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A test of the Environmental Kuznets Curve in the Nordic countries

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Abstract:

Climate change arising from global warming is an important issue for the global community to resolve for the prospect of a sustainable future. It is therefore crucial to gain understanding in how nations can contain the progression of global warming created by emissions of greenhouse gases. The Environmental Kuznets Curve (EKC) theory suggests that decoupling between CO_2 emissions and economic growth is possible when a certain level of economic development is reached. This study uses the EKC theory to investigate the relationship between CO_2 per capita and GDP per capita for the countries of Denmark, Finland, Norway, and Sweden from 1960 to 2021. These countries are considered suitable candidates as all satisfy the requirements for showing a clear decoupling in accordance with the EKC theory. This study uses a cubic parametric regression analysis model to investigate the EKC hypothesis. It finds suggestive evidence of an inverted U-shape relationship between CO_2 per capita and GDP per capita for the country of Sweden, implying that the EKC theory holds. This relationship cannot be found in the results on the analysis of Danish, Finnish, and Norwegian data. The extended analysis proposes that the sectorial composition of emissions explains the differences observed between the countries. The study also considers the possibility of a future EKC relationship for Denmark and Finland. Norwegian data does not provide any suggestive evidence of a future existence of an EKC. The study concludes that decoupling is country specific.

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1. Introduction

In the past centuries, the economic growth that humanity has experienced has led to improvement of living standards around the globe. These advances have been achieved through exploitation of the planet's natural resources, which has led to global environmental degradation. These trends have alarming effects on the environment (World Commission on Environment and Development, 1987). Human caused climate change has had a massive impact on the environment with increasingly irreversible damages (IPCC, 2022). This impact on the environment, largely caused by global warming, is mainly influenced by atmospheric carbon dioxide, contributing some 80% of global greenhouse gas emissions (GHG) (IPCC, 2022). Underdeveloped nations suffer from a combination of higher risk exposure and vulnerability due to low adaptive capacity (Engle, 2011). Therefore, the negative consequences of the resulting environmental conditions are the highest for the populations living in underdeveloped countries (Barbier and Hochard, 2018). This goes to show that the linkage between economic growth, inequality and environmental sustainability is a relevant topic. The Kuznets curve, developed in the 50's and 60's, gave economists a new hypothesis on the linkage between GDP-growth and inequality (Kuznets, 1955). Kuznets theorem later evolved into the hypothesis of an environmental Kuznets curve (Grossman and Krueger, 1991). The purpose of such a hypothesis being to explain the linkage between GDP growth and environmental performance (Özcan, 2019). The implication of the Environmental Kuznets Curve (EKC) model being that high levels of economic development can be consistent with low CO_2 emissions. To understand how nations can contain the progression of global warming and handle the issues arising from climate change is crucial for the development of a sustainable future. Nordic countries are often seen at the forefront of environmental sustainability among developed economies. Looking at how these countries stand in relation to decreasing their CO_2 emissions while maintaining economic growth is therefore of high relevance.

In 2022, the Nordic countries of Finland, Norway, Sweden, and Denmark ranked highest in accomplishing their sustainable development goals (SDG) (Sachs *et al.*, 2022). All Nordic countries have announced plans of becoming entirely, or mostly, carbon neutral by 2050. Countries as well as companies within the Nordic region have made successful efforts in reducing CO_2 emissions (Sovacool, 2017).

1.1 Literature review

Our study makes use of the Environmental Kuznets Curve theory to study the relationship between GDP growth and greenhouse gas emissions. This relationship has been the focal point for many researchers in the last decades.

In 1991, Grossman and Krueger published a paper on the effects of trade liberalization and the environment. The authors distinguished three mechanisms that could explain why economic development and environmental degradation correlated. In 1995, Grossman and Krueger expanded their research and introduced the EKC for the first time, asking the question if economic growth will bring greater harm to the environment or if we, with time, will see a decoupling effect between the two. The authors contribution to the research was that they set up a common methodology to study the relationship between economic activity and environmental quality (Grossman and Krueger, 1995). Their framework the is the foundation of this research.

Since then, the EKC has been used many times and with different focuses[1]. In 2010, He and Richard conducted a study on the Canadian EKC using data from 1948 to 2004. Their study is relevant to this study as Canada is a country of similar economic development to that of the Nordic countries. He and Richard found no significant evidence of an inverted u-shaped relationship between Co2 emissions and GDP growth. He and Richard's study laid the foundation for a bachelor's thesis at Gothenburg University on the Swedish EKC written by Forsström and Johansson (2020). We employ a similar econometric approach but, instead of focusing only on the case of Sweden, we extend previous research to also include the other Nordic countries, with the objective of comparing particularities between the countries.

A recent study by Frodyma, Papież and Śmiech (2022) examined the validity of the EKC theory in the countries of the European Union (EU). Just like He and Richard (2010) and Forsström and Johansson (2020), they conducted the research using a linear, quadratic, and cubic equation. However, they extended the research by production-based CO_2 emissions as well as consumption-based emissions in each of the countries. They found no signs of an EKC in 168 of the tests conducted and only some indication of an EKC relationship in 11 of the cases. The study conducted in this paper will expand their work by taking a closer look at the Nordic countries specifically.

Urban and Nordensvärd (2018) conducted a comparative data analysis of the EKC across Nordic countries with a focus on how energy transition could have explained decreases in emissions over time. Their paper provided signs of an EKC in Sweden, Denmark, Iceland, and Finland, but not in Norway. Although our study also contrasts characteristics specific to individual Nordic countries to explain a potential EKC relationship, our study differs from theirs in two important ways. First, whereas Urban focus on a visual inspection of how income correlate with emissions, we use an elaborate, previously tested, econometric model in the hope to obtain more robust results. Second, rather than focusing on energy transition alone, we look into multi-sectoral decoupling, like that of the transportation sector, to get a better understanding of why the EKC might differ between the countries.

Taghvaee, Nodehi and Saboori (2022) look at the EKC relationship for all OECD countries between the years 1971-2016. The paper, which looked at several economic sectors' effects on environmental pollution, concluded that the majority of OECD countries are still on the left-hand side of the EKC. Only three countries, none of them Nordic, are at the tipping point of the curve. Although this paper takes an extensive approach by analysing all economies within the OECD, our report will give a more detailed insight into the Nordic countries' relationship between CO_2 emissions and economic growth generally, and the transportation transition specifically.

[1] See (Dinda, 2004) and (Dasgupta *et al.*, 2002) for a review, and (He and Richard, 2010), (Lindmark, 2002) for two applications.

1.2 Purpose

The aim of this paper is to perform a quantitative data analysis on environmental and economic data for the Nordic countries according to a model used for the EKC hypothesis. Furthermore, in the analysis of the results we compare the obtained results between the countries. We discuss whether the country specific emissions from energy and transportation, as part of the total composition of CO_2 emissions, affect the shape of each country's CO_2 per capita to GDP per capita ratio curve.

1.3 Research questions

The main research question to be answered in this study is stated as follows:

> Does the Environmental Kuznets Curve theory hold for the relationship between CO_2 per capita and GDP per capita in the Nordic countries observed?

To further understand the potential differences between the countries we have stated a secondary research question as follows:

> Can the composition of emissions in the individual country, in part, explain potential differences between the countries' CO_2 per capita to GDP per capita ratio curve?

2. Background

In this section of the report, background information regarding the environmental Kuznets curve as well as economic and environmental development in each of the Nordic countries is presented.

2.1 The Environmental Kuznets Curve

The relationship between economic growth and different types of pollution takes on many forms. One that has grown popular in the last decades is the Environmental Kuznets Curve (Kaika and Zervas, 2013). In the 1970's, when the Club of Rome published the report "Limits to growth", the idea that our focus on economic growth would be restricted by limited natural resources became popular. During the same decade, the world experienced its first big oil crisis which highlighted the limited access to natural resources. The Stockholm conference in 1972, the Brundtland report in 1987 and the Kyoto protocol in 1997 have all been crucial to the development of economic growth and sustainability as a research field (Kaika and Zervas, 2013). By the 1990's, the concept "too poor to be green" became popular among economists when explaining water and air pollution in the developing world (Beckerman, 1992). The World Development report in 1992 concluded that certain environmental problems could be associated with the lack of economic growth (Ekins, 1993). This debate was the bedrock upon which the EKC was formed (Kaika and Zervas, 2013).

The EKC hypothesis requires strong decoupling between CO_2 emissions and economic development to hold. Decoupling can be defined as the process of de-linking economic development from environmental degradation (Taghvaee, Nodehi and Saboori, 2022). If there is no strong decoupling, the EKC relationship will not be significant on a statistical level. Even if the relationship holds, the curve might differ between the countries considered in this report. Therefore, in order to better interpret the EKC relationship for the different countries, a deeper analysis of the composition of emissions in each country is necessary. The different sectors, defined later in the theory section of this report, include the energy sector, the transportation sector, the agricultural sector, and the manufacturing sector (OECD, 2002).

Transportation accounts for a large share of emissions in each of the Nordic countries. Literature on transportation has historically shown a strong connection between GDP growth and traffic volume. Recent literature suggests no reduction in CO_2 intensity for the transport sector among developed economies. On the contrary, the positive environmental effects of technological advances shown in some sectors, such as the energy sector, are to a great extent nullified by higher capital intensiveness in the transport sector. For example, research shows that technological development results in stronger engines and heavier vehicles (Tapio, 2005).

2.2 Environmental Regulation

Available evidence suggests that environmental regulation could affect declining pollution in middle- and high-income countries, as described by Dasgupta et al. (2002) in the paper "Confronting Environmental Kuznets Curve". Studies find that environmental policies play a significant role in areas such as water pollution and sulphur dioxide. Dasgupta et al. (2002) suggest three main reasons for this relationship. Firstly, as countries achieve basic investments on health and education, they can put higher priority on pollution damage. Secondly, richer countries have more assets to monitor and enforce environmental regulations. Finally, research shows that higher income societies put more local effort into enforcing environmental regulations, whatever the stance of the national government in the country is. As a result, there is a close connection between national pollution regulation and GDP per capita (Dasgupta *et al.*, 2002).

