between short-run and long-run elasticity between income and CO_2 emissions.

The EKC hypothesis would be supported by a positive elasticity in the short-run and a negative elasticity in the long-run, defining a turning point at a level of economic growth where pollution starts to fall. This was found for only five countries. For the other countries the long-run elasticity was significantly lower than the short-run elasticity, meaning a stabilization of CO_2 emissions but no support for the EKC hypothesis.

Stern (2004) and Saboori et al. (2012) both state that the empirical results for the EKC are not only contradicting, also the econometric methods used are problematic. Stern states that in most empirical research there is a lack of attention for the statistical characteristics of the used data. These econometric problems “fall into four main categories: heteroskedasticity, simultaneity, omitted variables bias and cointegration.” (Stern 2004, p. 1429). Many researchers did adjust their econometric methods for these problems, but all are leading to different results. This makes it even harder to draw any conclusions on the existence of the EKC.

The environmental Kuznets curve implicitly assumes that economic growth affects environmental development and not vice versa. Several reports[12] find no reverse causality, meaning that pollution control does not endanger economic growth in the long-run. Coondoo and Dinda (2002) found that the existence and the characteristics of the relationship between carbon dioxide emissions and economic growth differ per country. In the literature some authors found a one way causal relationship from economic growth to CO_2 emissions and others from CO_2 emissions to economic growth. Also there has been found bilateral causality and the absence of any causal relationship (Saboori, Sulaiman, & Mohd, 2012). A causal relationship from environmental quality to CO_2 emissions has been stated by the Porter hypothesis (Porter & Linde, 1995).

The Porter hypothesis stems from the rejection of the view that environmental protection constitutes an inevitable trade-off with economic growth. Before the Porter hypothesis gained popularity it was generally assumed that measures to protect the environment would restrict companies and competition and therefore it could never lead to economic growth. On the contrary, environmental protection would have a negative effect on economic growth. Porter argues that this view comes from a static mindset where companies already operate at their cost-minimizing levels so that any environmental regulation would impose costs on companies.

[12] (Jaunky, 2010); (Saboori, Sulaiman, & Mohd, 2012)

Environmental regulation or policy can give incentives to innovation. Proper designed measures and policies should give these incentives. The innovations can lead to less-polluting or more energy-efficient technologies and therefore to more profitable technologies and production. This implies the reverse causality than the Kuznets hypothesis. According to Porter, environmental development leads indirectly to economic growth. If this can be proven to be true, the fear of countries to have competitive disadvantages due to stringent environmental regulations would disappear. In fact, the more stringent, but proper formulated, regulations, the more incentives there would be for innovations that lead to both the reduction of pollution and higher productivity. Stringent environmental regulations would become a competitive advantage and remove the difficulties for coming to international agreements. This is not something that is observed in practice. Attempts to close environmental agreements are always preceded with long negotiations and sometimes unsuccessful.

The emphasis in this concept is laid on innovation; this is the key to economic growth. It is divided in two types, innovation that merely reduces pollution control costs and innovation that improves pollution control while improving the product or its processes as well. This last type of innovation is the reason of economic growth in the Porter hypothesis. With pollution control is meant the compliance with environmental regulations. Empirical evidence has been found for the Porter hypothesis, depending on the circumstances and the stringency of environmental regulations, for certain industrial sectors and specific countries. The hypothesis cannot be said to hold in general for all countries and sectors under all types of regulations and conditions (Wagner, 2003).

Both the Kuznets and the Porter concept were developed in the early nineties. Although they constitute a contradiction for the direction of the causality between environmental quality and economic growth, they are originated from the same development. The view changed from a static view of environmental investments and technology to a more dynamic view. Another similarity for both concepts is that they only hold conditionally. The empirical results differ for different types of pollution.

2.4 CO_2 emissions and financial crises

The factors that influence carbon dioxide emission are factors that are likely to change significantly during economic crises. GDP, energy consumption, government policy, business investment and oil prices, they are all related to the state of the economy. Therefore it is expected to find a significant change in carbon dioxide emissions during crisis years. Several authors have tried to detect such influence of economic crises on CO_2, which is the aim of this paper for the global financial crisis. There are some difficulties with finding such a relationship.

The analysis of the 1870s and 1930s depressions shows there is reason to believe that those financial crises led to lower global temperatures (Giedraitis et al., 2010). ‘The Panic of 1873’ led to a global reduction of carbon dioxide emissions. The Great Depression of the 1930s led to an even larger reduction of emissions. During this crisis industrial activity was higher and the crisis itself had a larger impact than the crisis in the 1870s. A strong correlation between carbon dioxide emissions and economic situations such as economic crises is found. However, because of the approximate life time of two years of carbon dioxide gases in the atmosphere, there was no significant change in global temperature during the economic crises, that lasted 2 to 4 years. Also they note that the rapid increase of economic activity after economic crises diminishes the reducing effect of crisis on emissions. One important shortcoming of analysis with GDP as the sole independent variable is that GDP cannot capture the entire state of the economy of a country. The findings of this paper are especially enlightening because they show the relationship between GDP and CO_2 emission derived from a different time-frame. Again regional differences are found. According to Giedraitis et al. the regional differences in the relationship between GDP and CO_2 emissions can partly be explained by the different marginal costs of reducing pollution. For industrial intensive economies the marginal costs of pollution reduction are much higher than for service-oriented economies. Combining this with the displacement effect[13] developed countries can reduce emissions more easily by displacing polluting intensive production to developing countries. The poorest countries do not have this possibility and have higher marginal costs to reduce pollution.

Siddiqi (2000) examined the possible positive consequences of the Asian financial crisis (1997-1998) for the global environment. He uses the relationship between growth in GDP and growth in

[13] See (Jaunky, 2010) and (Stern, 2004)

energy consumption. Except for China and Japan, the countries involved in the Asian financial crisis experienced a higher energy consumption growth than GDP growth between 1980 and 1996. The explanation is that China and Japan were improving their energy efficiency and had growing service sectors. The Asian financial crisis led to large changes of future energy consumption predictions as opposed to pre-crisis predictions. One important characteristic of the Asian financial crisis is that it mainly affected intensive energy consuming sectors.

The growth rate of energy consumption somewhat declined due to the Asian financial situation. This led to a decline in emission growth, especially of carbon dioxide, but not to an absolute decline of CO_2 emissions. Noted should be that energy use and carbon dioxide emissions were increasing rapidly in the involved countries from the 1950s until the crisis started. The decline in emission growth thus might be caused by the financial crisis but cannot be extrapolated without its context to other countries that experience a financial crisis. When interpreting the decline in emissions growth it is important that the Asian financial crisis especially affected intensive energy industries and that the countries were experiencing a high emissions growth rate before the crisis.

However, this is not the whole story. The financial crisis also led to the deferment of measures to improve environmental quality. Transitions to non-fossil fuels and the use of more energy-efficient equipment were postponed in many sectors. The benefits for the environment of the Asian financial crisis are unlikely to exceed the costs. The global economy and environment were in another stage in the late nineties than today, but similar impacts of the recent crises ought to be expected (Siddiqi, 2000).

Solutions have been proposed where economic and environmental crises should be solved with the same measures. Argued is that the crises have common causes. Leichenko et al. (2010) use the global financial crisis as an example of the close linkage between globalization and climate change. The example is given of the low interest rate-loans as a common cause for the expansion of the pollution-intensive automobile industry and the global financial crisis of 2008. Both problems could be addressed by stimulating the renewable energy industry. This could lead to the creation of jobs and a more sustainable use of energy. The idea of Leichenko et al. is closely related to the Porter hypothesis. Proper designed regulations can lead to innovation which improves the environment and the company's profitability. In the paper of Leichenko et al.

however, is focused on the risk and vulnerability that is spread by the environmental crisis and the economic crisis. The measures taken should make the system more robust to both economic and environmental shocks. The conclusion of this study is that measures to improve the environmental or the economic situation should consider the interactions it might have with the other field. This should lead to solutions that address both, for instance the reformation of the energy system that can have a positive effect on the environment and the economy. Formal analysis of the effectiveness of such policies has not been done yet (Leichenko et al., 2010).

From the European Emissions Trading System is known that the global financial crisis caused a drop in carbon dioxide emissions in 2009 within the European Union. The reduced activity due to the crisis is the main explanation. Also, the low gas prices gave incentives to use gas rather than the more polluting energy source coal. The rest of the decline can be explained by the effect of the EU ETS. Worrying is that innovations in more energy-efficient production and renewable energy sources are not only postponed or deferred because of fewer available funds. The reduction of emissions because of the decrease in economic activity during crisis years itself reduces incentives to invest further. The targets of the Kyoto Protocol are met more easily. On the long term the reduction of environmental investment might be a threat to the expansion of renewable energy (UNEP's Division of Technology, Industry and Economics, 2012).

Globally carbon dioxide emissions from fossil-fuel combustion and cement production declined as well due to the global financial crisis. In 2009 there was a decrease of 1.4%. However, this decrease was already offset in 2010 with a growth of 5.9% (Peters et al., 2011). This seems to be the continuation of the growth in emissions as before the crisis. Peters et al. compare this effect to the effect on emissions after the oil crises in 1973 and 1979. Those crises led to a permanent shift of oil to natural gases, which meant a decrease in emissions. However, also the Asian financial crisis in 1997 led to a drop in global CO_2 emissions that lasted post-crisis but it was not caused by a structural change in the economy. In this case the decrease was caused by the economic and political changes.

There are several reasons why the global financial crisis did not have a similar impact on emissions. Peters et al. first recall the energy prices that rapidly adjusted back to normal. In contrast with the oil crises this did not pressured the global economy to shift to different energy sources. Secondly, there was government support in many countries in order to help the economy back on track. Lastly, the global financial crisis was preceded with many years of economic growth. The developing countries were affected to a lesser extent by the crisis. Their economic activity helped global recovery after the crisis but also increased emissions.

A distinction is made between emissions associated with exports and with imports. Again there is a clear division between developing and developed countries. The developed countries experienced an overall decrease in emissions associated with imports in 2009 and 2010. This can be explained by the focus on domestic activities and a decrease in international trade during and after the crisis. Developing countries experienced an increase in emissions associated with imports, even exceeding import-emissions of developed countries for the first time. In their paper that has been cited many times Peters et al. define the global financial crisis as a missed opportunity for emission reductions. They state that developed countries are meeting their Kyoto protocol commitments thanks to the global financial crisis but the reduction of their emissions is overruled by the emissions of emerging economies. This is not only due to their increased levels of economic activity and thus increased levels of energy use but also their tendency to rely on more polluting energy sources such as coal. Several studies came to this conclusion[14].

The view of a modest impact of the global financial crisis on CO_2 emissions is not uncommon. The global greenhouse gas abatement cost curve of the consultancy firm McKinsey & Company was adjusted after the global financial crisis. In a comment on this adjustment is concluded that the crisis had a small effect on greenhouse gas abatement costs. This is due to the small changes in the development of CO_2 emissions. Again the developing economies are cited as the explanation. Also the long term characteristic of CO_2 emission diminishes the effect of a two-year crisis (Enkvist, Dinkel, & Lin, 2010). The crisis had to last longer to have a permanent effect on CO_2 emissions[15].

2.5 Empirical analyses

The studies that analyse the empirical relationships between carbon dioxide emissions and factors that affect emissions are diverse in their methods and results. Results appear to depend strongly on the statistical method used.

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[14] See (UNEP’s Division of Technology, Industry and Economics, 2012) and (International Energy Agency, 2009).
[15] See also (Gierdraitis, Girdenas, & Rovas, 2010).

In the early nineties, when the dynamic view on CO_2 emissions and economic growth was introduced, the literature on this topic expanded rapidly. One study examined if this dynamic view could hold empirically. Holtz-Eakin and Selden (1995) used global panel data to see if economic growth was inevitably going to lead to the increase of CO_2 emissions. They estimated models using OLS and included country-specific fixed effects. This allows each country to have its individual intercept. This aims to capture the unobserved country-specific characteristics. They find that using fixed effects alters the results drastically but conclude that the use of fixed effects is appropriate. This global type of research was later followed by more country-individual analyses because of the large differences between countries.

Much research has been done on the empirical relationship between CO_2 emissions and indicators of economic growth. Azomahou and Van Phu (2001) analysed the relationship between CO_2 emissions per capita and GDP per capita using a nonparametric approach. They claim to have higher power tests than earlier research because the nonparametric approach allows them to avoid any assumptions about the distribution of the variables. They criticise studies that make such assumptions. The assumptions usually do not hold but the researchers using them do find evidence for the existence of the Environmental Kuznets Curve (EKC). Azomahou and Van Phu find a more complex pattern for the relationship between CO_2 emissions and GDP than the inverted U-shaped pattern implied by the EKC. In the early and advanced stages of economic development they find globally that the development has a negative effect of the emission of carbon dioxide. This is not in line with the EKC hypothesis.