2.3 Denmark

According to Jes Iversen and Andersen (2008), Denmark experienced a sharp turning point in the 1960s as the country went from being one of the slowest growing western economies to becoming one of the best preforming ones in the upcoming decade. The reason for this shift in economic growth was mainly an increase in export-oriented industries as well as a big expansion of the public service sector. However, in the early 1970s, Denmark's economic growth turned into one of the most severe economic crises since the 1930s as international trade halted while the public sector continued to grow. This changed in the 1980s when the Danish economy entered a formative period. The country got a conservative leadership resulting in substantial cuts of the public sector. The period was also affected by large structural changes in the industry. A report published in 1984 concluded that Denmark had fallen behind its neighbouring countries in the R&D department. Both the Danish government and business put great effort into injecting new knowledge and technology to the Danish business community. In the late 1980s and early 1990s, the country experienced high unemployment. The country has been a liberalized economy part of the intensive international competition since the 1990s. Denmark has also its welfare system in place resulting in a form of co-operative liberalism (Jes Iversen and Andersen, 2008).

According to the Environmental Protection Agency, environmental problems became a topic of discussion in Denmark already in the 1960s (COWI, 2001). As the industry sector grew, environmental degradation such as air and water pollution followed. However, the discussion of the topic mainly focused on local issues and environmental problem related to public health. The Danish Environmental Protection Agency was established in 1971 to be able to supervise and coordinate regulatory activities. Denmark became a member state of the European Community and adopted the community's legally binding instruments in environmental issues in 1975. Environmental policy in Denmark has since been dominated by EU wide regulation. After the adoption of the revised Environmental Protection Act in 1992, the country started focusing on clean technology (COWI, 2001). As part of the EU, Denmark is part of the EU Emissions Trading Scheme (EU-ETS) (IEA, 2017).

In 2016, transportation succeeded electricity and heat as the largest emissions sector in Denmark (Friedlingstein *et al.*, 2022). Emissions in the electricity and heat sector halved in the past decade. This can be explained by a large increase in wind power generation which has replaced coal and gas usage. Renewable energy increased from 29% to 70% of total power generation between 2007 and 2017. As transportation is now the sector which emits the most greenhouse gases (GHG), reducing its transportation emissions is crucial to achieve GHG targets. The country has invested in several projects, such as converting the main train lines from diesel to electric and a metro development project in Copenhagen. In 2007, a change in vehicle taxation was implemented to promote cars with low fuel consumption (IEA, 2017).

2.4 Finland

The chapter *"*Growth and investment: Finnish capitalism, 1850s-2005*"* explains how in the 1960s and early 1970s, Finland experienced high economic development with an average growth of 4.2 percent (Fellman, 2008). During the 1970s, Finland was severely affected by the global recession caused by the oil crisis. However, they experienced a greater growth than most western countries in the 1980s and their economy managed to catch up with other Western economies. During the same decade, the country developed from being a traditional industrial economy into a more service-oriented economy. Manufacturing and industry were still important sectors, especially politically as the industry sector comprised most of the export. One of Finland's biggest export partners was the Soviet Union which was positive for the Finnish economy in the 1970s. However, this turned out to have dire consequences for the economy in the 1990s when the Soviet Union collapsed, contributing to Finland going into its worst financial crisis since the 1930s. In the late 1990s, the economy recovered and experienced one of the highest growth rates in the EU at over four percent a year. During this period, Finland fully transformed into a service economy where the technological sector became the main force driving economic growth (Fellman, 2008).

The general development of environmental policy in Finland has followed that of the other Nordic countries since the 1970s (Sairinen, 2003). Since the 1980s, environmental protection has been high in Finland compared to other European countries. The country became the first in the world to implement a carbon tax in 1990. After the entry into the European Union in 1995, Finnish environmental policy has, as all countries within the EU, been largely influenced by the EU-wide approach (Sairinen, 2003).

According to the International Energy Agency (IEA), Finland held the second place in usage of bioenergy within IEA countries in 2017 (2018). The electricity and heating sector is the largest CO_2 emitter in Finland, accounting for 33% of total emissions. Transportation is the second largest emitter, accounting for 22% of total emissions. The transportation sector relies mainly on oil-based fuels. According to 2016 data, Finland has nearly halved its carbon intensity levels compared to 1990 levels. However, in comparison to Sweden and Norway, Finnish carbon intensity levels are still high. One explanation for this is the fact that Finland is more dependent on fossil fuelled power plants than its neighbouring Nordic countries (IEA, 2018).

2.5 Norway

Norwegian economic development was at a high level in the 1960's. Foreign trade increased, and GDP grew steadily throughout the decade and unemployment was low. In 1969, Philips Petroleum found oil on the Norwegian coastline. Even though the economy suffered from stagnation in the early 1970s, the new oil revenues gave the Norwegian government financial strength resulting in a higher economic growth during this period than similar western economies. However, the new oil sector also resulted in a deindustrialization of the manufacturing industry as they could not compete with the salaries in the oil sector. The country liberalized the credit market in the 1980s which resulted in a severe financial crisis at the end of the decade, similar to the other Nordic countries. In the early 1990, the government took over most of the private banks. During the same time period, the Norwegian krone stopped pegging the European Currency Unit (ECU) and the Norwegian economy grew significantly throughout the decade. However, in 1998, the petroleum prices fell significantly and eventually resulted in the government abandoning the fixed exchange rate. The implementation of the state-owned oil fund in the 1990s was a step in making sure the economy would not overheat. The oil fund has contributed to the economic welfare of the country, for example funding the national pension fund. In the 2000s, it has also been used as a fiscal instrument to counteract financial fluctuations (Grytten, 2021)

The introduction of oil production in the 1970s led to an increased interest in environmental issues in Norway (Grytten, 2021). The country has been viewed as a pusher state in some areas, such as acid rain, as the wellbeing of lakes and forests in Norway are dependent on parties outside the country reducing emissions. Gro Harlem Brundtland, former prime minister of Norway, set the country on the map as putting high priority on sustainable development. The process of founding an environmental strategy for Norway started in 1987. However, it coincided with a doubling of oil production from 1990 to 2001 leading to a steady increase of offshore CO_2 emissions from the oil platforms. Even though Norway is not part pf the European Union, the majority of EU environmental legislation applies to the country (Skjaerseth, 2004).

Although Norway is not part of the EU, it has a legally binding commitment to the EU-ETS on the same terms as all EU countries. In Norway, the industry is the biggest GHG emitter, accounting for almost 60% of total emissions. In second place is the transport sector accounting for 34% of total emissions. Due to the mountainous landscape, the domestic transportation sector heavily relies on road transportation. Road transport accounts for 52% of total transports. The government has targeted the emissions in the transportations sector by introducing carbon taxation. Great benefits for those using electrical vehicles have resulted in Norway having the highest share of electric vehicles out of all the IEA countries. Drivkraft Norge, their energy industry association, estimated that electric vehicles reduced emissions by 5% in 2020 (IEA, 2022).

2.6 Sweden

Historically, the Swedish economy has been focused on capital intensive industries, such as mining, forestry, and steel production which required large capital investments. Swedish companies, such as AGA, SKF and Ericsson, reached dominant positions around the world in the early 20th century. From the end of the war until the mid-1970s, Sweden had strong economic growth. The country experienced a four-fold increase in exports during the 1960s and 1970s largely due to liberalization of world trade. Sweden saw large structural changes in the economy between the 1960s and the late 1990s. The relative importance of industry and agriculture decreased as the service sector, both public and private, grew. Nearly half of all employment in Sweden came from the service sector in the 1990s, compared to a third in 1970. The industrial society had transformed into a service society. This was partly due to the Swedish industry no longer being able to compete with industries in South Europe and Southeast Asia, as globalization and international trade increased. Another important explanation to this trend was that the level of education had increased rapidly. Sweden contributed more to higher specialization in the international market than to producing goods (Sjögren, 2008).

Sweden was among the first countries in the world to establish an environmental protection act, adopted in 1969. In 1972, Sweden hosted the first worldwide conference focusing on the environment – UN Conference on Human Environment. The country's tax on CO_2, implemented in 1991, has also been an important factor in reducing emissions across all sectors. The Swedish environmental code was adopted in 1999 and laid the foundation for environmental policy in the country. As part of the EU, Sweden has also been affected by EU-wide legislation such as the EU-ETS scheme in trading with greenhouse gas emissions (Hysing, 2014).

The large technological and structural changes that Sweden experienced contributed to a relative decrease in aggregate country emissions. The energy sourced from nuclear power has been a major contributor to this development. Increases in fuel prices also has a negative impact on emissions in the country (Lindmark, 2002). The transportation sector is the largest contributor to CO_2 emissions. This has been the case for over 30 years (Friedlingstein *et al.*, 2022). Since 2013, there has been a rapid increase in the use of biofuels. Sweden has also implemented a bonus-malus system which subsidizes the purchase of low-emitting cars with taxes from high-emitting cars (IEA, 2019).

3. Theoretical Framework

This section will give a brief theoretical presentation of the EKC as well as the theory on transportation decoupling.

3.1 The Environmental Kuznets Curve

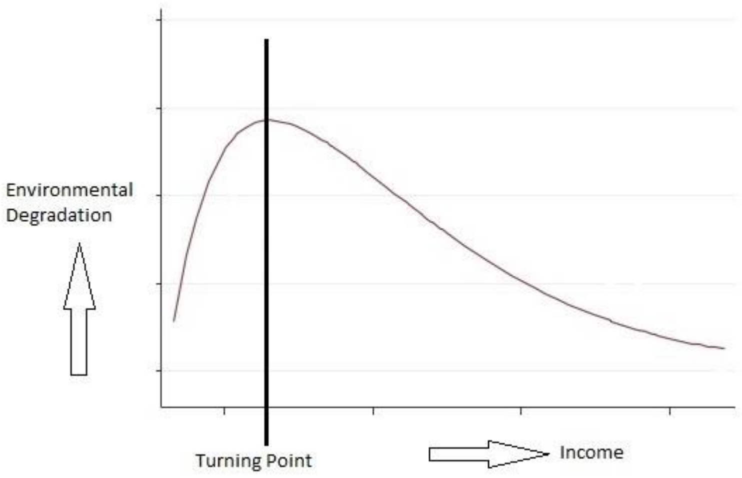

Figure 1 (The Environmental Kuznets Curve)

The environmental Kuznets curve aims to explain the relationship between economic development and environmental degradation, predicting an inverted U-shape relationship between the two. The theory assumes that early stages of economic development will lead to a deterioration of the environment, as material output is the main goal. Economic development is initiated as a society moves from an agrarian economy onto early stages of industrialization. During this stage, economic activity, such as creating jobs, is of higher importance than potential environmental harm. Therefore, economic development through industrialization will drive the negative effects on the environment. During this developmental stage, there will be a strong positive relationship between economic growth and environmental degradation. Over time, the economic development continues in a country with increased access to technology, a growing service sector, and implementation of stricter environmental policy standards. According to the EKC theory, this facilitates continued economic growth with less environmental degradation. At this point, the theory predicts a negative relationship between economic growth and environmental degradation (Kaika and Zervas, 2013). This shift between positive and negative correlation is the foundation of the EKC model. The mechanisms behind the shape of the EKC is better understood by distinguishing three separate concepts: scale, technology, and composition effects. Firstly, as trade liberalization and globalization increase the prospect of trade, increased economic activity will follow. Increased economic activity with unchanged underlying nature, will increase the need for additional energy and materials to support this activity, which will lead to an increase in pollution. This is called the *scale* effect. The second mechanism, the *composition* effect, arises as trade increases and countries specialize their production as per comparative advantage. If the comparative advantage is a result of low environmental regulation in a local or country specific market, the result will be increased environmental degradation. Finally, the *technology* effect explains why pollution per unit of output might decrease. As technology progresses, cleaner manufacturing technologies which are more efficient than previous ones, enter the market. The result of which is lower levels of pollution. (Grossman and Krueger, 1991).

3.2 Theory on sectorial decoupling

In 2002, OECD set up a framework for looking at decoupling of environmental pressures from economic growth. The framework looks at 31 decoupling indicators all focusing on different environmental aspects. Some of the indicators are widespread while 16 of them focuses on issues within four specific sectors: Energy, transport, agriculture, and manufacturing. Energy is used in all sectors of an economy and is an essential part of modern life. A decoupling indicator in the energy sector refers to a reduction of an air pollutant, including CO2, from any form of energy use. Passenger and freight transportation has, historically, been strongly correlated with economic growth in the OECD countries. Transportation causes local air pollution as well as global CO2 emissions. The agriculture sector can impose major impact on the environment. As this sector must keep pace with a growing world population, the emission from this sector is an important factor in decoupling theory. The manufacturing sector is composed of a large range of production activities. Natural resources are used in the production and emissions a biproduct. The decoupling of this sector therefore focuses both on the efficiency of use of natural recourses and pollutants such as CO_2 (OECD, 2002).

On a theoretical level, the transportation sector can be in one of three different stages: coupled, decoupled, or negatively decoupled. The transport sector is *coupled* with GDP when they are positively correlated; as GDP grows, transportation CO_2 emissions intensifies. *Decoupling* happens when GDP can continue to grow while the transportation sector stabilizes, or even reduces, its emissions. In the case GDP stagnates while transportation CO_2 emissions continue to increase, *negative decoupling* is happening (Tapio, 2005).

4. Methodology and Data

This section of the report is dedicated to presenting the models, variables and the data used.

4.1 Methodology

To answer the research-question this study tests the following hypothesis for each country:

The Economic development is correlated with the generated pollution in accordance with the predictions made by the EKC theory.

The prediction made by the environmental Kuznets curve theory is that there should exist a correlation between the pollution, and the economic development, such that, this correlation is positive up to a certain turning point at which it switches and becomes negative. This sign change in correlation is described as the decoupling effect in EKC literature.

To evaluate whether this decoupling is plausible, we start by using a relatively standard cubic parametric OLS model previously employed in EKC literature (Dinda, 2004; He and Richard, 2010).

$$E_t = \alpha_0 + \alpha_1 t + \beta_1 y_t + \beta_2 {y_t}^2 + \beta_3 {y_t}^3 + \gamma X_t + u_t \quad \text{(He and Richard, 2010)}$$

Where the outcome variable E_t represents *CO_2 per capita, and* y_t is the variable of interest; *GDP per capita*. The variable X_t represent all the variables that might affect the outcome variable (controls) and u_t is the residual. The reason for the inclusion of a cubic component in this model being that the pollution realistically will approach a plateau, thus making a quadradic estimation insufficient in the long run.

For positive correlation between economic development and pollution to exist, we observe that $\beta_1 > 0$ needs to be satisfied. Then, for the EKC theory inverted U-shape relationship to exist we observe that $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$ needs to hold. If this is also satisfied, the turning point of the environmental Kuznets curve will be found at:

$$GDP\_PC^* = -\frac{\beta_1}{2\beta_2} \quad \text{(Dinda, 2004; Frodyma, Papież and Śmiech, 2022)}$$

All countries are affected by respective circumstances and their outcome will not be the same. As a result of this heterogeneity, we expect the turning point to be found at different levels of GDP for the different countries.

Initially, to test whether the inverted U-shape relationship can be found, we use a quadratic and a cubic model where we allow for the restriction $\gamma = 0$ (omitting the controls) as is often done in empirical studies on the EKC to create a benchmark. To inhibit issues arising from spurious correlation between the outcome variable and the variable of interest the time trend variable $time$, which corresponds to each year, is added. This gives us our model (1) and (2) as follows in equation (1) and (2):

$$CO2\_PC_t = \beta_1\, GDP\_PC_t + \beta_2\, {GDP\_PC_t}^2 + \alpha_1\, time + U_t \qquad (1)$$

$$CO2\_PC_t = \beta_1\, GDP\_PC_t + \beta_2\, {GDP\_PC_t}^2 + \beta_3\, {GDP\_PC_t}^3 + \alpha_1\, time + U_t \qquad (2)$$

Since these regression models are probably under-specified, due to lack of controls, the results lack the robustness required to draw substantial conclusions. We therefore lift the restriction on γ and introduce three control variables: $Oilprice$, $Exports$ and $Imports$, which are considered to affect the outcome variable, thereby reducing the omitted variable bias. This gives us our final and preferred model in equation (3):

$$CO2\_PC_t = \beta_1\, GDP\_PC_t + \beta_2\, GDP\_PC_t{}^2 + \beta_3\, GDP\_PC_t{}^3 + \alpha_1\, time + \alpha_2\, Oilprice_t + \alpha_3\, Exports_t + \alpha_4\, Imports_t + U_t \qquad (3)$$

Where the beta (β) values are the coefficients of the variable of interest GDP_PC. The alpha (α) values represent the coefficients of the control variables. As homogeneity cannot be assumed for the covariates, all regressions are performed with heteroscedastic assumptions.

4.2 Data

All the data used to carry out the regression analysis consists of time series data for the Nordic countries of Denmark, Finland, Norway, and Sweden between the years 1960 and 2021. To carry out the extended analysis including composition of territorial CO_2 we employ another dataset ranging from 1990 to 2019 due to limitations in availability of composition data for years prior to 1990. Table C-1 in appendix C provides information and descriptive statistics regarding all the variables used in this study.

CO_2 per capita ($CO2\_PC$) is the outcome variable in the regressions. It is calculated by dividing country specific total territorial CO_2 emissions, by the country midyear population for each year in the series. The indicator used to represent CO_2 emissions include all consumption/burning of fossil fuels including cement production *(Glossary | DataBank, 2022)*. It is measured in metric tons of CO_2 equivalents (tCO_2-equivalent). Since emission of one unit of CO_2 is equal to one CO_2- equivalent all consumption of CO_2 translates effortlessly. The CO_2 and population data are collected from the world bank database (*CO2 emissions (kt) | Data*, 2022, p. 2; *Population, total | Data*, 2022)

GDP per capita (GDP_PC) constitutes the variable of interest in the regressions. It is calculated by dividing the total country specific gross domestic product by the country's midyear population for each year in the series. *GDP per capita* is expressed in 2015 US dollars. The GDP data is retrieved from the World Bank database which states that the data is sourced from the World Bank national accounts data and the OECD National Accounts data (*GDP (constant 2015 US$) | Data*, 2022).

The control variables used in our models are *Oil price, Exports*, and *Imports* with the time trend variable *Time*. *Oil price* is expressed in 2015 US dollars and is sourced from the BP Statistical review of world energy (*Statistical Review of World Energy | Energy economics | Home*, 2022). *Exports* and *Imports* are also expressed in 2015 US dollars and are sourced from the World Bank database (*Exports of goods and services (constant 2015 US$) | Data*, 2022; *Imports of goods and services (constant 2015 US$) | Data*, 2022).

5. Results

In this section of the report the results of the regression analysis are presented. The raw Stata output together with illustrative graphs of the polynomial estimation for each country is also available in appendix B.