Lee and Lee (2008) conducted empirical research to analyse the same relationship. Instead of a nonparametric approach, they took account for unit roots in the data of GDP per capita and CO_2 emissions per capita in 109 countries. By considering the different orders of integration and using cointegration when possible for the two variables and the differences for each country they claim to conduct the econometric analysis with higher power. Their most important finding is that policy makers should take into account the characteristics of GDP and CO_2 emission data of their country.

There is no consensus in the literature about the econometric methods to be used for examining relationships between CO_2 emissions and its factors. The methods used do seem very determining for the results. The regional differences make it more problematic to conduct global analysis.

3. Description of the data

Based on the literature research the most important factors for examining the effect of the financial crisis on the emission of carbon dioxide are determined. These are economic activity, environmental policies and investment and the oil market. Economic activity is quantified by the variables GDP per capita and energy use per capita. Environmental policies and investments will be measured by a country's percentage of fossil fuel and alternative energy consumption. The oil market is included by the oil price. For these variables the data was collected. The data used in this study stems from several sources. It consists of a balanced panel dataset of 55 countries for a period of 39 years, from 1971 until 2009. The countries selected are the countries for which data on all variables included was available through the used sources for the whole time span.

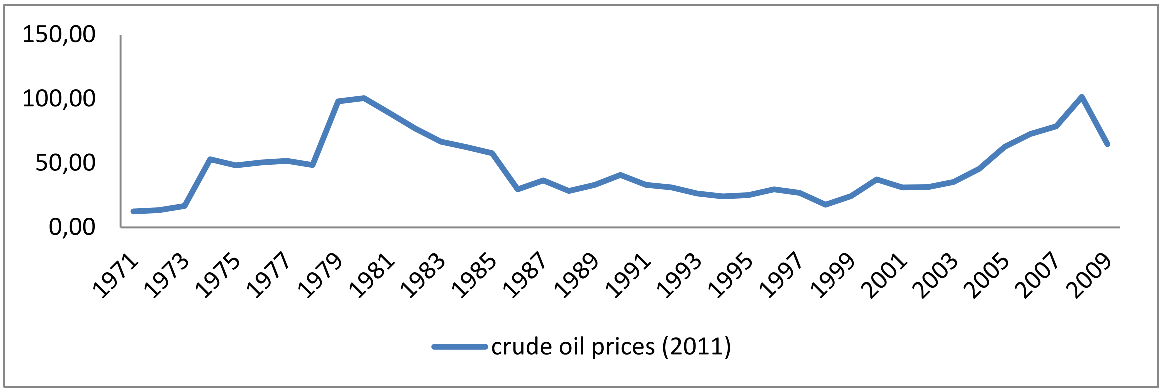
The data on carbon dioxide emissions per capita, GDP per capita, energy use per capita and the share of fossil fuel and alternative energy consumption are retrieved from the World Development Indicators (WDI) of the World Databank. The data on carbon dioxide emissions includes the emissions from consumption of fossil fuel and the production of cement but excludes emissions from other activities such as deforestation. The variable metric tons of CO_2 emissions per capita is obtained by dividing the country's CO_2 emission for the specific year by the midyear population. Luxembourg has the highest CO_2 emissions per capita in 2009 in the panel dataset (20,38 metric tons per capita). Luxembourg also has the highest GDP per capita and the second-highest energy use per capita.

GDP is measured at constant prices expressed in 2000 US dollars. Energy use consists of the primary energy use, computed as the indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. Energy use and GDP are divided as well by the midyear population in order to obtain the per capita variables used in this paper. CO_2 emissions, GDP and energy are expressed in per capita figures to exclude the effect of the country's population size on the results.

Fossil fuel energy consumption constitutes the percentage of non-renewable energy use of the total energy use. Alternative and nuclear energy consumption is the percentage of renewable energy use of the total energy use (WDI, 2013). The data shows the diversity between countries in the use of alternative energy sources. Paraguay for example leads the list with 94%, whereas Saudi Arabia has a reported percentage equal to zero.

The data on crude oil prices consists of the average of the Brent, West Texas Intermediate (WTI), Nigerian Focados and Dubai US dollar price per barrel expressed in 2011 US dollars. The data comes from the BP Review of World Energy 2012. The oil prices show a clear increasing trend in the seventies. This was due to the oil crises. Again starting from 1999 there is an increasing trend visible with a sharp decline in 2009 (see Graph 2).

Graph 2: Crude oil prices in 2011 US$



The data contains several crisis dummies. These dummies take the value of 1 in the years and countries involved in the crisis and the value of 0 in the other years and countries. Table 1 shows the crisis dummies that are used in the estimations. Only crises are included that lasted for one year or longer. For example the Black Monday of 1987 is not included. This shock had a severe impact because stock markets crashed globally but the short length of the event makes it not feasible to detect its effects in a dataset of 39 years. From the crises in the period of 1970-2009 that lasted for one year or more the banking crises were included because of the similarities with the global financial crisis, of which we aim to find the effect. The crises in the period of 1970-2009 that affected more than one country or lasted for more than one year are also included. These crises are more likely to affect CO_2 emissions because of their scope or length. The global financial crisis is defined in two ways, for the years 2007-2008 and for the years 2008-2009. This is because it is hard to draw a sharp line of when the crisis started and ended. Estimation of the models will show which dummy is most appropriate to use.

Table 1: economic crises and their dummies

Year	Country	Crisis	Dummy
1973-1974	Global	Oil crisis	D_1
1973-1975	United Kingdom	Secondary banking crisis	D_2
1979-1980	Global	Second oil crisis	D_3
1983	Israel	Bank stock crisis	D_4
1986-2003	Japan	Japanese asset price bubble	D_5
1991-1993	Finland	Banking crisis	D_6
1991-1993	Sweden	Banking crisis	D_7
1997	Asia: Thailand, Indonesia, Malaysia, China, Japan, Singapore	Asian financial crisis	D_8
2007-2008	Global	Global financial crisis	D_9
2008-2009	Global	Global financial crisis	D_{10}

4. Models and methodology

With the described data several models are estimated with carbon dioxide emissions as the dependent variable. The major factors for the effect of the financial crisis on the emission of carbon dioxide are economic activity, policies, investment and the oil market. From the literature it is apparent that economic activity is the most important determinant of CO_2 emissions. Economic activity will be measured by the variables GDP per capita (*GDP*) and energy use per capita (*EU*). These are the first two explanatory variables in the model. It is expected to find a positive relationship between economic activity and carbon dioxide emissions. During crisis years a lower GDP per capita and less energy use per capita is expected, which leads to lower emissions.

Reduction of emissions can be done in two ways. The use of fossil fuel energy can be made more efficient or there can be a shift to renewable, non-polluting energy sources. Policies and investment are the means to reduce carbon dioxide emissions in these ways. The more efficient use of fossil fuel energy is captured in the relationship between GDP and CO_2. If the same output leads to fewer emissions, the energy was used more efficiently. Another way of saying this is that GDP is less CO_2-intensive. To measure the shift to renewable energy sources as a result of policies and investments, the percentage of fossil fuel energy use (*FF*) and the percentage of alternative and nuclear energy use (*AN*) are included in the model. Including both would theoretically not be right because they are almost interchangeable. A higher percentage of alternative and nuclear energy should mean a lower percentage of fossil fuel energy use. There are only a few energy sources that are not included by these two variables and they account for a very small percentage. The correlation between *FF* and *AN* (-0.29) indicates the presence of some but no perfect correlation. This might be a reason to doubt the preciseness of the data, since the two indicators are collected separately and countries might use different measurement methods.

Because of their theoretical interchangeability it is not correct to include both in one model. The variables will be replaced by each other to see if this improves results. Expected is that the percentage of fossil fuel energy use has a positive effect on emissions and alternative energy use a negative effect. These percentages do not measure the actual environmental investments and policies that aim to reduce emissions. It is hard to quantify the investments for the 55 countries included over 39 years. The percentages do give a good indication of what a country's policies and innovations are resulting in.

The oil market is included by the variable oil price (*OP*). It is uncertain what the effect is of the price of oil on carbon dioxide emissions. A low oil price is likely to give incentives to use more gas and reduce incentives for innovations of renewable energy sources. It reduces the shift to less polluting alternatives. On the other hand it keeps companies from shifting to the more polluting alternatives, such as coal.

Crisis dummy-variables are used to detect the effect of economic crisis on CO_2 emissions. The dummy takes the value of 1 during crisis years. The estimated coefficient of the crisis dummy shows the deviation of emissions during crisis years. The significance of a crisis dummy-variable means significantly different carbon dioxide emissions during the economic crisis.

Based on these explanatory variables and the crisis dummies several models will be estimated. An overview of all models can be found in Appendix 1. All estimations are made with the statistical program Eviews 7.The models are estimated using the panel dataset. An important characteristic of panel data is that the observations are not independently distributed over time. A country's GDP per capita in 2008 is not independent of its GDP per capita in 2007. This is a disadvantage of working with panel data because it can lead to autocorrelation of the error. Another drawback would be when the number of cross-sections exceeds by far the number of time-series or vice versa. The extra variation given by the cross-sections or time-series cannot be used for estimating more precisely. In this dataset this is not a big problem, with 55 countries and 39 years.

Working with panel data also has many advantages. It leads to the increased precision of regression estimates because it has variation over time and over cross-sections. The large number of observations gives increased degrees of freedom. Therefore the panel data gives more reliable and stable estimations for the parameters. Because of the temporal ordering it is easier to find causal relationships, but sequencing is not sufficient for causal interference.

Most importantly it is possible to account for individual heterogeneity in a panel dataset. The panel data shows the changes in emissions and in the other variables per country over time. Each country has its own characteristics. The variables might have similar influences on CO_2 emission but each country might have, next to this, unobserved influencing factors. Therefore the method of fixed effects is used. This means estimating a regression with a dependent variable and explanatory variables for the panel data but allowing for each cross-section unit, in this case each country, a different intercept. This intercept, the so-called fixed effect, captures the country-specific effect. This is one of the benefits of working with panel data. It allows you to isolate the effect of unobserved differences between cross-sections. Ignoring the individual characteristics of a country would lead to autocorrelation of the error terms within a country. The absence of such correlation is one of the assumptions of the OLS estimation method that is used. If there is a country-specific effect and fixed effects would not be used, this effect would end up in the error term. The error terms over time for one country would then be correlated. This is called autocorrelation.

A cross-section fixed effects model allows for varying intercepts across countries and assumes constant error variances and constant slopes for the models. This model will be estimated using OLS. The fixed effect is included as a dummy for each country. Adding this dummy to the overall intercept gives us the country-specific intercept. For each country there is a different dummy. This is different from the ordinary use of dummy-variables, which contains one cross-section unit as the base and does not have a dummy-variable. This is why in each model there is an overall intercept β included and an 'individual' intercept β_{0i}. Examining CO_2 emissions with panel data and a fixed effects model was for example also done by Holtz-Eakin and Selden (1995).

The first model uses the explanatory variables retrieved from the literature energy use per capita (*EU*), GDP per capita (*GDP*), fossil fuel energy use (*FF*) as a percentage of total energy use, the crude oil price (*OP*) and a crisis dummy (D_9) for the global financial crisis. Put formally:

$$CO2 = \beta_0 + \beta_1 EU + \beta_2 FF + \beta_3 GDP + \beta_4 OP + \beta_5 D_9 + \varepsilon \qquad (1)$$

Estimating this model for the panel data using the fixed effects method converts this model into:

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_9 + \varepsilon_{it} \qquad (1.1)$$

$$\text{with } i = 1,2,\ldots,N \ (N = 55)$$

$$t = 1,2,\ldots,T \ \ (T = 39)$$

Adjustments are made based on the results of the estimations, discussed in the next chapter.

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 GDP_{it}^{\ 2} + \beta_5 OP_{it} + \beta_6 D_9 + \varepsilon_{it} \qquad (1.2)$$

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 AN_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_9 + \varepsilon_{it} \qquad (1.3)$$

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_{10} + \varepsilon_{it} \qquad (1.4)$$

Model 1.2 includes the squared GDP per capita (GDP^2) as a variable. This is done in order to find evidence for the EKC hypothesis. The EKC would hold if *GDP* has a positive parameter and GDP^2 a negative parameter because this indicates the inverted u-shaped Kuznets curve. Emissions are increasing with GDP up to a turning point from where emissions are decreasing when GDP increases. Model 1.3 replaces *FF* for *AN*. Model 1.4 replaces the crisis dummy for a different defined crisis dummy (see Table 1).