5.1 Regression output for Denmark

Coefficient (Variable)	Model 1	Model 2	Model 3
β_1 (GDP per capita)	1.401***	1.566***	-0.672
	(0.0822)	(0.310)	(0.693)
β_2 (GDP per capita^2)	-0.0116***	-0.0160*	0.0331**
	(0.00102)	(0.00841)	(0.0150)
β_3 (GDP per capita^3)		3.91e-05	-0.000301***
		(7.36e-05)	(0.000104)
α_1 (time)	-0.380***	-0.384***	-0.202**
	(0.0371)	(0.0366)	(0.0938)
α_2 (Oilprice)			0.000546
			(0.00466)
α_3 (Exports)			-0.0942*
			(0.0475)
α_4 (Imports)			0.0433
			(0.0351)
Constant	731.1***	736.9***	411.6**
	(72.00)	(71.00)	(177.1)
Observations	62	62	56
R^2	0.861	0.861	0.876

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The table above shows the regression output for Denmark with *CO_2 per capita* ($CO2\_PC$) as outcome variable and *GDP per capita* (GDP_PC) as variable of interest. Model 1, the quadratic model, shows some evidence for the EKC relationship. The beta coefficients for both GDP_PC and GDP_PC^2 are significant. With GDP_PC having a positive beta-coefficient and GDP_PC^2 having a negative coefficient. This indicates the existence of a maximum point to the curve, which is in line with EKC theory. According to (He and Richard, 2010), literature on the EKC theory argues that there is academic support for using a cubic polynomial for estimation of the EKC. Therefore, model 2 incorporates a cubic polynomial. Model 2, like model 1, shows the appropriate beta-coefficients to support an EKC relationship. The beta value for GDP_PC^3 is close to zero which is also in line with the EKC theory. However, only the beta-coefficient for GDP_PC is satisfactorily significant, hence we do not attain statistical evidence from the cubic regression regarding the plausibility of an inverted u-shape relationship. Model 3, our preferred model, adds the control variables to the cubic regression. The cubic model, together with the chosen control variables, is the final model of this regression analysis. In this model, only the beta-coefficient for GDP_PC^3 is significant. β_2 shows statistical significance at a five percent confidence level and β_1 is insignificant. The beta-coefficients have also changed signs compared to the previous two models which results in an output that completely contradicts the EKC theory of an inverted

U-shape. This might indicate model specification problems. In conclusion, the regression analysis on Danish data does not provide a statistically justifiable relationship between *GDP per capita* and *CO_2 per capita* needed to substantiate the EKC theory.

5.2 Regression output for Finland

Coefficient (Variable)	Model 1	Model 2	Model 3
β_1 (GDP per capita)	1.561***	2.310***	-0.505
	(0.124)	(0.379)	(0.945)
β_2 (GDP per capita^2)	-0.0176***	-0.0453***	0.0286
	(0.00150)	(0.0137)	(0.0289)
β_3 (GDP per capita^3)		0.000318**	-0.000278
		(0.000156)	(0.000277)
α_1 (time)	-0.260***	-0.268***	-0.0484
	(0.0483)	(0.0477)	(0.0795)
α_2 (Oilprice)			0.00417
			(0.00578)
α_3 (Exports)			0.122***
			(0.0399)
α_4 (Imports)			-0.260***
			(0.0585)
Constant	499.1***	508.2***	108.7
	(93.80)	(92.76)	(151.4)
Observations	62	62	52
R^2	0.792	0.803	0.654

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The table above shows the regression output for Finland. *CO_2 per capita* ($CO2\_PC$) is the outcome variable and *GDP per capita* (GDP_PC) is the variable of interest. Observing Model 1 output we see a relationship in line with the EKC inverted U-shape as the β_1 is positive and β_2 is negative. As both variables are significant, this model signals a potential EKC relationship for Finland. In model 2, the cubic term GDP_PC^3 is added. In this model all coefficients are still significant, although β_3 is significant only at a five percent confidence level. The EKC theory continues to hold as β_1 is positive, β_2 is negative and β_3 is slightly positive and close to zero. When the control variables are added in model 3, we observe that the signs are no longer preserved. This might indicate model specification problems, as indicated by a substantial decrease in R-squared in model 3. Nevertheless, none of the betas are significant. In conclusion, the regression analysis on Finnish data does not provide a statistically justifiable relationship between *GDP per capita* and *CO_2 per capita* needed to substantiate the EKC theory.

5.3 Regression output for Norway

Coefficient (Variable)	Model 1	Model 2	Model 3
β_1 (GDP per capita)	0.384***	1.193***	0.0938
	(0.0288)	(0.125)	(0.153)
β_2 (GDP per capita^2)	-0.00253***	-0.0194***	0.00154
	(0.000298)	(0.00266)	(0.00321)
β_3 (GDP per capita^3)		0.000117***	-1.98e-05
		(1.85e-05)	(1.97e-05)
α_1 (time)	-0.0731***	-0.155***	-0.197***
	(0.0179)	(0.0182)	(0.0197)
α_2 (Oilprice)			0.00305
			(0.00214)
α_3 (Exports)			0.0273**
			(0.0115)
α_4 (Imports)			0.0282***
			(0.00719)
Constant	141.2***	290.1***	390.3***
	(35.00)	(34.83)	(37.20)
Observations	62	62	52
R^2	0.872	0.920	0.905

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The table above shows the regression output for Norway. *CO_2 per capita* $(CO2\_PC)$ is the outcome variable and *GDP per capita* (GDP_PC) is the variable of interest. In the regression output, model 1 shows evidence of an EKC relationship as β_1 is positive and β_2 is negative. In model 2, β_1 remains positive and β_2 negative with positive but close to zero β_3, all coefficients are significant. When adding controls in model 3 however, all beta coefficients lose significance while β_2 also change sign. In conclusion, the regression analysis on Norwegian data does not provide a statistically justifiable relationship between *GDP per capita* and *CO_2 per capita* needed to substantiate the EKC theory.

5.4 Regression output for Sweden

Coefficient (Variable)	Model 1	Model 2	Model 3
β_1 (GDP per capita	0.866***	2.713***	3.170***
	(0.165)	(0.334)	(0.444)
β_2 (GDP per capita^2)	-0.00744***	-0.0634***	-0.0717***
	(0.00148)	(0.00886)	(0.0141)
β_3 (GDP per capita^3)		0.000532***	0.000491***
		(8.08e-05)	(0.000145)
α_1 (time)	-0.294***	-0.295***	-0.407***
	(0.0457)	(0.0345)	(0.0511)
α_2 (Oilprice)			0.000451
			(0.00414)
α_3 (Exports)			0.0491**
			(0.0213)
α_4 (Imports)			0.0264
			(0.0334)
Constant	572.4***	554.5***	767.4***
	(87.34)	(65.49)	(99.75)
Observations	62	62	62
R^2	0.788	0.856	0.891

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The table above shows the regression output for Sweden. *CO_2 per capita* $(CO2\_PC)$ is the outcome variable and *GDP per capita* (GDP_PC) is the variable of interest. Observing Model 1 output, we see a relationship in line with the EKC inverted U-shape as the β_1 is positive and β_2 is negative. As both variables are significant at the 1%, this model implies some sort of EKC relationship for Sweden. In model 2, the cubic term GDP_PC^3 is added. In this model all coefficients are still significant at the 1%. The EKC theory continues to hold as β_1 is positive, β_2 is negative and β_3 is slightly positive and close to zero. When the control variables are added in model 3, interestingly, we observe that the signs are preserved while beta coefficients remain significant at the 1%. The beta coefficients retain their EKC consistent signs throughout model 1-3, giving support to the model specification. Using the equation explained under methodology on how to find the EKC turning point we find that the turning point for Sweden occurred at around $22 100 (2015 USD) per capita.

In conclusion, the regression analysis on Swedish data implies a statistically justifiable relationship between *GDP per capita* and *CO_2 per capita* needed to substantiate the EKC theory. If this relationship exists, the decoupling between *GDP per capita* and *CO_2 per capita* occurred at $22 100 (2015 USD) per capita.

6. Discussion

The data in the results allow us to infer that a cubic polynomial can be used as a plausible estimation for the relationship between Swedish CO_2 emissions and GDP per capita in accordance with the environmental Kuznets curve theory. The decoupling between Swedish CO_2 emissions and GDP per capita is estimated to have occurred at $22100 in 2015 USD. Sweden achieved this level of GDP per capita in the late 1960s and has increased since. Simultaneously the decoupling also took place in the late 1960s. However, this is not the case for Denmark, Finland, and Norway. The other Nordic countries have surpassed the level of GDP at which the Swedish turning point occurred during the time period examined. It is therefore possible to hypothesize that decoupling, as per the EKC theory, is not certain and to be expected for all countries. All countries in this report are to be considered good candidates for achieving decoupling, but only one country shows signs of decoupling. Our research thus indicates it cannot be suggested that countries, in general, can grow out of a positive relationship between economic growth and higher levels of pollution as decoupling is country specific.

Our study is consistent with other studies in the field in that for some cases we find evidence of a long-term relationship between economic growth and CO_2 emissions whereas in most cases we cannot. This is in line with the study made by Frodyma, Papież and Śmiech (2022), on EU countries. Their analysis concludes that, when looking at the EU countries production-based emissions for an extended time period, the EKC theory does not hold. They only find evidence of a long-term relationship between economic growth and CO_2 emissions in 11 out of 168 cases.

Both the visual inspection and regression analysis on Swedish data indicates the plausibility of an EKC relationship. The visual inspection on Danish and Finnish data suggests a turning point might have been reached. This indication is not validated by the regression analysis of the respective country data.