One of the assumptions of a fixed effects model is a constant slope across countries. If this assumption is violated, it means that countries not only have different intercept but also different parameters. This comes down to estimating the following model for each country separately:

$$CO2_t = \beta_0 + \beta_1 EU_t + \beta_2 FF_t + \beta_3 GDP_t + \beta_4 OP_t + \beta_5 D_{10} + \varepsilon_t \qquad (1.4.1)$$

The adjustments made to obtain Model 1.5 are based on the results of the estimations, discussed in the next chapter.

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \varepsilon_{it} \qquad (1.5)$$

Model 1.6 is obtained by taking the natural logarithms of *CO2*, *EU* and *GDP*.

$$LN\_CO2_{it} = \beta + \beta_{0i} + \beta_1 LN\_EU_{it} + \beta_2 FF_{it} + \beta_3 LN\_GDP_{it} + \beta_4 OP_{it} + \beta_5 D_9 + \varepsilon_{it} \qquad (1.6)$$

The reason for taking the natural logarithms is the possible existence of unit roots in the data of these variables. Unit roots are often found in other studies[16] when examining carbon dioxide emissions. This means that the variables follow a random walk and are non-stationary. This is problematic because using OLS estimators with unit root data leads to spurious regressions. This means that the dependent and the explanatory variables are both affected by a third variable. The variables that have a unit root can be made stationary by taking the natural logarithms. Testing

[16] Lee and Lee (2008) find evidence for unit roots and cointegration in data on GDP per capita and CO_2 emissions per capita.

for unit roots and cointegration is out of the scope of this study but estimating the model with natural logarithms gives an indication of the results when taking account for possible unit roots.

The explanatory variables are all related to the global economic situation. If the explanatory variables change significantly during crisis years they can captured part of the crisis-effect. In order to reveal this, the model is estimated with the crisis dummy only:

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 D_9 + \varepsilon_{it} \tag{2.1}$$

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 D_{10} + \varepsilon_{it} \tag{2.2}$$

In Model 3.1 other crisis dummies of crises between 1970 and 2009 are included in order to improve the econometric results (see Table 1). Model 3.2 replaces the variable *FF* for *AN*.

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_1 + \beta_6 D_2 + \beta_7 D_3 + \beta_8 D_4 + \beta_9 D_5 + \beta_{10} D_6 + \beta_{11} D_7 + \beta_{12} D_8 + \beta_{13} D_9 + \varepsilon_{it} \tag{3.1}$$

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 AN_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_1 + \beta_6 D_2 + \beta_7 D_3 + \beta_8 D_4 + \beta_9 D_5 + \beta_{10} D_6 + \beta_{11} D_7 + \beta_{12} D_8 + \beta_{13} D_9 + \varepsilon_{it} \tag{3.2}$$

Again the model is estimated without explanatory variables in order to capture the effect of the crises in the crisis dummies.

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \beta_8 D_8 + \beta_9 D_9 + \varepsilon_{it} \tag{4}$$

The results of models 1 to 4 and their adjustments are examined. The goodness of fit of the estimated model to the data is measured by the R^2-within. It is controversial which R^2 should be used when examining fixed effects models estimated with panel data. In this paper the R^2-within is used. The overall-R^2 is not very informative. It compares the variation explained by the fixed effects model to an intercept only-model without fixed effects. This percentage will always be very high if the use of fixed effects is appropriate but it does not give a good indication of the goodness of fit of the model to the data. The R^2-between indicates the part of the variation between countries that is explained by the model. The R^2-within gives the percentage of variation within a country over time that is explained by the regression. This indicator is computed by comparing the sum of squared residuals (SSR) of the fixed effects model to a fixed effects model with only an intercept. It is the most useful R^2 for comparing models.

For each model an F-test is performed to examine the redundancy of the variables. It compares the same models as the R^2, the fixed effects model considered and a fixed effects model with intercept only. This F-test checks whether the variables included are together significantly different from zero.

The redundancy of the fixed effects is examined with an F-test as well. This test compares the fixed effects model to the model with the same variables but without using fixed effects. That is, the joint significance of the fixed effects is tested by comparing the model to a model that does not allow for individual heterogeneity.

As mentioned earlier in this chapter, the models are estimated using the method of Ordinary Least Squares (OLS). When including the dummies for the country intercepts the estimation method is sometimes called the Least Squares Dummy Variables method (LSDV). The assumptions that come with this method are tested for the estimated models. When the model complies with all assumptions, the estimations for the parameters are the best linear unbiased estimators (BLUE). These assumptions are:

1. $E(e_{it}) = 0$ The expected mean of the errors is zero. This is achieved if the model is correct. The error terms do not contain any systematic deviations in that case, which leads to an average of zero.
2. $var(e_{it}) = E(e_{it}^2) = \sigma_e^2$ The error terms are homoscedastic; the variances are the same for each observation.
3. $cov(e_{it}, e_{js}) = cov(e_{it}, e_{js}) = 0$ for $i \neq j$ or $t \neq s$ The error terms are not correlated over the cross-sections (section-correlation) or over time (autocorrelation).
4. $cov(e_{it}, x_{2it}) = 0$, $cov(e_{it}, x_{3it}) = 0$ The error terms are uncorrelated with the regressors. This would be the case if there is an omitted variable.
5. No multicollinearity. The regressors cannot be correlated perfectly. This would mean that they contain the same information.

Assumption 1 and 4 can be met by using the correct model. This means a model that is based on a consistent theory. Assumption 2 can be checked by plotting the residuals and observing the outliers. If there are many outliers the error terms are not homoscedastic. If there is any observed heteroskedasticity this can be controlled by using adjusted error terms. In this paper the White estimation method is used as presented in Eviews 7 for panel data. This estimation method accounts at the same time for any correlation of the error terms.

Correlation between the error terms in panel data can exist cross-sectional In the case of cross-sectional correlation the errors of the different countries in a year are correlated. Another way to say this is that the years are clustered. The other possible form of correlation of the errors in a panel dataset is between time-series, autocorrelation. The errors of one country are correlated over time in this case, the countries are clustered. Including fixed effects diminishes the chance of autocorrelation because the country-specific effect is removed from the error term into the country dummy. The error terms for one country over the years do not contain the country-specific effect, which would correlate them. Considering the type of data it is likely to find autocorrelation, since the variables develop over time. Including fixed effects might already remove the autocorrelation from the errors.

In order to account for heteroskedasticity and section-correlation of the error terms, the White cross-section method is used. This estimation method uses a so-called White Robust-covariance. It assumes the existence of cross-sectional correlation of the error terms. The years are clustered, the variance in one year is correlated for the different countries. The method computes standard errors robust for contemporaneous correlation and heteroskedasticity by estimating an equation for each country[17].

In order to account for heteroskedasticity and autocorrelation of the error terms, the White period method is used. The White-Robust variance assumes the existence of autocorrelation between the errors and heteroskedasticity. The countries are clustered so that the variance for a country is correlated over the years. This is to be expected in the panel dataset. The White period covariance estimator is robust for heteroskedasticity and autocorrelation within a country.

Eviews 7 does not allow for specific tests for heteroskedasticity, cross-section correlation or autocorrelation with panel data. The standard errors of the normal model, the model with White cross-section method and the model with White period method are compared. The comparison is

[17] See (Wooldridge, 2002) and (Arellano, 1987).

not the same as a test for heteroskedasticity or correlation. Systematic larger standard errors when using the White method indicate that ignoring the heteroskedasticity or correlation overstates the preciseness of the estimations. When the results deteriorate with the White method this indicates a problem with heteroskedasticity or correlation.

The explanatory variables should not be correlated perfectly. If this is the case the variables will contain the same information. Multicollinearity can be checked by using a covariance matrix. The matrix shows the correlation between each of the explanatory variables. The correlation should not be close to 1. Correlation equal to 1 indicates perfect correlation.

5. Empirical results

The described data and methodology are used to estimate the models (see Appendix 1). By estimating these models the relationship between the economic crisis and carbon dioxide can be evaluated. First a fixed effects model is estimated with the explanatory variables retrieved from the literature. This model is estimated with an intercept and the crisis dummy only to capture the entire crisis effect in the dummy-variable. To improve empirical evidence the fixed effects model with explanatory variables is expanded by including more crisis dummies for other economic crises that occurred between 1971 and 2009. Table 1 gives an overview of the different crisis dummies and their definitions. This model is estimated without explanatory variables as well, including an intercept and the crisis dummies only. Several adjustments are made to see if this improves estimations. Finally the first model is estimated for each country separately.

5.1 OLS estimation and testing of Model 1

Model 1.1 is estimated from the panel dataset. CO_2 emissions per capita for country *i* in year *t* are estimated by the deviation of the country's individual intercept β_{0i} from the overall intercept β and the different parameters times the variables for country *i* in year *t*, the effect of the crisis dummy in crisis years plus an error term. The results for this estimation can be found in Table 2.

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_9 + \varepsilon_{it} \quad (1.1)$$

$$\text{with } i = 1,2,\ldots,N \ (N = 55)$$

$$t = 1,2,\ldots,T \ \ (T = 39)$$

At a 5% significance level the coefficients of the oil price (*OP*) and the crisis dummy do not have a significant influence. The other coefficients are all significantly different from zero at a 5% significance level. The positive sign of energy use per capita (*EU*) and the percentage of fossil fuel energy use (*FF*) are intuitive to interpret. The higher the use of energy or the higher the percentage of polluting energy use, the higher the emission of CO_2. The negative parameter of GDP per capita (*GDP*) is less in compliance with the general theory. In general it is assumed that a higher GDP per capita leads to higher emissions per capita. However, the negative sign might be proof for the EKC, which assumes a decline in emissions after a certain turning point in GDP. This can be tested by including the squared variable of *GDP* in the model, GDP^2 (Model 1.2). The results are shown in Table 3, which do provide evidence for the existence of the EKC. The variable *GDP* has a positive significant coefficient and the variable GDP^2 a negative significant coefficient. This indicates that carbon dioxide emissions increase with income until reaching a turning point from which they will decline. This constitutes the so-called inverted u-shaped curve as suggested by the Environmental Kuznets Curve hypothesis.

Table 2: OLS estimations fixed effects model 1.1

Variable	Coefficient		P-value
C	-1.393159***		0.0000
EU	0.001161***		0.0000
FF	0.073085***		0.0000
GDP	-7.69E-05***		0.0000
OP	5.43E-05		0.9557
D_9	-0.131231		0.2378
***P-value<0.01; **P-value<0.05; *P-value<0.10			
Number of observations	2145		
R^2-within	0.39597		
F-test	**Value**	**df**	**Prob.**
Redundant variables	273.3630	(5,2085)	0.0000
Redundant fixed effects	153.234531	(54,2085)	0.0000

Table 3: OLS estimations fixed effects model 1.2

Variable	Coefficient		P-value
C	-2.642841***		0.0000
EU	0.000992***		0.0000
FF	0.072293***		0.0000
GDP	0.000223***		0.0000
GDP^2	-5.81E-09***		0.0000
OP	0.000418		0.6505
D_9	-0.197856*		0.0594
***P-value<0.01; **P-value<0.05; *P-value<0.10			
Number of observations	2145		
R^2-within	0.46278		
F-test	**Value**	**df**	**Prob.**
Redundant variables	299.2053	(6, 2084)	0.0000
Redundant fixed effects	176.9818	(54,2084)	0.0000

The positive coefficient of *OP* would mean higher CO_2 emissions per capita when the oil price increases, but since its p-value is very high this coefficient should be interpreted with caution. The crisis dummy has a negative coefficient, which would indicate a decline in emissions during crisis years. However, the dummy is not significant either, although the p-value is lower than for *OP*.

The R^2-within shows that almost 40% of the variation in *CO2* within a country over time, for all countries, is explained by the model. The F-statistic is the result of an F-test that compares the complete model with a model that has an intercept only and allows for fixed effects. The F-statistic and its p-value strongly reject the null hypothesis of no joint significance for the explanatory variables. The variables have jointly significant explanatory power.

The fixed effects (see Appendix 2) show the large differences for the countries, varying from a negative fixed effect of -4.66 for Morocco to a positive fixed effect equal to 12.98 for Luxembourg. This is the country-specific but not time-varying effect. It should be noted that the fixed effect for each country is the deviation of the overall intercept, -1.39, in Model 1.1. This does not necessarily mean that Morocco has the lowest CO_2 emissions per capita or Luxembourg the highest, although Luxembourg does have the highest emissions per capita in 2009 in the dataset. It expresses the country-specific unobserved characteristics for emissions. The variation suggests that the use of different intercepts for the countries is appropriate. With a redundant fixed effects test the joint significance of the fixed effects is tested. By performing an F-test the model with fixed effects is compared to the same model without fixed effects. The null hypothesis of no joint significant fixed effect is rejected at a significance level of 5% (see Table 2). The joint significance of the fixed effects can be assumed.

In order to check for the OLS-assumption of homogeneity of the variance, the residuals are plotted in Graph 3. In the graph a few outliers are clearly visible. The most divergent are the residuals of Iceland in 1979 and 2009, Luxembourg in 1974 and 1999, Saudi Arabia in 1980 and 1998 and Singapore in 1979, 1997 and 2008. These four countries in general have more heteroskedastic variances than the other countries. The variances of the other countries look relatively homoscedastic. A possible solution would be to exclude the four countries to keep OLS the best linear unbiased estimator (BLEU). Model 1.1 was estimated with the same dataset but excludes Iceland, Luxembourg, Saudi Arabia and Singapore. The results are shown in Table 4.This leads to a higher R^2-within, more of the variation within a country is explained. The crisis dummy is significant at a 10% significance level.

In order to see if heteroskedasticity, contemporaneous correlation or autocorrelation of the errors are a problem Model 1.1 with the complete dataset is estimated using White robust covariances. The White cross-section method is used to estimate standard errors that are robust to cross-sectional correlation and heteroskedasticity. The White period method is used to estimate standard errors that are robust to autocorrelation and heteroskedasticity. The standard errors of the normal model are compared with White cross-section standard errors and White period standard errors in Table 5.

Table 4: OLS estimations fixed effects model 1.1 excluding outliers

Variable	Coefficient	P-value
C	-3.153736***	0.0000
EU	0.002145***	0.0000
FF	0.061993***	0.0000
GDP	-6.26E-05***	0.0000
OP	0.000291	0.5922
D_9	-0.108453*	0.0789

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations	1989
R^2-within	0.65473

F-test	Value	df	Prob.
Redundant variables	733.1158	(5, 1933)	0.0000
Redundant fixed effects	166.9930	(50,1933)	0.0000

Graph 3: The residuals of model 1.1

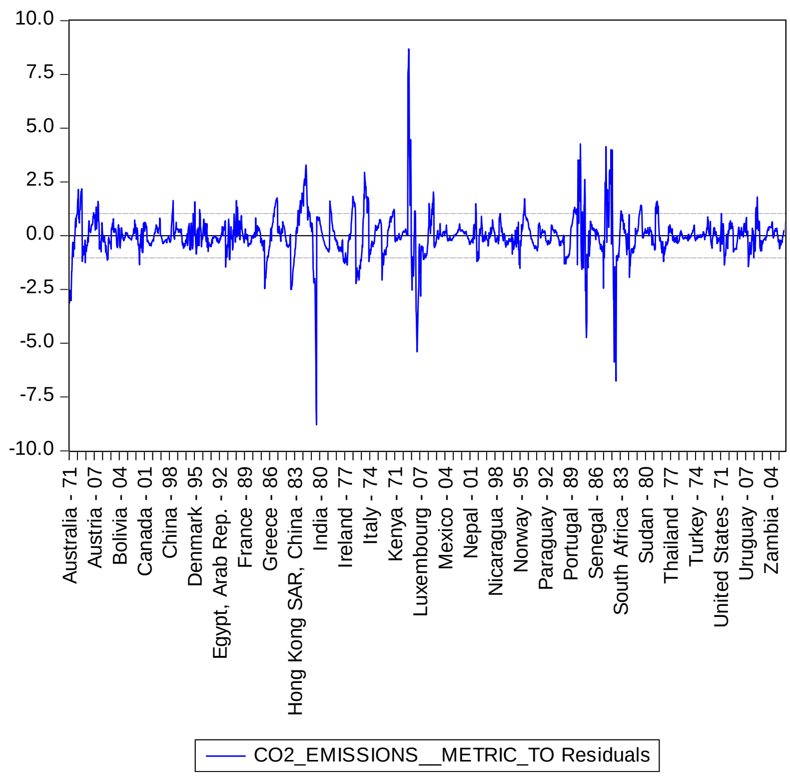


Table 5: comparison of Least Squares, White cross-section and White period standard errors for model 1.1

	Least Squares standard errors			White cross-section standard errors			White period standard errors		
Variable	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.
C	0.279781	-4.979467	0.0000	0.242254	-5.750825	0.0000	1.042157	-1.336804	0.1814
EU	3.75E-05	30.91796	0.0000	0.000149	7.808071	0.0000	0.000559	2.077053	0.0379
FF	0.003635	20.10651	0.0000	0.001738	42.06179	0.0000	0.012999	5.622339	0.0000
GDP	6.78E-06	-11.34347	0.0000	1.10E-05	-6.989427	0.0000	7.12E-05	-1.080539	0.2800
OP	0.000977	0.055601	0.9557	0.000930	0.058427	0.9534	0.001029	0.052797	0.9579
D_9	0.111122	-1.180963	0.2378	0.078661	-1.668323	0.0954	0.109361	-1.199987	0.2303

Some of the normal standard errors are smaller than the White cross-section standard errors, some are larger. If all normal standard errors would be smaller, this would indicate that the normal model overstates the precision of the estimation.

The White period standard errors are all larger than the normal standard errors, except for the crisis dummy standard error. This indicates the existence of autocorrelation between the errors because ignoring the autocorrelation leads to smaller standard errors. With autocorrelation the OLS estimator is no longer BLUE. It is still unbiased but it can lead to spurious regressions. That means that there is another variable influencing both CO_2 emission and the explanatory variables. In this dataset it is expected to find autocorrelation since the variables develop over the years and are not independent from each other over time. By including fixed effects for the cross-sections it is less likely for autocorrelation between the errors to occur, because the country-specific effect is included in the country dummy instead of in the error term. The estimation with the White period method indicates there is still autocorrelation left in the error terms.The test statistics following from the White period method should be interpreted with some caution. The coefficients are of reduced rank. This means there are less effective observations, because of the estimation method with the panel data that includes fewer periods than cross-sections. The White period method accounts for autocorrelation by clustering the countries. Estimation with the White period method leads to the non-significance of the intercept and GDP and reduced significance of EU. The intercept p-value is less straightforward to interpret since it constitutes the average intercept, of which the fixed effects are deviations.

Lastly, the OLS-assumption of no multicollinearity can be checked by using the covariance matrix (see Appendix 3). The parameters should not be perfectly correlated because this would mean one predictor can be predicted linearly by the other predictor. The low values of the covariances indicate that multicollinearity is not a problem for this model.

In order to see if the model can be improved the variable *FF*, the percentage of fossil fuel energy consumption of total energy use, is replaced by the percentage of alternative and nuclear energy consumption of total energy use (*AN*) (Model1.3). The percentage of non-emitting energy use has a negative effect (coefficient: -0,02945) on CO_2 emission and a smaller impact than *FF*. The results for this model are shown in Appendix 4.

The R^2-within for Model 1.3 is lower than for Model 1.1. Therefore it explains less of the variation in *CO2* in a country over time. The F-statistic for this model is significant as well but smaller than for the model with *FF* with the same degrees of freedom. The null hypothesis of no joint significance for the explanatory variables is rejected but less strongly.

The F-statistic for the redundant fixed effect test is also lower, which means less joint significance for the joint fixed effects in this model. The results for the residual plot and the estimation with cluster-robust standard errors are similar to the results with *FF*. Multicollinearity does not appear to be a problem from the covariance matrix (See Appendix 3).

In the preceding models the crisis dummy was not significant. There are a few possible explanations for this. The crisis could have no effect indeed on the emission of $CO_{2.}$ The literature research points out several reasons for a limited effect of the economic crisis on emissions. The high emissions of developing country that counteract reductions of emissions in developed countries are seen as the main reason. Another explanation would be that the effect of the crisis is in fact delayed and the dummy variable is not defined correctly. Changing the crisis dummy for the years 2007 and 2008 to the years 2008 and 2009 could lead to an improvement (Model1.4). Table 6 shows that this leads to an even less significant crisis dummy. The sign of the crisis dummy changes from negative to positive.

Table 6: OLS estimations fixed effects model 1.4

Variable	Coefficient	P-value
C	-1.318013***	0.0000
EU	0.001157***	0.0000
FF	0.072655***	0.0000
GDP	-7.90E-05***	0.0000
OP	-0.000487	0.6290
D_{10}	0.039637	0.7314

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations	2145		
R^2-within	0.39560		
F-test	**Value**	**df**	**Prob.**
Redundant variables	272.9405	(5, 2085)	0.0000
Redundant fixed effects	153.3427	(54,2085	0.0000

The following models (for Model 1.5 see Appendix 5) are compared with an F-test by testing the null-hypothesis of *OP* and the crisis dummy being equal to zero:

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_{10} + \varepsilon_{it} \quad (1.4)$$

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \varepsilon_{it} \quad (1.5)$$

The results of the F-test are shown in Table 7. The null-hypothesis cannot be rejected. This means that the variables *OP* and the crisis dummy '08-'09 do not have significant explanatory power together.

Table 7: Comparing models 1.4 and 1.5

	Statistic	d.f.	Prob.
F-test	0.129097	(2, 2085)	0.8789

All the coefficients of Model 1.5 are significant at a 1% significance level. However, when estimating Model 1.5 with the White period standard errors the significance of the coefficients decreases (see Appendix 5). This could indicate that the estimation with normal standard errors overstates the precision. Autocorrelation or heteroskedasticity appears to be a problem.

5.2 OLS estimation and testing of Model 2

The effect of the crisis could be captured by the other variables. Especially for GDP per capita and oil prices it is likely that they are affected by the economic crisis. Also energy use could be lower and therefore capture part of the crisis effect. In order to explore this, the fixed effects model is estimated without any explanatory variables and only an intercept and the crisis dummy. Any possible effect of the crisis will be captured entirely by the crisis dummy and not partly by the other variables. Put formally:

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 D + \varepsilon_{it} \quad (2)$$

The results for this model using the 2007-2008 dummy D_9 (Model 2.1) and the 2008-2009

Table 8: OLS estimations fixed effects model 2.1 and 2.2

Variable	Model 2.1	P-value	Model 2.2	P-value
C	5.512792***	0.0000	5.504250***	0.0000
Crisis dummy	0.159912	0.2168	0.326470**	0.0116
***P-value<0.01; **P-value<0.05; *P-value<0.10				
Number of observations	2145			
R^2-within	0.000729		0.003042	

dummy D_{10} (Model 2.2) are shown in Table 8.

The fixed effects model with intercept and the ’07-’08 crisis dummy does not lead to a significant crisis dummy. However, estimating the same model with the ’08-’09 dummy gives a significant crisis dummy at 5% significance level with a positive coefficient. During the crisis years there would be a rise in emissions. Since the model does not contain any other explanatory variables, the dummy will contain partly other effects and should be interpreted with caution. The R^2-within for both models is low, almost none of the variation in CO2 in a country is explained by the model. When estimating the models with the White period method it appears that the normal standard error is smaller than the robust standard error. This indicates autocorrelation. Ignoring this autocorrelation by estimating with normal standard errors overstates the preciseness of the estimation. When the model is estimated with the White period method the crisis dummy is no longer significant at a 5% significance level (see Appendix 6).

5.3 OLS estimation and testing of Model 3

In order to improve empirical evidence for the effect of economic crises on the emission of CO_2, crisis dummies for several other economic crises are included (see Table 1). The results should be interpreted with caution because not every crisis had the same impact. The dummies for each crisis take the value of 1 in the mentioned years for the country and 0 in the other years of the included periods. The fixed effects model that is estimated is the following:

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_1 + \beta_6 D_2 + \beta_7 D_3 + \beta_8 D_4 + \beta_9 D_5 + \beta_{10} D_6 + \beta_{11} D_7 + \beta_{12} D_8 + \beta_{13} D_9 + \varepsilon_{it} \quad (3.1)$$

The results for the estimation with OLS are shown in Table 9. The crisis dummies should capture the deviations which are cross-section and period specific, the crisis years in one country. The t-statistics and p-values for the various coefficients are not confirming the crisis effect. Again *EU*, *FF* and *GDP* are significant and of the same sign and magnitude as in the model with one crisis dummy. Out of 9 crisis dummies included, 4 dummies have a negative coefficient. This does not clarify the crisis effect. *OP* is not significantly different from zero, just like all crisis dummies at a 5% significance level, except for the Japanese crisis. This result is somewhat enlightening. The Japanese crisis lasted longer than all the other crises used in the model. The reason for not finding a significant crisis dummy might be because the effect of a one- or two-year lasting crisis is hard to detect in the long and broad panel dataset. This presumption is supported by the p-value of the Asian crisis dummy. This crisis includes more than one country, namely 7 countries. Although not significant at a 5% significance level, with a p-value of 6% it is the second-most significant coefficient after the Japanese crisis dummy. Both these crisis dummies have a relatively large coefficient, which would mean higher carbon dioxide emissions of 0.91 and 0.74 metric tons per capita during the Japanese and the Asian crisis respectively. With an average of 5.5 metric tons CO_2 emissions per capita in 2009 in the dataset this is a large increase. The oil crises were global crises, just like the recent global financial crisis. Their high p-values reject the presumption that the problem with the crisis dummies would be the few countries involved, since the oil crises include all countries. From these results it appears that crises that last two years or less may simply not have a significant effect on CO_2 emissions. This has also been pointed out as an explanation by other authors[18].