In the case of Denmark, it could be because the energy transition started off at later stage compared to Sweden. Sweden and Denmark started off at similar levels of economic development at the beginning of the time period. The EKC theory then implies that both countries should have had comparable developments in the relationship between economic growth and pollution. As we have seen in the results section, this is not the case. A possible explanation for these findings might be that Denmark, initially, was unable to make productive use of the technological advances in the energy sector. Unlike the other Nordic countries, Denmark did not have access to hydropower due to geographical conditions. Denmark was almost entirely dependent on fossil-based energy production up until the 1990s. During the same period, Denmark also experienced economic growth. According to the scale effect, increased economic activity with unchanged underlying nature, results in higher resource demand, the outcome of which is higher emissions. Denmark was unable to make use of existing technologies, such as hydropower. This gave Denmark a comparative advantage in investing into renewable energy sources such as wind power. Denmark has made great advancements in wind technologies and since the late 1990s investments have been made into transforming the Danish energy sector. The technological advancements in renewable energies have influenced the Danish economic development (Lipp, 2007). Today, Denmark is the world leader in green energy transition which could potentially be an explaining aspect for the tendency of an EKC relationship in the visual inspection of the Danish data.

In the Finnish data, as in the Danish data, we observe the tendency of a turning point in the ocular inspection. However, the existence of an EKC relationship is not found in the regression analysis. According to EKC theory, the turning point should appear at a high level of economic development. Finland had a lower level of economic development than Sweden at the beginning of the time series. As countries need to attain a certain level of economic development before reaching the turning point of the inverted U shape curve, the Finnish turning point may well lag behind that of Sweden. The turning point observed in the Finnish data appears late in the time series. More data points are therefore needed after the turning point for the analysis to make certain conclusions on the existence of a Finnish EKC.

Norway started off at a similar level of economic development as Sweden at the beginning of the time period. Even though Norway shares geographical and cultural similarities with Sweden, the Norwegian curve differs significantly due to the fact that the Norwegian economy is heavily reliant on the primary sector, specifically the oil industry. Ever since big oil discoveries were made in Norway, the country has focused its development to this industrial sector. The Norwegian oil industry has generated large revenues. This has enabled the country to invest heavily into environmental technologies. However, the effect of these investments has not materialized in a way that our econometric analysis can capture. Norway is also battling the offshore CO_2 emissions from extracting oil. Therefore, there is less potential for an EKC relationship in the case of Norway.

The energy sector used to be the largest emitter whereas today it is more often the transportation sector. In Denmark and Sweden, the transportation sector is the largest CO_2 emitter. In Finland and Norway, emissions from the transportation sector are the second largest. In Finland, the largest emitting sector is electricity and heat while in Norway, it is industry. According to the technique effect in decoupling theory, modern technology should lead to a decrease in emissions as new technology improve efficiency. However, in the transportation sector, these improvements are often nullified by increased road traffic and heavier vehicles with stronger engines. This is a challenge to all countries in this report, but Norway, due to a mountainous and inaccessible landscape, faces even greater challenges. Road transport accounts for 52% of Norwegian transports. However, the country has implemented carbon taxation in order to target the transportation sector. Denmark has invested heavily in converting main train lines from diesel to electric propulsion. From the information gathered, analysis of the graphs in appendix D, it is difficult to draw conclusions on the impact of emissions reduction in the transportation sector. Essentially, due to the technology effect being largely nullified, achieving a decoupling in the transportation is a more difficult task than that of the energy sector. This hypothesis is also supported in literature. The goal to decrease CO_2 intensity levels within the transportation sector will only be achieved if policies that prevent the nullification of the technology effect are introduced in a way that allows CO_2 intensity levels to reduce.

Whether environmental policy can influence a nation's potential of reaching an EKC is an important topic. Infrastructure and resources allow richer countries to put more priority on environmental regulation. All the nations included in this study are developed economies. In 2022, Martinsson *et al.* found evidence that the carbon tax implemented in Sweden in 1991 helped decrease aggregate CO_2 emissions in the manufacturing sector. Since Finland implemented a carbon tax in 1990, the study by Martinsson et al. could imply that similar effects will show up in Finland. The effect of environmental policy on minimizing CO_2 emissions is further proven by Ahmed *et al.* (2022), arguing that green taxation in the Nordic countries have contributed to environmental consciousness and minimizing emissions. All the Nordic countries are part of the EU wide policies such as the EU-ETS which will push the countries even further on implementing environmental regulation.

This study finds some evidence for a Swedish EKC curve. In the case of Denmark and Finland, arguments can be made that the beginning of a U-shaped relationship according to the EKC theory might emerge. According to our data on Norway, the country does not show any prospect in being compatible with the EKC theory.

7. Final remarks

This study set out to investigate whether the Environmental Kuznets Curve theory is applicable to the Nordic countries. Denmark, Finland, Norway, and Sweden are all developed economies considered to be at the forefront of environmental policy and application. Theoretically, all these countries meet the requirements on economic development needed to show a full inverted U-shape relationship in accordance with the EKC theory. The data set used in the analysis includes GDP and CO_2 emissions data together with controls to strengthen the robustness of the analysis. The result of the regression analysis implies country specific decoupling. Sweden is the only country in this study that shows a plausible EKC relationship. By testing the theory for four top candidate countries, we indirectly test the theory itself. As only one country shows clearly positive results, this begs the question if the theory is applicable at all. A breakdown analysis of aggregate territorial emissions reveals varying prospects of achieving decoupling in the different sectors. The extended analysis finally suggests possible future EKC compatibility for Danish and Finnish data, although more data points are required to conclude statistically significant results. In conclusion, increasing economic development will itself not be enough to create a decoupling between economic growth and emissions. Deliberate policy efforts by the government might be needed.

A natural progression of this work would be to repeat this study as more data points become available to see whether the inverted U-shape relationship becomes more evident in Danish and Finnish data. It could also be beneficial to investigate whether technological advances within environmental energy production and sustainable energy transition have had a positive effect on economic development in Denmark. Positive results from such a study could imply that investments into the environmental sector may drive economic development.

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List of appendices

Appendix A

Year	Dco2	Dgdp	Oilprice	Dexp	Dimp
1960	6.50	18.11	14.07	.	.
1961	6.87	19.13	13.20	.	.
1962	7.94	20.06	13.06	.	.
1963	8.68	20.03	12.90	.	.
1964	9.14	21.71	12.73	.	.
1965	9.31	22.52	12.51	.	.
1966	10.44	22.95	12.17	19.25	17.20
1967	10.14	24.03	11.83	19.97	18.40
1968	10.95	25.21	11.36	21.92	19.58
1969	12.13	26.70	10.77	23.24	22.08
1970	12.59	26.93	10.17	24.13	24.10
1971	11.49	27.55	12.13	25.65	24.45
1972	11.94	28.46	13.02	27.00	24.73
1973	11.79	29.45	16.26	29.26	29.13
1974	10.91	28.98	51.59	30.26	28.54
1975	11.02	28.48	47.06	30.04	27.12
1976	11.85	30.09	49.38	31.07	31.68
1977	12.15	30.56	50.40	32.18	31.95
1978	11.97	31.14	47.22	32.63	32.26
1979	12.31	32.27	95.60	36.19	34.41
1980	11.78	32.07	98.14	38.21	32.49
1981	10.11	31.87	86.79	41.51	32.67
1982	10.49	33.07	75.02	42.83	33.70
1983	9.81	33.95	65.15	44.80	34.36
1984	9.95	35.38	60.82	46.27	36.20
1985	11.75	36.78	56.24	49.07	39.80
1986	11.50	38.54	28.91	49.72	43.17
1987	11.38	38.59	35.63	52.14	42.67
1988	10.74	38.56	27.70	56.91	44.47
1989	9.51	38.79	32.27	59.56	46.87
1990	10.42	39.30	39.86	63.44	47.98
1991	12.46	39.74	32.24	67.36	49.92
1992	11.29	40.38	30.24	67.54	49.85
1993	11.69	40.25	25.79	68.37	49.15
1994	12.43	42.26	23.44	74.00	55.68
1995	11.77	43.31	24.52	76.01	59.47
1996	14.23	44.31	28.92	79.56	61.33
1997	12.39	45.57	26.12	83.14	67.00
1998	11.55	46.41	17.13	86.55	72.07
1999	11.02	47.62	23.68	96.31	73.91
2000	10.17	49.24	36.34	108.46	84.04
2001	10.43	49.47	30.31	112.10	86.06
2002	10.33	49.54	30.54	116.98	91.55
2003	11.25	49.60	34.40	115.57	90.60
2004	10.20	50.79	44.48	119.07	97.08
2005	9.51	51.84	61.30	128.38	108.15
2006	10.94	53.69	70.95	141.65	123.25
2007	10.02	53.94	76.66	146.82	130.45
2008	9.33	53.35	99.19	152.51	136.67
2009	8.84	50.46	63.12	138.44	120.35
2010	8.87	51.17	80.05	142.51	121.00
2011	7.94	51.64	108.60	152.76	130.00
2012	7.13	51.57	106.80	154.54	133.53
2013	7.44	51.83	102.42	157.03	135.49
2014	6.66	52.40	91.77	161.94	140.77
2015	6.20	53.25	48.53	167.74	147.19
2016	6.47	54.56	40.01	174.63	152.58
2017	6.03	55.74	48.54	183.04	158.96
2018	5.99	56.56	62.36	189.17	167.06
2019	5.32	57.55	55.15	198.69	172.00
2020	4.85	56.20	37.16	184.77	164.98
2021	5.05	58.59	60.16	199.22	178.54

Year	Fco2	Fgdp	Oilprice	Fexp	Fimp
1960	3.41	11.43	14.07	.	.
1961	3.34	12.21	13.20	.	.
1962	3.74	12.49	13.06	.	.
1963	4.27	12.81	12.90	.	.
1964	5.02	13.40	12.73	.	.
1965	5.54	14.07	12.51	.	.
1966	6.44	14.35	12.17	.	.
1967	6.21	14.58	11.83	.	.
1968	7.19	14.85	11.36	.	.
1969	8.20	16.28	10.77	.	.
1970	8.76	17.13	10.17	10.67	14.02
1971	8.79	17.51	12.13	10.54	13.99
1972	9.51	18.75	13.02	12.07	14.69
1973	10.57	19.95	16.26	12.94	16.57
1974	9.94	20.49	51.59	12.96	17.64
1975	9.77	20.76	47.06	11.25	18.08
1976	10.83	20.77	49.38	12.87	17.82
1977	10.58	20.76	50.40	14.94	17.52
1978	10.90	21.31	47.22	16.10	16.82
1979	11.38	22.77	95.60	17.65	19.93
1980	12.16	23.92	98.14	19.08	21.63
1981	10.71	24.13	86.79	20.19	20.64
1982	8.90	24.74	75.02	19.81	21.10
1983	8.54	25.36	65.15	20.67	21.96
1984	8.63	26.05	60.82	22.02	22.17
1985	10.11	26.86	56.24	22.16	23.58
1986	10.82	27.51	28.91	22.73	24.41
1987	11.67	28.41	35.63	23.49	26.55
1988	10.52	29.81	27.70	24.31	29.44
1989	10.56	31.21	32.27	24.72	32.09
1990	11.41	31.28	39.86	25.07	31.97
1991	11.01	29.28	32.24	23.09	27.71
1992	10.76	28.16	30.24	25.49	27.90
1993	11.11	27.83	25.79	29.74	28.28
1994	12.13	28.81	23.44	33.69	31.91
1995	11.38	29.91	24.52	36.64	34.52
1996	12.50	30.91	28.92	38.75	37.02
1997	12.20	32.77	26.12	44.18	41.42
1998	11.52	34.46	17.13	48.10	44.93
1999	11.40	35.89	23.68	53.56	46.85
2000	11.01	37.88	36.34	62.18	53.81
2001	12.05	38.78	30.31	63.31	54.56
2002	12.51	39.35	30.54	65.84	56.90
2003	13.94	40.04	34.40	65.17	59.24
2004	13.19	41.52	44.48	70.87	64.05
2005	10.87	42.53	61.30	75.79	71.21
2006	12.98	44.07	70.95	83.23	75.91
2007	12.62	46.21	76.66	90.71	81.51
2008	11.03	46.36	99.19	96.70	88.00
2009	10.47	42.41	63.12	77.25	73.04
2010	11.95	43.56	80.05	82.02	77.65
2011	10.51	44.47	108.60	83.69	82.47
2012	9.45	43.64	106.80	83.88	83.40
2013	9.51	43.04	102.42	84.36	83.50
2014	8.71	42.71	91.77	82.72	82.75
2015	8.05	42.80	48.53	83.04	84.38
2016	8.59	43.88	40.01	86.27	89.20
2017	8.09	45.17	48.54	93.89	93.05
2018	8.30	45.63	62.36	95.30	98.38
2019	7.68	46.14	55.15	101.66	100.71
2020	6.80	45.01	37.16	94.06	94.02
2021	6.79	46.47	60.16	98.44	99.03

Table A-1 (Regression input, Denmark) & Table A-2 (Regression input, Finland)

Year	Nco2	Ngdp	Oilprice	Nexp	Nimp
1960	3.65	19.13	14.07	.	.
1961	3.69	20.17	13.20	.	.
1962	3.86	20.58	13.06	.	.
1963	4.08	21.19	12.90	.	.
1964	4.38	22.09	12.73	.	.
1965	4.40	23.07	12.51	.	.
1966	5.21	23.76	12.17	.	.
1967	5.10	25.03	11.83	.	.
1968	5.53	25.39	11.36	.	.
1969	5.77	26.31	10.77	.	.
1970	7.22	26.63	10.17	27.41	26.41
1971	6.96	27.94	12.13	27.83	28.20
1972	7.47	29.21	13.02	31.61	27.97
1973	7.70	30.32	16.26	34.06	32.21
1974	6.95	31.32	51.59	34.33	33.62
1975	7.64	32.69	47.06	35.62	35.02
1976	8.28	34.43	49.38	39.97	39.56
1977	8.24	35.71	50.40	40.98	40.40
1978	8.04	36.95	47.22	45.08	34.02
1979	8.51	38.43	95.60	46.15	34.33
1980	7.79	40.06	98.14	48.29	35.25
1981	7.77	40.56	86.79	49.13	35.79
1982	7.52	40.51	75.02	49.20	37.63
1983	7.75	41.98	65.15	52.67	36.51
1984	8.18	44.39	60.82	56.81	38.61
1985	7.79	46.72	56.24	60.91	42.03
1986	8.36	48.43	28.91	62.29	46.95
1987	7.95	49.05	35.63	62.99	43.96
1988	8.48	48.66	27.70	66.93	42.90
1989	8.10	48.97	32.27	74.21	43.80
1990	8.27	49.74	39.86	80.56	44.90
1991	7.87	51.03	32.24	85.43	45.09
1992	8.04	52.55	30.24	89.54	45.86
1993	8.35	53.73	25.79	92.36	48.07
1994	8.74	56.12	23.44	100.15	50.86
1995	8.83	58.15	24.52	105.16	53.83
1996	9.49	60.77	28.92	115.70	58.56
1997	9.47	63.63	26.12	124.68	65.85
1998	9.45	64.91	17.13	125.51	71.62
1999	9.56	65.77	23.68	129.08	70.51
2000	9.38	67.44	36.34	133.18	71.93
2001	9.64	68.49	30.31	138.97	73.18
2002	9.39	69.11	30.54	138.59	73.91
2003	9.63	69.33	34.40	138.43	74.82
2004	9.65	71.65	44.48	139.86	81.56
2005	9.37	73.04	61.30	140.49	88.01
2006	9.42	74.19	70.95	139.36	96.00
2007	9.70	75.62	76.66	141.25	105.62
2008	9.39	75.04	99.19	141.44	109.00
2009	8.95	72.82	63.12	135.64	97.76
2010	9.35	72.43	80.05	136.39	105.98
2011	9.04	72.19	108.60	135.28	110.17
2012	8.83	73.18	106.80	137.61	113.31
2013	8.78	73.05	102.42	135.17	118.95
2014	8.77	73.65	91.77	139.77	121.33
2015	8.79	74.36	48.53	145.84	123.68
2016	8.55	74.49	40.01	147.39	126.98
2017	8.38	75.61	48.54	149.90	129.37
2018	8.36	75.95	62.36	148.06	131.18
2019	8.00	76.01	55.15	149.75	137.87
2020	7.66	75.02	37.16	147.92	121.41
2021	7.57	77.54	60.16	154.96	123.85

Year	Sco2	Sgdp	Oilprice	Sexp	Simp
1960	6.57	16.53	14.07	13.75	19.60
1961	6.49	17.38	13.20	14.46	19.64
1962	6.78	18.02	13.06	15.63	20.76
1963	7.27	18.88	12.90	16.77	22.24
1964	7.88	20.01	12.73	18.79	24.39
1965	8.09	20.58	12.51	19.84	27.15
1966	9.29	20.82	12.17	20.81	28.32
1967	8.76	21.35	11.83	21.96	29.03
1968	9.81	22.00	11.36	23.63	31.44
1969	10.84	22.94	10.77	26.34	35.49
1970	11.47	24.39	10.17	28.67	38.91
1971	10.44	24.45	12.13	30.05	37.62
1972	10.43	24.94	13.02	31.82	39.13
1973	10.73	25.88	16.26	36.18	41.83
1974	9.78	26.63	51.59	38.09	45.97
1975	9.86	27.20	47.06	34.55	44.36
1976	10.73	27.39	49.38	36.04	48.35
1977	10.39	26.86	50.40	36.58	46.51
1978	9.60	27.25	47.22	39.43	43.96
1979	10.23	28.23	95.60	41.84	49.06
1980	8.63	28.65	98.14	41.59	49.25
1981	8.34	28.75	86.79	42.88	47.35
1982	7.48	29.09	75.02	45.77	49.60
1983	7.00	29.63	65.15	50.13	50.10
1984	6.87	30.86	60.82	53.68	52.76
1985	7.47	31.47	56.24	54.36	56.91
1986	7.41	32.24	28.91	56.25	58.94
1987	7.11	33.21	35.63	58.52	63.27
1988	6.81	33.91	27.70	60.47	66.44
1989	6.54	34.58	32.27	62.39	71.56
1990	6.73	34.57	39.86	63.83	72.37
1991	6.72	33.94	32.24	62.58	68.83
1992	6.66	33.35	30.24	63.93	69.96
1993	6.62	32.47	25.79	68.92	68.05
1994	6.85	33.51	23.44	78.30	76.80
1995	6.75	34.65	24.52	87.13	82.35
1996	7.18	35.14	28.92	90.98	85.17
1997	6.60	36.20	26.12	103.66	95.67
1998	6.65	37.74	17.13	112.90	106.12
1999	6.33	39.31	23.68	121.03	111.86
2000	6.19	41.12	36.34	135.60	125.56
2001	6.27	41.60	30.31	136.40	123.75
2002	6.36	42.38	30.54	138.72	122.48
2003	6.40	43.19	34.40	144.69	126.33
2004	6.30	44.89	44.48	160.98	134.97
2005	5.99	45.99	61.30	171.29	144.20
2006	5.93	47.86	70.95	186.04	156.21
2007	5.81	49.15	76.66	194.59	168.75
2008	5.54	48.54	99.19	198.19	173.90
2009	5.10	46.04	63.12	169.54	148.63
2010	5.68	48.37	80.05	187.59	165.69
2011	5.23	49.54	108.60	200.20	177.43
2012	4.93	48.89	106.80	202.44	179.23
2013	4.72	49.05	102.42	200.21	178.87
2014	4.48	49.86	91.77	208.95	190.29
2015	4.46	51.55	48.53	221.07	201.82
2016	4.38	51.96	40.01	226.37	210.85
2017	4.25	52.58	48.54	235.73	220.82
2018	4.14	52.98	62.36	245.74	229.26
2019	3.99	53.49	55.15	260.42	234.14
2020	3.53	51.54	37.16	248.46	221.11
2021	3.44	53.69	60.16	267.06	241.98

Table A-3 (Regression input, Norway) & Table A-4 (Regression input, Sweden)

Appendix B

This appendix contains the raw Stata output presented in the results section together with illustrative graphs of the polynomial estimation for each country.