The R^2-within is almost equal to the R^2-within of Model 1.1. The crisis dummies do not explain more of the variation in CO2 within a country. The F-test compares the model with a fixed effects model with an intercept only. It strongly rejects the null hypothesis of no joint significant effect for all variables and crisis dummies.

[18] See (Gierdraitis, Girdenas, & Rovas, 2010) and (Enkvist, Dinkel, & Lin, 2010)

The fixed effects for each country (see Appendix 2) show different results than for Model 1.1. Especially interesting is to check the differences for the countries whose crises were included. The largest difference between the fixed effects of both models is for Japan. Its fixed effect increased by 0.40. The joint significance of the fixed effect is tested with an F-test. The fixed effects have joint significance, which was to be expected from the large differences among the fixed effects for each country.

Table 9: OLS estimations fixed effects model 3.1

Variable	Coefficient	P-value
C	-1.358864***	0.0000
EU	0.001161***	0.0000
FF	0.072850***	0.0000
GDP	-7.77E-05***	0.0000
OP	-0.000766	0.5186
D_1	0.096004	0.3539
D_2	0.312376	0.6154
D_3	0.219823*	0.0727
D_4	-1.372016	0.1875
D_5	0.893331***	0.0079
D_6	-0.419566	0.4968
D_7	-0.575304	0.3524
D_8	0.733098*	0.0638
D_9	-0.070346	0.5396

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations 2145

R^2-within	0.40147

F-test	Value	Df	Prob.
Redundant variables	107.1650	(13, 2077)	0.0000
Redundant fixed effects	152.860861	(54,2077)	0.0000

The graph of the residuals (see Appendix 7) shows the same outliers as in the previous model. Again the residuals of Iceland, Luxembourg, Saudi Arabia and Singapore stand out. The Least squared standard errors are compared with the White robust standard errors in Appendix 7. When estimating the same model using the White cross-section method, almost all standard errors of the normal model are higher. This does not indicate overstated precision when not taking account for cross-sectional correlation. When estimating the same model but taking account for possible autocorrelation, the cluster-robust standard errors are not systematically larger than the normal standard errors. Autocorrelation is not expected to be a problem in a fixed effects model because the fixed effects already account for the individual heterogeneity. In this model the country-specific effects that correlate over time do not appear to be left in the error terms, but estimating with the White method is not the same as a test for correlation. Interestingly, without including all the crisis dummies autocorrelation was presumed to be present. It is possible that the crisis dummies captured these effects.

Correlation between the error terms does not seem to be a problem, but the White estimation methods are also robust to heteroskedasticity in the error terms. The observed heteroskedasticity in the residuals, although not dominantly present, might be a reason to work with cluster-robust standard errors.

The covariance matrix shows small figures. Therefore multicollinearity is not expected to be a problem (see Appendix 3).

When the variable *FF* is replaced by the variable *AN*, this coefficient is again found to be significant and negative (see Appendix 8). The F-statistic of the model (Model 3.2) with *AN* is smaller, while computed with the same degrees of freedom. This means that the null hypothesis of no joint significance for all variables included is rejected but less strongly. This gives incentives to use the percentage of fossil fuel energy use instead of the percentage of alternative and nuclear energy use.

For comparing the redundant fixed effects tests for both models, the same outcomes are found as for Model 1.1 and Model 1.3. The null hypothesis of joint significance for all fixed effects is rejected less strongly for the model with *AN*. Because of these results the model with *AN* will not be considered any further.

5.4 OLS estimation and testing of Model 4

The effect of the different crises could again be captured by the other explanatory variables. Therefore a fixed effects model will be estimated including only the 9 crisis dummy variables and an intercept. The model is the following:

$$CO2_{it} = \beta + \beta_{0i} + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \beta_8 D_8 + \beta_9 D_9 + \varepsilon_{it} \quad (4)$$

The results for the OLS estimations are shown in Table 10. The estimation of this model leads to hardly any significant results. Even the crisis dummy for Japan is no longer significant. Only the Asian crisis dummy has a p-value below the 5% significance level. Its coefficient is large and positive. The UK banking crisis has a significant crisis dummy at a 10% significance level. This dummy is positive as well. It does not appear that including more crisis dummies leads to the detection of an economic crisis effect on carbon dioxide emission.

Table 10: OLS estimations fixed effects model 4

Variable	Coefficient	P-value
C	5.498840***	0.0000
D_1	-0.044905	0.7305
D_2	1.409977*	0.0771
D_3	0.175801	0.1751
D_4	-1.786685	0.1813
D_5	0.368525	0.3861
D_6	-0.670821	0.3975
D_7	-1.156725	0.1446
D_8	1.485713***	0.0034
D_9	0.173864	0.1799

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations 2145

R^2-within	0.00992

F-test	Value	df	Prob.
Redundant variables	2.316518	(9, 2081)	0.0137
Redundant fixed effects	712.282851	(54,2081)	0.0000

The R^2-within for this model is very low. The F-statistic is still significant at a 5% significance level when comparing this model to the intercept only fixed effect model. However, the p-value is a few percent higher than for all the models estimated previously. The redundancy of the fixed effects is tested with an F-test. The null-hypothesis of no joint significance for the fixed effects is rejected at a 5% significance level.

When estimating with cluster-robust estimators there is no reason to presume correlation between the error terms (see Appendix 9). The standard errors are smaller when estimating with the White cross-section method so that the normal estimation probably does not overstate precision by ignoring any cross-sectional correlation. Nor do the standard errors estimated with the White period method imply the existence of autocorrelation in this model. When plotting the residuals, the same outliers are found as before (see Appendix 9). Multicollinearity is not a problem in this model (see Appendix 3).

Summarizing we found that for the OLS estimations the fixed effects were appropriate to include. Every country has individual characteristics which should be taken account for. The heteroskedasticity of the errors could be a problem. For the estimation of Model 1 and its adjustments autocorrelation of the errors was also a possible problem. This means that the fixed effects do not capture all effects within a country that are correlated over time. Both heteroskedasticity and autocorrelation of the errors can be corrected by using the White period method. For Model 3 and its adjustments autocorrelation was not a problem. Cross-sectional correlation was not a problem in any of the models.

The replacement of the percentage of fossil fuel energy use by the percentage of alternative and nuclear energy use did not lead to an improvement of the models. In both Model 1 and 3 the variables *EU*, *FF* and *GDP* had significant coefficients. For both models the same model was estimated without including the explanatory variables. For the model with one crisis dummy this was only successful when defining the global financial crisis for 2008 and 2009. When taking account for autocorrelation the crisis dummy lost its significance. Estimating the model with all crisis dummies with fixed effects was not successful. Only one crisis dummy had a significant coefficient at a 5% significance level.

The effect of economic crisis on the emission of carbon dioxide was examined by these econometric tests. The results did not show significant changes in the emission of CO_2 during crisis years. One possible explanation is that the several changes due to economic crisis together do not change emissions significantly. Less energy use might decrease emissions while lower GDP leads to higher emissions, according to the signs of the estimated models. The literature points out other explanations, such as the fast recovery of the global economy thanks to emerging economies.

5.5 Adjustments of Model 1 based on the empirical results

The problem may also be the econometric methods used in this study. They do not take account for possible unit roots in the panel data. In similar studies there is often tested for unit roots and cointegration. The existence of unit roots in the data would mean that it is not appropriate to estimate a fixed effects model as was estimated in this paper. If the variables follow a random walk it is not correct to use OLS estimators. Testing for unit roots and cointegration is out of the scope of this study and left for future research. To see if the presumption changes the results Model 1.1 is estimated with the natural logarithms of *CO2, EU* and *GDP* (Model 1.6). The results are shown in Table 11. By taking the natural logarithms of the explanatory variables the problem of possible unit roots in the data is avoided. The higher R^2- within indicates that more of the variance within countries is explained by the model. If unit roots are indeed present, the significance of the results is improved.

Table 11: OLS estimations fixed effects model 1.6

Variable	Coefficient	P-value
C	-6.029746***	0.0000
LN_EU	0.564476***	0.0000
FF	0.180184***	0.0000
LN_GDP	0.021495***	0.0000
OP	-9.38E-06	0.9486
D_9	-0.035476**	0.0335

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations	2145
R^2-within	0.726237

F-test	Value	df	Prob.
Redundant variables	1106.076	(5, 2085)	0.0000
Redundant fixed effects	85.679342	(54,2085)	0.0000

When testing with CO_2 emissions it should not be forgotten that it is regarded a long term process. Changes might not be directly measurable. Also the effect of postponement or forego of investments in renewable energy will only be notable after a longer period of time.

The estimations with panel data should lead to more precise estimations. However, if the behavior of the different countries differs a lot it might not be appropriate to use the same parameters for every country. Therefore the following model was estimated for each country separately:

$$CO2_t = \beta_0 + \beta_1 EU_t + \beta_2 FF_t + \beta_3 GDP_t + \beta_4 OP_t + \beta_5 D_{10} + \varepsilon_t \quad (1.4.1)$$

The results for this model can be found in Appendix 10. The large differences between the intercepts were to be expected since the use of fixed effects already turned out to be appropriate. The coefficients for *EU* do not differ much, although there are five countries with negative coefficients. The coefficients vary from -0.001757 (Kenya) till 0.005512 (China). Out of the smallest 10 coefficients 9 turn out not be significantly different from zero. For the other 45 countries the coefficients are all positive and significant. Therefore we can conclude that energy use has a modest but positive relationship with carbon dioxide.

In the coefficients of *FF* more variation is observed. There are 10 countries with a negative coefficient, but again these coefficients are less significant. The largest coefficient of 1.637477 (Singapore) seems to be an outlier and is not significant at a 5% significance level. From the residual plot for the estimation of Model 1.1 Singapore also appeared to be one of the outliers. For the other 44 countries the parameters are all positive and almost all are significant. From these results we can conclude that a higher percentage of fossil fuel energy use increases the emission of CO_2 for most countries.

The last parameter that was found significant in the estimation of the model for the entire dataset is GDP per capita. The results per country show wide variety. There are 32 out of 55 countries that have a negative coefficient for GDP per capita. In these countries an increase in GDP per capita would lower the emission of CO_2. When the countries are ordered by their level of 2009 GDP per capita no evidence is found for the EKC. This would be the case if the poorer countries have a positive coefficient for *GDP* and the richer countries a negative coefficient. The four countries with the lowest GDP per capita do have positive coefficients but this is followed by alternating positive and negative coefficients for all the other countries. For the estimations per country 30 countries do not have a significant coefficient for GDP at a 5% significance level. The interpretation of this variable is less straightforward and estimating one parameter for all countries together seems less appropriate.

The variable *OP* was not significant in the fixed effects panel data model. For the country-specific estimations 34 countries were found not to have a coefficient significantly different from zero for *OP*. There are 27 countries with a negative coefficient for *OP*. Not only was the variable not significant in the model for the entire data, from the country-specific estimations it appears not to be appropriate to estimate one parameter for all countries.

The crisis dummy is the other variable that was not significantly different from zero in fixed effects Model 1.4. From the 55 countries 24 countries have a negative coefficient for the dummy.

The other 31 countries thus experience higher CO_2 emissions during crisis years. However, it might not be right to interpret the crisis dummy because only one country (Hong Kong, China) has a significant coefficient. The differences in the coefficients indicate that estimating the same parameters for all countries is not appropriate.

The estimations per country show again the large regional differences. It might not be possible to capture this with fixed effects only. Estimating different models per country or region might be necessary. The relationships between the explanatory variables and carbon dioxide emission differ largely per country. Only *EU* and *FF* have a similar coefficient for most countries.

Detecting the effect of the GFC on carbon dioxide emissions with the models that were used did not turn out to be feasible. From the econometric tests the main problems appear to be the large regional differences, autocorrelation and the uncertainty about when and how the crisis actually affects emissions. This is supported by the literature. The GFC appears to have little impact on CO_2 emissions because of the fast recovery of energy prices, government support to recover from the crisis and emerging economies that have increasing emissions. For the developed countries, that were affected more by the GFC than the developing countries, the effects might only appear years later, when they will be hard to distillate from other changes. The data used for this study, which runs until 2009, does not enable us to detect later effects.

6. Conclusion

The aim of this study is to find the effect of the global financial crisis on the emission of carbon dioxide. At first sight it appears that economic crisis lowers CO_2 emissions because less economic activity results in less energy use. In this study the relationship between economic crisis and CO_2 emission was found not to be this straightforward. The length, type and context of the economic crisis are important for the determination of the effect. There are a few reasons why the global financial crisis had a small impact on carbon dioxide emissions.

Carbon dioxide emissions constitute the largest part of greenhouse gases, the cause of global warming. The greenhouse effect is an international problem. Global cooperation is required to reduce emissions and prevent the global temperature from increasing by more than 2 degrees Celsius. This is the target set by the Kyoto protocol. The existing environmental international agreements and organizations have not proven to be effective for reducing global emissions during and after the global financial crisis. The Kyoto protocol only binds developed countries, which are decreasing their emissions. The emerging economies that are not bound by the Kyoto protocol have rapidly growing carbon dioxide emissions.

The global financial crisis led to a reduction in environmental investments by governments and companies to reduce CO_2 emissions. Important policy instruments such as carbon dioxide emission trading schemes are not effective. This is due to discrepancies between the design and the practice of such markets but is not necessarily related to the GFC.

The most important economic determinant of carbon dioxide emissions is GDP. However, the magnitude and the sign of the relationship between GDP and emissions differ widely per country. This was the reason to examine the evidence for the EKC hypothesis. This hypothesis states that carbon dioxide emissions increase initially when income rises but decline after a turning point in income, the inverted u-shaped curve. The estimations for the fixed effects model show evidence for an inverted u-shaped relationship between GDP per capita and CO_2 emissions per capita. This is contradicted by the country-specific estimations for the model. Countries with higher GDP per capita did not have systematically negative relationships between GDP per capita and CO_2 emissions. The literature also finds contradictory results for the EKC. The results depend heavily on the econometric methods used. There is no consensus on the direction of the causal relationship between GDP and carbon dioxide emissions. The evidence that was found for the EKC has been explained by some authors[19] by the displacement effect. Economic growth would not be sustainable with higher pollution levels. Developed countries tend to displace their polluting industries to developing countries, from which they import the pollution-intensive products.

Energy use and the percentage of fossil fuel energy use have a relatively consistent positive effect over the world on carbon dioxide emissions. The relationship between GDP per capita and carbon dioxide emissions per capita shows that large regional differences exist. This is shown by the significance of the country-specific fixed effects in the estimated models from the panel data. It is confirmed by the large differences in the parameters for the country-specific models. Although there is no consistent pattern related to the level of income for the sign of the relationship income-emissions, the division between developing and developed countries appears to be important. Generally it is observed that developed countries are decreasing their CO_2 emissions thanks to investments and policies and because of the global financial crisis, by which the developed countries were affected most. The developing countries have increasing CO_2 emissions because of the use of the polluting energy source coal, increasing economic activity and growing populations. This is worrisome because the developing countries account for 80% of the world population. If they arrive at the same levels of CO_2 emissions per capita as the developed countries, the target of 2 degrees Celsius will not be met.

These regional differences are the main explanation why the global financial crisis did not have a significant effect on carbon dioxide emissions, as shown by the econometric models estimated. The literature research also points out the modest impact of the GFC on emissions. In 2009 there was a decrease of 1.4% in global CO_2 emissions, followed by an increase of 5.9% in 2010. The emerging economies that helped the global economy back on track also increased global carbon dioxide emissions.

Important for the determination of the effect of an economic crisis on carbon dioxide emissions are its length, the sectors it affects and the context it occurs in. The economic crises in the 1870s and the 1930s had a small impact on carbon dioxide emissions. The crises were too short to have a more significant effect. This is confirmed by the insignificance of other short crises in the

[19] See (Stern, 2004) and (Jaunky, 2010).

empirical results. The oil crises in the 1970s had a significant effect on emissions according to the literature. There was a permanent shift from oil to natural gases because of the high oil prices. The empirical results in this study did not find this effect significant. The environmental benefits of the Asian financial crisis were not expected to exceed the environmental costs, short after its occurring[20]. The decline in emissions from less economic activity was expected to be offset by the deferment and postponement of environmental investments. This crisis affected industrial intensive sectors heavily. A later evaluation of this crisis did observe a drop in emissions[21]. From the empirical results in this study the carbon dioxide emissions during the Asian financial crisis appeared to have increased rather than decreased. The Japanese crisis had a positive and the most significant effect on CO_2 emissions. This crisis lasted longer than the other crises included. Therefore we can conclude that an economic crises needs to last more than 2 years in order to have a significant observable effect on CO_2 emissions.

The global financial crisis was preceded by many years of economic growth. This growth partly stemmed from emerging economies, which led to a faster recovery of the global economy and therefore to the continuation of growing CO_2 emissions. The energy prices returned back to their normal levels so that there was no permanent shift of energy sources, as case with the oil crises. The empirical results do not show a significant effect of the oil price on emissions. The emerging economies, the fast recovery of the energy prices combined with wide government support to limit the GFC led to the small impact of the global financial crisis on carbon dioxide emissions.

Concluding, the empirical results of this study find that the global financial crisis had no significant impact on the emission of carbon dioxide. This is in accordance with the literature on this topic. The main reasons for this are the short length of the crisis and the developing countries that continue to have increasing carbon dioxide emissions. The global financial crisis has even been called a missed opportunity for the reduction of carbon dioxide emissions[22].

The empirical results in this study can also be affected by problems with the used econometric methods. For the estimations of the first model autocorrelation of the error terms was observed, which can lead to spurious regressions. For all estimated models there was some

[20] (Siddiqi, 2000)
[21] (Peters, Marland, Le Quéré, Boden, Canadell, & Raupach, 2011)
[22] Ibid.

heteroskedasticity of the residuals present. The variables might follow a random walk, which would make OLS estimation inappropriate. If this is true, the significance of the estimations would improve when taking account for the unit roots. Testing for unit roots and cointegration is recommended for further examination of the impact of the GFC on carbon dioxide emissions. Research that limits itself to one or a few countries is more appropriate than a global examination. Because of the regional differences it is hard to draw conclusions that hold globally. These problems have also been pointed out by the literature on this topic.

Based on the results a few policy recommendations for carbon dioxide emissions reduction can be made. Measures to reduce carbon dioxide emissions should be country-specific and consider the characteristics of CO_2 emissions in the country. Therefore detailed international agreements are less appropriate. However, international cooperation in this field is essential. As was made obvious by the GFC, the reductions in emissions made by developed countries are counteracted by increasing emissions from emerging economies. It is important to come to international agreements that include developing countries as well. If not, the effort made by the developed countries is meaningless. The developed countries should help the developing countries in terms of innovations in more energy-efficient and renewable energy technologies. If the developed countries simply displace their polluting industries to developing countries, their efforts to reduce emissions in their own countries are lost. The international agreements should give incentives to decrease global CO_2 emissions rather than to decrease national CO_2 emissions regardless the consequences for other countries. The latter leads to the displacement of pollution, which does not improve environmental quality.

Governments and policymakers should not lean back when economic crises reduce emissions during one or two years. The effects of economic crises on carbon dioxide on the long term have shown to be limited. Emissions tend to increase after crisis years are over. Innovations in energy-efficient and renewable energy technology require on-going investments.

7. References

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8. Appendices

Appendix 1: List of models

Model	Specification
1.1	$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_9 + \varepsilon_{it}$
1.2	$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 {GDP_{it}}^2 + \beta_5 OP_{it} + \beta_6 D_9 + \varepsilon_{it}$
1.3	$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 AN_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_9 + \varepsilon_{it}$
1.4	$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_{10} + \varepsilon_{it}$
1.4.1	$CO2_t = \beta_0 + \beta_1 EU_t + \beta_2 FF_t + \beta_3 GDP_t + \beta_4 OP_t + \beta_5 D_{10} + \varepsilon_t$
1.5	$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \varepsilon_{it}$
1.6	$LN\_CO2_{it} = \beta + \beta_{0i} + \beta_1 LN\_EU_{it} + \beta_2 FF_{it} + \beta_3 LN\_GDP_{it} + \beta_4 OP_{it} + \beta_5 D_9 + \varepsilon_{it}$
2.1	$CO2_{it} = \beta + \beta_{0i} + \beta_1 D_9 + \varepsilon_{it}$
2.2	$CO2_{it} = \beta + \beta_{0i} + \beta_1 D_{10} + \varepsilon_{it}$
3.1	$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 FF_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_1 + \beta_6 D_2 + \beta_7 D_3 + \beta_8 D_4 + \beta_9 D_5 + \beta_{10} D_6 + \beta_{11} D_7 + \beta_{12} D_8 + \beta_{13} D_9 + \varepsilon_{it}$
3.2	$CO2_{it} = \beta + \beta_{0i} + \beta_1 EU_{it} + \beta_2 AN_{it} + \beta_3 GDP_{it} + \beta_4 OP_{it} + \beta_5 D_1 + \beta_6 D_2 + \beta_7 D_3 + \beta_8 D_4 + \beta_9 D_5 + \beta_{10} D_6 + \beta_{11} D_7 + \beta_{12} D_8 + \beta_{13} D_9 + \varepsilon_{it}$
4	$CO2_{it} = \beta + \beta_{0i} + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \beta_8 D_8 + \beta_9 D_9 + \varepsilon_{it}$

Appendix 2: Fixed effects for models 1.1 and 3.1

	Country	Model 1.1	Model 3.1
1	Australia	6.039231	6.060509
2	Austria	0.934895	0.953833
3	Belgium	2.535321	2.554499
4	Bolivia	-3.313458	-3.311007
5	Brazil	-1.777530	-1.777758
6	Canada	4.868888	4.888199
7	Chile	-2.177790	-2.172992
8	China	-2.509312	-2.525378
9	Colombia	-2.777698	-2.774744
10	Denmark	2.900150	2.925938
11	Ecuador	-3.174351	-3.170410
12	Egypt, Arab Rep.	-4.390937	-4.383704
13	Finland	2.731327	2.777861
14	France	0.907809	0.922496
15	Ghana	-0.314410	-0.324513
16	Greece	-0.327350	-0.312287
17	Guatemala	-0.942037	-0.948182
18	Hong Kong SAR, China	-1.372322	-1.368173
19	Iceland	-1.560995	-1.546891
20	India	-2.131780	-2.134215
21	Indonesia	-2.016104	-2.037618
22	Ireland	1.871966	1.890263
23	Israel	0.236930	0.292369
24	Italy	0.003876	0.022782
25	Japan	2.334090	1.932124
26	Kenya	-0.097694	-0.108651
27	Luxembourg	12.98440	13.01749
28	Malaysia	-2.501236	-2.512567
29	Mexico	-2.550386	-2.541088
30	Morocco	-4.660078	-4.652683
31	Nepal	0.657661	0.643824
32	Netherlands	1.642457	1.665427
33	Nicaragua	-1.317998	-1.323240
34	Nigeria	0.037685	0.026528
35	Norway	2.006720	2.027628
36	Pakistan	-2.089228	-2.092511
37	Paraguay	-0.497065	-0.505749
38	Peru	-2.607972	-2.606389
39	Portugal	-1.715277	-1.704425
40	Saudi Arabia	4.618342	4.635430
41	Senegal	-1.708661	-1.713125
42	Singapore	3.291732	3.294285
43	South Africa	1.149354	1.157418
44	Spain	-0.570451	-0.556790
45	Sudan	-0.116022	-0.127086
46	Sweden	0.845176	0.904056
47	Thailand	-2.067416	-2.085369
48	Tunisia	-3.678136	-3.672147
49	Turkey	-2.675546	-2.669417
50	United Kingdom	1.980182	1.978532
51	United States	8.023944	8.052615
52	Uruguay	-2.264151	-2.259478
53	Venezuela, RB	-1.502848	-1.492234
54	Zambia	-0.192888	-0.204015
55	Zimbabwe	-1.003010	-1.009270

Appendix 3: Covariance matrices

Model 1.1

	C	EU	FF	GDP	OP	D_1
C	0.078277	-2.50E-06	-0.000952	-6.23E-07	-3.72E-05	0.005230
EU	-2.50E-06	1.41E-09	2.17E-09	-9.96E-11	8.76E-10	-3.07E-07
FF	-0.000952	2.17E-09	1.32E-05	6.18E-09	-1.15E-07	-2.98E-05
GDP	-6.23E-07	-9.96E-11	6.18E-09	4.60E-11	4.86E-11	-1.45E-07
OP	-3.72E-05	8.76E-10	-1.15E-07	4.86E-11	9.54E-07	-3.74E-05
D_1	0.005230	-3.07E-07	-2.98E-05	-1.45E-07	-3.74E-05	0.012348