Linear regression		
Number of obs	=	62
F(3, 58)	=	262.82
Prob > F	=	0.0000
R-squared	=	0.8605
Root MSE	=	.84319

Dco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Dgdp	1.400799	.0821891	17.04	0.000	1.23628	1.565318
Dgdp2	-.0115596	.0010184	-11.35	0.000	-.0135982	-.009521
time	-.3802766	.0370701	-10.26	0.000	-.4544803	-.3060728
_cons	731.0653	72.00471	10.15	0.000	586.9322	875.1984

Table B-1 (Regression Output, Model 1 Denmark)

Linear regression		
Number of obs	=	62
F(4, 57)	=	192.13
Prob > F	=	0.0000
R-squared	=	0.8610
Root MSE	=	.84906

Dco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Dgdp	1.565538	.3098511	5.05	0.000	.9450716	2.186004
Dgdp2	-.0160005	.0084117	-1.90	0.062	-.0328446	.0008436
Dgdp3	.0000391	.0000736	0.53	0.598	-.0001084	.0001865
time	-.3842065	.0365871	-10.50	0.000	-.4574708	-.3109421
_cons	736.8819	70.99624	10.38	0.000	594.7144	879.0494

Table B-2 (Regression Output, Model 2, Denmark)

```
Linear regression                               Number of obs     =         56
                                                F(7, 48)          =     110.71
                                                Prob > F          =     0.0000
                                                R-squared         =     0.8758
                                                Root MSE          =     .82957
```

Dco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Dgdp	-.672445	.693002	-0.97	0.337	-2.065819	.720929
Dgdp2	.0330563	.0149665	2.21	0.032	.0029642	.0631485
Dgdp3	-.0003006	.0001035	-2.90	0.006	-.0005088	-.0000925
time	-.2024688	.0938144	-2.16	0.036	-.3910954	-.0138422
Oilprice	.0005458	.0046624	0.12	0.907	-.0088285	.0099201
Dexp	-.0941692	.0475116	-1.98	0.053	-.1896977	.0013592
Dimp	.0432699	.0350866	1.23	0.223	-.0272764	.1138161
_cons	411.5827	177.1449	2.32	0.024	55.40894	767.7565

Table B-3 (Regression Output Table, Model 3, Denmark)

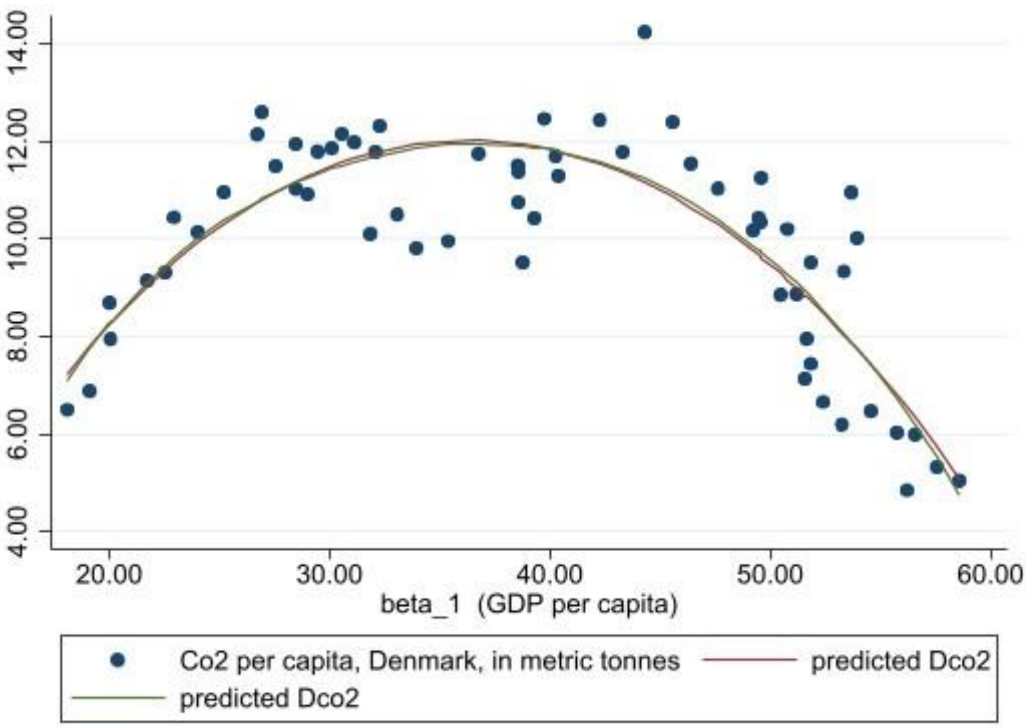

Figure B-1 (Polynomial fit, Denmark)

Linear regression

Number of obs	=	62
F(3, 58)	=	75.29
Prob > F	=	0.0000
R-squared	=	0.7916
Root MSE	=	1.1723

Fco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Fgdp	1.560502	.1240907	12.58	0.000	1.312108	1.808897
Fgdp2	-.0175617	.001498	-11.72	0.000	-.0205602	-.0145632
time	-.2603861	.048327	-5.39	0.000	-.357123	-.1636492
_cons	499.1315	93.79831	5.32	0.000	311.3738	686.8892

Table B-4 (Regression Output Table, Model 1, Finland)

Linear regression

Number of obs	=	62
F(4, 57)	=	79.51
Prob > F	=	0.0000
R-squared	=	0.8027
Root MSE	=	1.1507

Fco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Fgdp	2.310203	.3794169	6.09	0.000	1.550434	3.069973
Fgdp2	-.0453091	.0137436	-3.30	0.002	-.0728302	-.0177879
Fgdp3	.0003185	.0001562	2.04	0.046	5.68e-06	.0006313
time	-.2680611	.0477166	-5.62	0.000	-.363612	-.1725102
_cons	508.1771	92.75675	5.48	0.000	322.4349	693.9193

Table B-5 (Regression Output Table, Model 2, Finland)

Linear regression		
	Number of obs =	52
	F(7, 44) =	16.62
	Prob > F =	0.0000
	R-squared =	0.6543
	Root MSE =	1.0365

Fco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Fgdp	-.504665	.9454542	-0.53	0.596	-2.410103	1.400773
Fgdp2	.0286013	.0288622	0.99	0.327	-.0295665	.0867692
Fgdp3	-.0002782	.0002772	-1.00	0.321	-.0008368	.0002804
time	-.048373	.0795258	-0.61	0.546	-.2086468	.1119007
Oilprice	.0041668	.0057757	0.72	0.474	-.0074733	.015807
Fexp	.1215006	.0399161	3.04	0.004	.0410551	.2019462
Fimp	-.260276	.0584802	-4.45	0.000	-.378135	-.1424169
_cons	108.7286	151.3695	0.72	0.476	-196.3366	413.7937

Table B- 6 (Regression Output Table, Model 3, Finland)

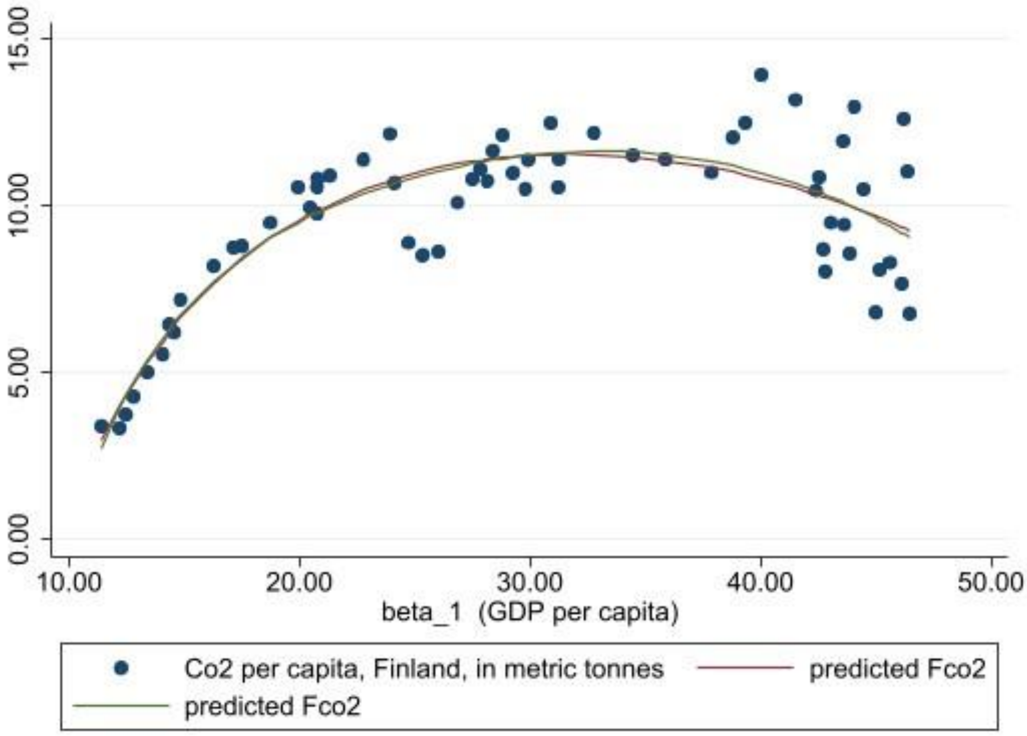

Figure B-2 (Polynomial fit, Finland)