Model 1.3

	C	EU	AN	GDP	OP	D_1
C	0.011368	-2.63E-06	-5.59E-05	-1.93E-07	-5.37E-05	0.003646
EU	-2.63E-06	1.65E-09	-1.79E-08	-1.12E-10	6.47E-10	-3.20E-07
AN	-5.59E-05	-1.79E-08	1.23E-05	-2.68E-09	2.64E-07	-1.95E-05
GDP	-1.93E-07	-1.12E-10	-2.68E-09	5.04E-11	6.03E-11	-1.47E-07
OP	-5.37E-05	6.47E-10	2.64E-07	6.03E-11	1.11E-06	-4.40E-05
D_1	0.003646	-3.20E-07	-1.95E-05	-1.47E-07	-4.40E-05	0.014212

Model 3.1

	C	EU	FF	GDP	OP
C	0.079647	-2.57E-06	-0.000959	-6.41E-07	-4.86E-05
EU	-2.57E-06	1.41E-09	2.59E-09	-9.73E-11	7.95E-10
FF	-0.000959	2.59E-09	1.33E-05	6.24E-09	-1.24E-07
GDP	-6.41E-07	-9.73E-11	6.24E-09	4.82E-11	-4.11E-10
OP	-4.86E-05	7.95E-10	-1.24E-07	-4.11E-10	1.41E-06
D_1	-0.003068	2.35E-07	8.95E-06	9.65E-08	9.48E-06
D_2	0.002720	-9.25E-07	-3.88E-05	2.16E-07	-5.02E-06
D_3	0.001487	4.58E-08	4.95E-06	9.15E-08	-8.10E-05
D_4	-0.000636	6.23E-07	-6.20E-06	5.50E-08	-3.63E-05
D_5	-0.002581	8.17E-08	4.19E-05	-2.94E-07	3.16E-05
D_6	-0.006310	-5.57E-08	6.45E-05	7.70E-08	1.67E-05
D_7	-0.012062	-2.08E-07	0.000149	1.23E-07	1.59E-05
D_8	0.006095	-4.60E-07	-8.13E-05	-8.78E-08	1.91E-05
D_9	0.005670	-3.01E-07	-2.88E-05	-1.29E-07	-5.65E-05

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9
C	-0.003068	0.002720	0.001487	-0.000636	-0.002581	-0.006310	-0.012062	0.006095	0.00567
EU	2.35E-07	-9.25E-07	4.58E-08	6.23E-07	8.17E-08	-5.57E-08	-2.08E-07	-4.60E-07	-3.01E-07
FF	8.95E-06	-3.88E-05	4.95E-06	-6.20E-06	4.19E-05	6.45E-05	0.000149	-8.13E-05	-2.88E-05
GDP	9.65E-08	2.16E-07	9.15E-08	5.50E-08	-2.94E-07	7.70E-08	1.23E-07	-8.78E-08	-1.29E-07
OP	9.48E-06	-5.02E-06	-8.10E-05	-3.63E-05	3.16E-05	1.67E-05	1.59E-05	1.91E-05	-5.65E-05
D_1	0.010718	-0.006518	0.000276	0.000727	0.000448	0.000918	0.000931	0.000296	-0.000283
D_2	-0.006518	0.386433	0.000772	-0.000184	-0.002205	-0.000358	-0.000520	-0.000166	2.23E-05
D_3	0.000276	0.000772	0.014987	0.002914	-0.001363	-0.000258	-0.000246	-0.000754	0.003546
D_4	0.000727	-0.000184	0.002914	1.082718	-0.001393	-0.000303	-0.000431	-0.000751	0.001596
D_5	0.000448	-0.002205	-0.001363	-0.001393	0.112701	0.000412	0.000714	-0.007727	0.000827
D_6	0.000918	-0.000358	-0.000258	-0.000303	0.000412	0.381098	0.001103	-0.000148	-0.000371
D_7	0.000931	-0.000520	-0.000246	-0.000431	0.000714	0.001103	0.382478	-0.000600	-0.000499
D_8	0.000296	-0.000166	-0.000754	-0.000751	-0.007727	-0.000148	-0.000600	0.156239	0.000330
D_9	-0.000283	2.23E-05	0.003546	0.001596	0.000827	-0.000371	-0.000499	0.000330	0.013149

Appendix 4: Model 1.3

OLS estimations with fixed effects

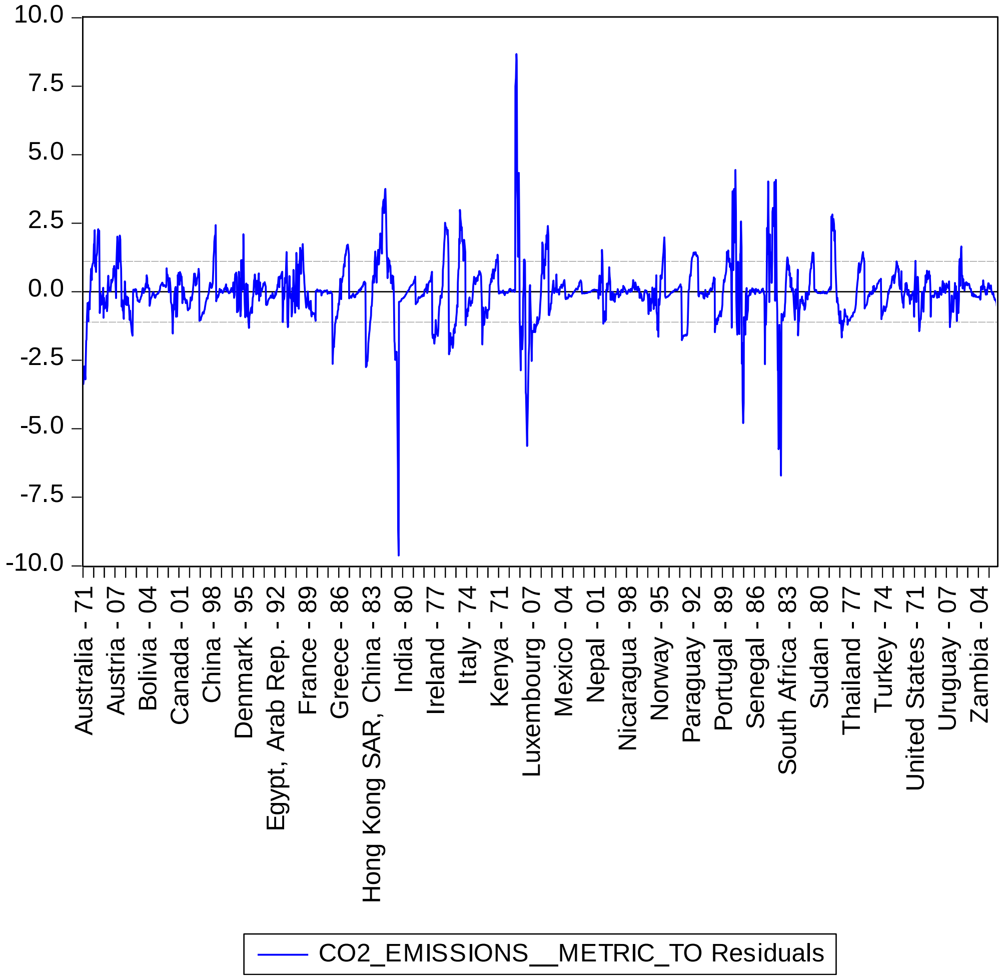
Variable	Coefficient	P-value
C	4.009441***	0.0000
EU	0.001192***	0.0000
AN	-0.029450***	0.0000
GDP	-0.000105***	0.0000
OP	5.25E-05	0.9602
D_9	0.080425	0.5000

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations	2145
R^2-within	0.30253

F-test	Value	df	Prob.
Redundant variables	180.8758	(5, 2085)	0.0000
Redundant fixed effects	119.791238	(54,2085)	0.0000

Residual graph



Appendix 5: Model 1.5

OLS estimations with fixed effects

Variable	Coefficient	P-value
C	-1.346285***	0.0000
EU	0.001158***	0.0000
FF	0.072685***	0.0000
GDP	-7.86E-05***	0.0000

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations	2145		
R^2-within	0.39553		
F-test	**Value**	**df**	**Prob.**
Redundant variables	455.1947	(3, 2087)	0.0000
Redundant fixed effects	154.222143	(54,2087)	0.0000

Comparison of Least Squares and White period standard errors

	Least Squares standard errors			White period standard errors		
Var.	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.
C	0.27478	-4.89946	0.000	1.05201	-1.27973	0.201
EU	3.74E-05	30.91765	0.000	0.00056	2.06878	0.039
FF	0.00362	20.09146	0.000	0.01291	5.62897	0.000
GDP	6.64E-06	-11.83872	0.000	7.06E-05	-1.11399	0.265

Appendix 6: Comparison of Least Squares and White period standard errors for Model 2.1 and 2.2

Model 2.1

	Least Squares standard errors			White period standard errors		
Var.	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.
C	0.02931	188.0633	0.000	0.011806	466.9378	0.000
D_9	0.12945	1.23536	0.217	0.230222	0.694597	0.487

Model 2.2

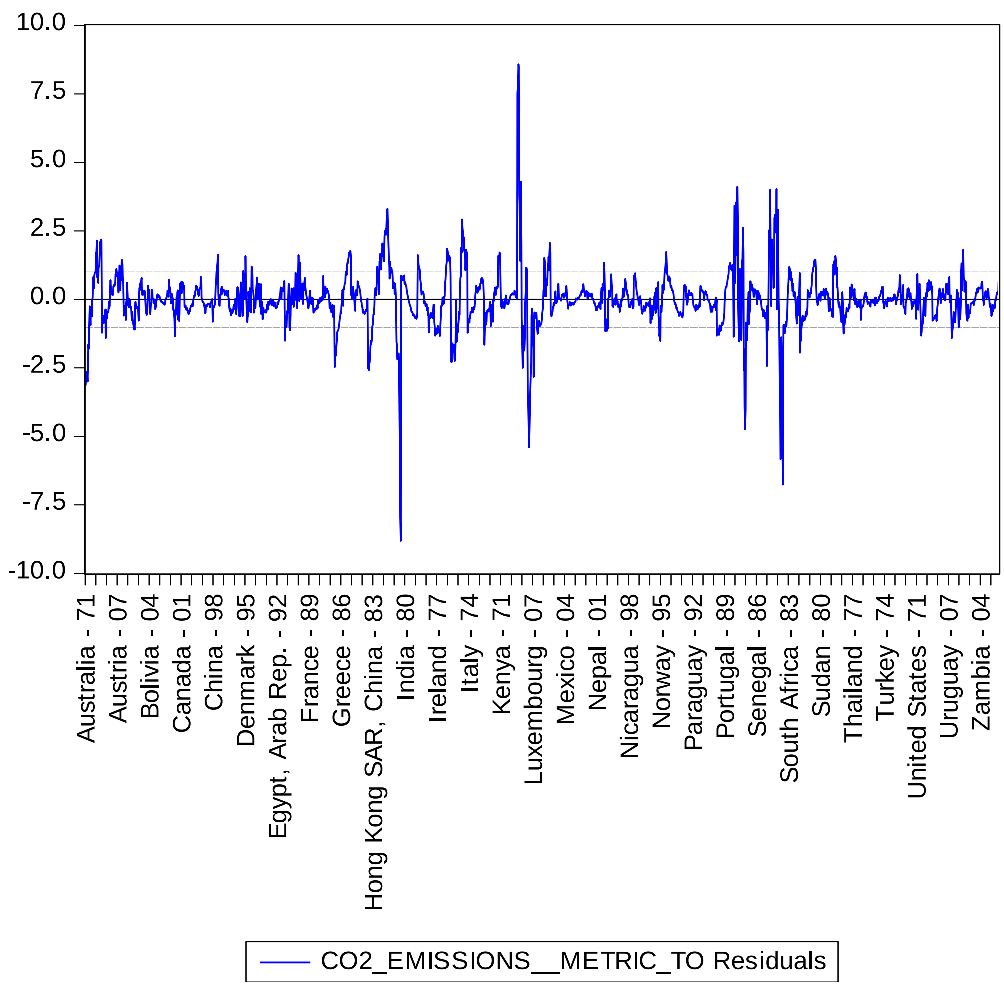
	Least Squares standard errors			White period standard errors		
Var.	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.
C	0.02928	187.9896	0.000	0.01061	518.996	0.000
D_{10}	0.12930	2.52500	0.012	0.20681	1.57861	0.115

Appendix 7: Model 3.1

Comparison of Least Squares, White cross-section and White period standard errors

	Least Squares standard errors			White cross-section standard errors			White period standard errors		
Variable	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.
C	0.282219	-4.814932	0.0000	0.250060	-5.434148	0.0000	1.074245	-1.264948	0.2060
EU	3.76E-05	30.89875	0.0000	0.000150	7.721681	0.0000	0.000561	2.069490	0.0386
FF	0.003644	19.99286	0.0000	0.001762	41.34381	0.0000	0.012914	5.641001	0.0000
GDP	6.94E-06	-11.19194	0.0000	1.16E-05	-6.684426	0.0000	7.11E-05	-1.093095	0.2745
OP	0.001186	-0.645680	0.5186	0.000992	-0.771736	0.4404	0.001028	-0.745104	0.4563
D_1	0.103528	0.927321	0.3539	0.048558	1.977078	0.0482	0.204238	0.470058	0.6384
D_2	0.621637	0.502505	0.6154	0.176134	1.773516	0.0763	0.557608	0.560207	0.5754
D_3	0.122422	1.795611	0.0727	0.079903	2.751119	0.0060	0.092065	2.387698	0.0170
D_4	1.040537	-1.318565	0.1875	0.324760	-4.224712	0.0000	0.259944	-5.278129	0.0000
D_5	0.335710	2.661018	0.0079	0.267711	3.336929	0.0009	0.414393	2.155759	0.0312
D_6	0.617332	-0.679644	0.4968	0.212402	-1.975341	0.0484	0.093084	-4.507388	0.0000
D_7	0.618448	-0.930237	0.3524	0.183865	-3.128950	0.0018	0.201336	-2.857426	0.0043
D_8	0.395271	1.854672	0.0638	0.184312	3.977485	0.0001	0.624505	1.173885	0.2406
D_9	0.114670	-0.613461	0.5396	0.087531	-0.803667	0.4217	0.091972	-0.764858	0.4444

Residual graph



Appendix 8: Model 3.2

OLS estimations with fixed effects

Variable	Coefficient	P-value
C	4.052753***	0.0000
EU	0.001187***	0.0000
AN	-0.029202***	0.0000
GDP	-0.000107***	0.0000
OP	-0.000510	0.6893
D_1	-0.056686	0.6125
D_2	0.490960	0.4623
D_3	0.141452	0.2828
D_4	-1.363282	0.2228
D_5	0.772656**	0.0323
D_6	-0.630640	0.3418
D_7	-1.085359	0.1023
D_8	1.132787***	0.0076
D_9	0.126240	0.3048

***P-value<0.01; **P-value<0.05; *P-value<0.10

Number of observations 2145

R^2-within	0.40147

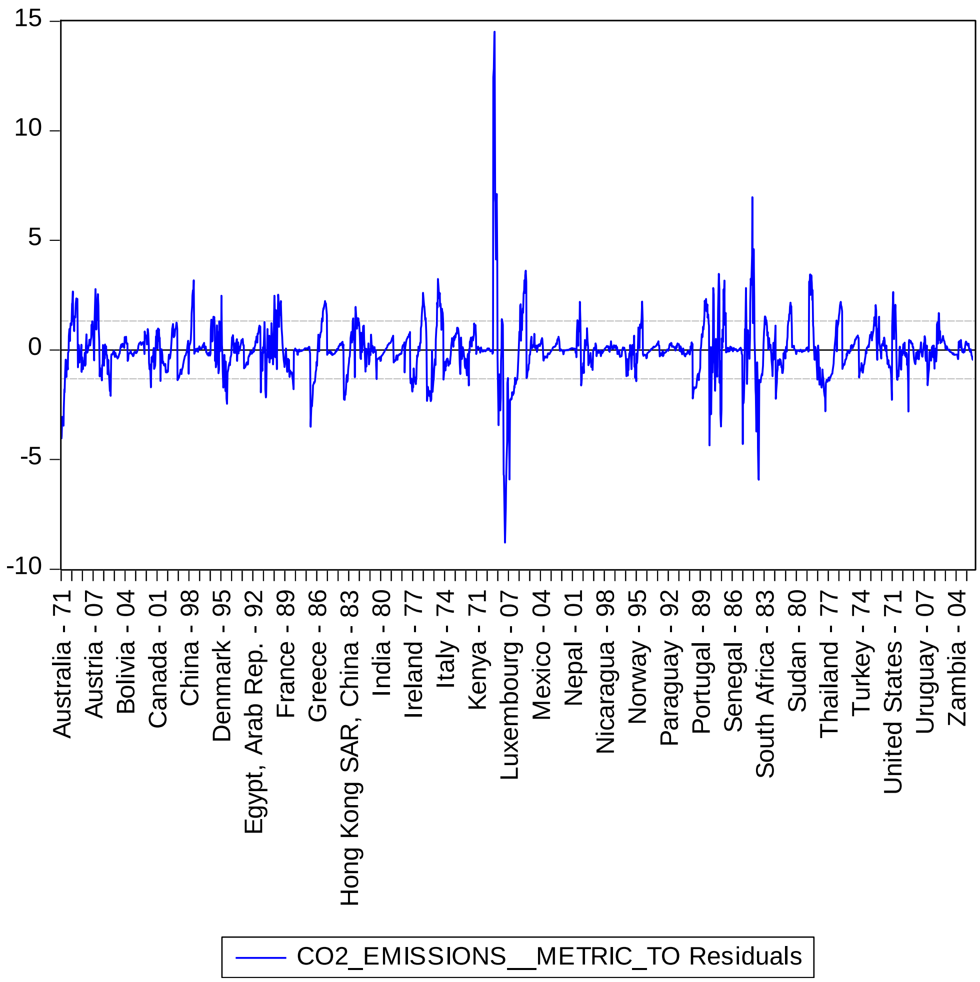
F-test	Value	Df	Prob.
Redundant variables	71.47754	(13, 2077)	0.0000
Redundant fixed effects	120.027242	(54,2077)	0.0000

Appendix 9: Model 4

Comparison of Least Squares, White cross-section and White period standard errors

	Least Squares standard errors			White cross-section standard errors			White period standard errors		
Variable	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.	Std. Error	t-Statistic	Prob.
C	0.031352	175.3910	0.0000	0.053036	103.6811	0.0000	0.020680	265.9038	0.0000
D_1	0.130353	-0.344486	0.7305	0.064402	-0.697258	0.4857	0.337921	-0.132885	0.8943
D_2	0.797225	1.768606	0.0771	0.298746	4.719656	0.0000	0.222795	6.328598	0.0000
D_3	0.129592	1.356577	0.1751	0.074396	2.363044	0.0182	0.188006	0.935081	0.3499
D_4	1.336092	-1.337247	0.1813	0.315651	-5.660310	0.0000	0.021545	-82.92633	0.0000
D_5	0.425110	0.866893	0.3861	0.213588	1.725402	0.0846	0.065076	5.663007	0.0000
D_6	0.792606	-0.846348	0.3975	0.353036	-1.900149	0.0576	0.022742	-29.49646	0.0000
D_7	0.792606	-1.459394	0.1446	0.326941	-3.538023	0.0004	0.022742	-50.86201	0.0000
D_8	0.506199	2.935040	0.0034	0.369154	4.024644	0.0001	0.783690	1.895792	0.0581
D_9	0.129592	1.341628	0.1799	0.101799	1.707917	0.0878	0.211398	0.822448	0.4109

Residual plot



Appendix 10: The coefficients for model 1.4.1 (*P-value<0.05)

Country	C	EU	GDP	FF	OP	D10
All	-1.31801*	0.001157*	-7.90E-05*	0.072655*	-0.00049	0.039637
Australia	-102.635*	0.002395*	-5.92E-05	1.154608*	-0.00347	0.139013
Austria	-4.38517*	0.002085*	-3.38E-05	0.076049*	-0.00412*	0.05081
Belgium	-2.71073*	0.002767*	-0.00038*	0.084612*	0.010073*	-0.21107
Bolivia	-1.13556*	0.001608*	0.000875	0.010433	-0.00372*	0.068475
Brazil	-1.26815*	0.002388*	-0.00031*	0.028878*	0.00019	0.015359
Canada	-9.93986*	0.001269*	2.02E-05	0.213026*	-0.00308	0.04378
Chile	-3.88889*	0.001322*	9.58E-05	0.067448*	-0.00277*	0.136078
China	-1.00627*	0.005512*	-0.00085*	-0.00603	-0.00281*	0.119004
Colombia	-0.48657	0.002974*	-0.00015*	0.00391	0.002674*	-0.0352
Denmark	-8.53712*	0.003221*	-5.94E-05*	0.094538*	0.002755	-0.08241
Ecuador	-0.21466	0.003078*	-0.0013	0.020605	0.003122	0.032375
Egypt, Arab Rep.	4.478155*	0.001569*	0.001158*	-0.05607*	0.000752	-0.06488
Finland	-8.27719*	0.002988*	-0.00024*	0.109296*	0.007335*	0.213983
France	-3.97227*	0.002612*	-0.00026*	0.08949*	0.005888*	0.037089
Ghana	-0.18797	0.001107*	0.000143	0.002096	-0.00021	0.055716
Greece	-7.34905*	0.003948*	-0.00019*	0.085207*	0.00252	0.072352
Guatemala	-1.06966*	0.000898*	0.000715*	0.00565	-0.00161*	0.042171
Hong Kong	-11.6549*	0.002534*	3.01E-05	0.121622*	0.000564	-0.56413*
Iceland	1.129733	-0.00018*	0.000189*	0.086814*	0.004585	-0.10292
India	-0.99104*	0.004843*	-0.00049	0.003353	0.000293	-0.00349
Indonesia	-0.15297*	0.000934*	0.001173*	-0.00369	0.001849*	-0.03868
Ireland	1.270955	0.003059*	-3.51E-05*	-0.00492	-0.00284*	0.066694
Israel	-38.421*	0.001784*	0.000434*	0.363813*	-0.01762*	-0.60625
Italy	-15.8047*	0.001419*	9.17E-05*	0.192243*	0.00193*	-0.17391
Japan	-5.00599*	0.00204*	-1.07E-05	0.082086*	0.002499*	-0.04989
Kenya	0.886753*	-0.00176	-0.00027	0.015643*	0.000431	0.010973
Luxembourg	-13.406*	0.003115*	-0.00013*	0.174133*	-0.00493	0.640626
Malaysia	2.567664	0.000555	0.001594*	-0.04525	-0.00385	0.08286
Mexico	-6.17137*	0.002089*	-6.31E-05	0.083641*	-0.00086	0.093092
Morocco	-1.16729*	0.003568*	-2.40E-05	0.012293	-0.00028	0.015351
Nepal	0.022384	-0.00013	0.000125	0.010275*	-3.38E-05	-0.00132
Netherlands	-2.66154	0.00338*	-0.00019	0.021507	0.001094	-0.11493
Nicaragua	-0.68602*	0.001364*	-3.23E-05	0.017107*	0.000128	-0.00313
Nigeria	1.606348	-0.00112	-0.0008	-0.00596	0.005469*	-0.16291
Norway	-3.05643	0.000581	2.94E-05	0.125281*	0.011812*	0.141057
Pakistan	-0.34109*	0.001856*	0.000918*	-0.00349	-0.00015	0.022661
Paraguay	-0.50967*	0.001088*	-8.04E-05	0.018566*	-0.00024	0.031922
Peru	-1.20876*	0.001761*	0.00024*	0.015048*	-0.00059	0.057862
Portugal	-3.14552*	0.002251*	3.14E-05	0.042435*	-0.00274*	0.015793
Saudi Arabia	5101.945	0.001117*	0.000393	-50.9736	0.011066	-0.18793
Senegal	0.682458*	9.60E-05	-0.00082	0.001036	0.002459*	-0.07117
Singapore	-152.381	0.002171*	-0.00036	1.637477	-0.00096	-1.00108
South Africa	-13.8107*	0.004008*	-0.00128*	0.190678*	-0.00119	-0.40873
Spain	-4.10206*	0.003039*	-0.0002*	0.062212*	0.003027*	0.059372
Sudan	-0.42616*	0.00115*	-0.0002	0.013175*	0.00015	0.014896
Sweden	-6.48004*	0.001439*	-2.95E-05*	0.139974*	0.004465*	-0.05803
Thailand	-1.47867*	0.002431*	6.90E-06	0.024411*	-0.00086	-0.12049
Tunisia	-2.88568*	0.001194	0.000257	0.039779*	1.26E-05	-0.02097
Turkey	-1.4083*	0.002918*	-5.64E-05	0.018128*	-0.00065	0.058118
United Kingdom	-8.64744*	0.002638*	-8.93E-05*	0.119405*	-0.00295	0.366901
United States	-14.6153*	0.002561*	9.12E-07	0.168275*	-0.0057*	0.196937
Uruguay	-1.44408*	0.002006*	-2.21E-05	0.023957*	-0.00025	0.070233
Venezuela, RB	19.36378*	-0.00037	-0.00061*	-0.10349	0.003573	0.276759
Zambia	-0.62691	0.000386	0.001324*	0.0152328	-0.0007	-0.02183
Zimbabwe	-1.59801*	0.002107*	2.93E-05	0.026107	0.001679	-0.10633