Linear regression	Number of obs	=	62
	F(3, 58)	=	102.55
	Prob > F	=	0.0000
	R-squared	=	0.8724
	Root MSE	=	.60206

Nco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Ngdp	.3837916	.0287643	13.34	0.000	.3262135	.4413697
Ngdp2	-.0025273	.0002976	-8.49	0.000	-.003123	-.0019316
time	-.0730532	.0178755	-4.09	0.000	-.1088348	-.0372716
_cons	141.1945	34.99631	4.03	0.000	71.1418	211.2472

Table B-7 (Regression Output Table, Model 1, Norway)

Linear regression	Number of obs	=	62
	F(4, 57)	=	200.88
	Prob > F	=	0.0000
	R-squared	=	0.9200
	Root MSE	=	.48087

Nco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Ngdp	1.19263	.1247765	9.56	0.000	.9427698	1.442491
Ngdp2	-.019371	.0026596	-7.28	0.000	-.0246966	-.0140453
Ngdp3	.0001174	.0000185	6.36	0.000	.0000804	.0001543
time	-.1545532	.0182259	-8.48	0.000	-.19105	-.1180564
_cons	290.0739	34.83135	8.33	0.000	220.3253	359.8225

Table B-8 (Regression Output Table, Model 2, Norway)

```
Linear regression                               Number of obs     =         52
                                                F(7, 44)          =      90.59
                                                Prob > F          =     0.0000
                                                R-squared         =     0.9053
                                                Root MSE          =      .2556
```

Nco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Ngdp	.0937689	.1534301	0.61	0.544	-.2154492	.4029869
Ngdp2	.0015442	.003213	0.48	0.633	-.0049312	.0080196
Ngdp3	-.0000198	.0000197	-1.00	0.321	-.0000594	.0000199
time	-.1968529	.0197341	-9.98	0.000	-.2366245	-.1570814
Oilprice	.0030493	.0021394	1.43	0.161	-.0012624	.0073611
Nexp	.0273258	.0115262	2.37	0.022	.0040963	.0505553
Nimp	.0282152	.0071851	3.93	0.000	.0137346	.0426958
_cons	390.2703	37.20233	10.49	0.000	315.2939	465.2466

Table B-9 (Regression Output Table, Model 3, Norway)

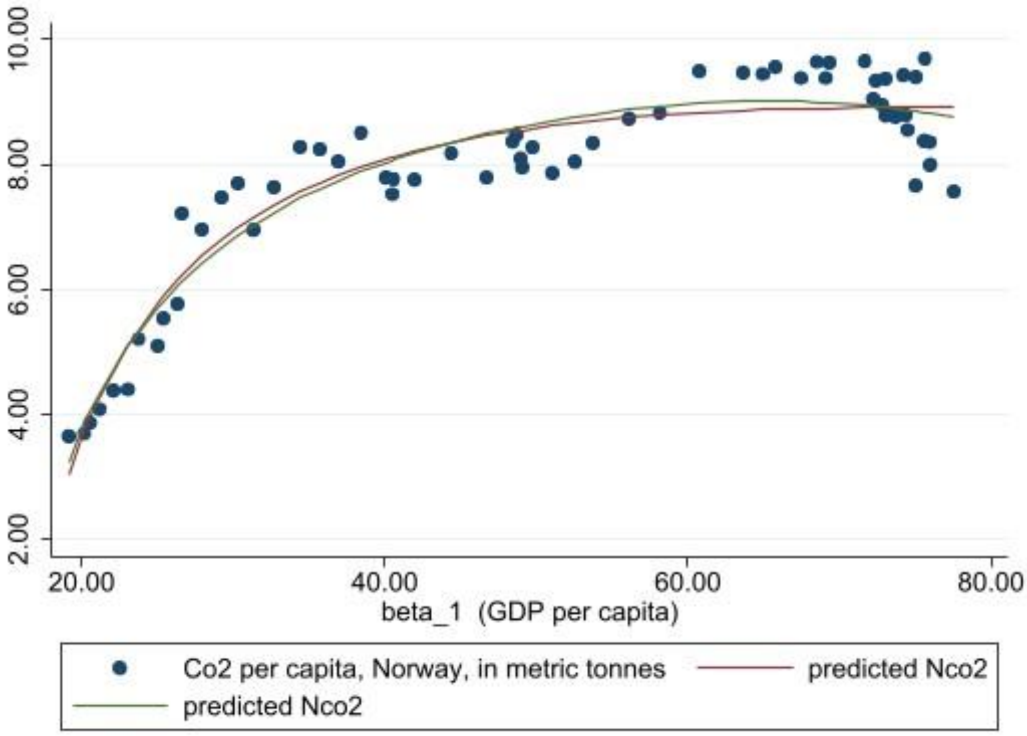

Figure B-3 (Polynomial fit, Norway)

Linear regression	
Number of obs	= 62
F(3, 58)	= 91.45
Prob > F	= 0.0000
R-squared	= 0.7876
Root MSE	= .95876

Sco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Sgdp	.8660551	.1651259	5.24	0.000	.5355197	1.19659
Sgdp2	-.0074408	.0014837	-5.02	0.000	-.0104107	-.004471
time	-.2942437	.045671	-6.44	0.000	-.3856641	-.2028233
_cons	572.3835	87.34036	6.55	0.000	397.5527	747.2142

Table B-10 (Regression Output Table, Model 1, Sweden)

Linear regression	
Number of obs	= 62
F(4, 57)	= 114.65
Prob > F	= 0.0000
R-squared	= 0.8557
Root MSE	= .79708

Sco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Sgdp	2.713077	.3341877	8.12	0.000	2.043878	3.382276
Sgdp2	-.063425	.0088647	-7.15	0.000	-.0811763	-.0456737
Sgdp3	.0005322	.0000808	6.59	0.000	.0003704	.0006939
time	-.2947878	.0345486	-8.53	0.000	-.3639702	-.2256053
_cons	554.46	65.49102	8.47	0.000	423.3165	685.6035

Table B-11 (Regression Output Table, Model 2, Sweden)

Linear regression

Number of obs	=	62
F(7, 54)	=	62.12
Prob > F	=	0.0000
R-squared	=	0.8914
Root MSE	=	.71061

Sco2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
Sgdp	3.170472	.443885	7.14	0.000	2.280536	4.060408
Sgdp2	-.071675	.014145	-5.07	0.000	-.100034	-.043316
Sgdp3	.0004906	.0001448	3.39	0.001	.0002003	.000781
time	-.4067867	.0510746	-7.96	0.000	-.5091851	-.3043883
Oilprice	.000451	.004138	0.11	0.914	-.0078452	.0087473
Sexp	.0491295	.0212731	2.31	0.025	.0064795	.0917795
Simp	.0264173	.0333899	0.79	0.432	-.0405254	.0933601
_cons	767.3826	99.7523	7.69	0.000	567.3913	967.374

Table B-12 (Regression Output Table, Model 3, Sweden)

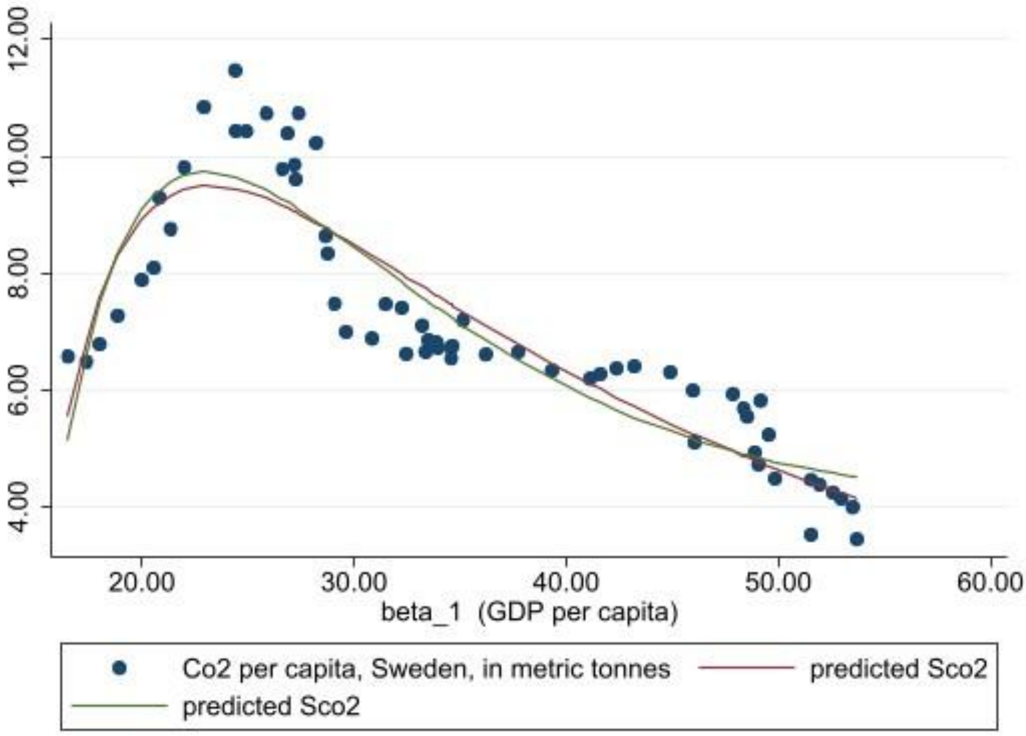

Figure B-4 (Polynomial fit, Sweden)

Appendix C

Variable	Obs	Mean	Std. dev.	Min	Max
Dco2	62	9.92476	2.201656	4.849947	14.22526
Fco2	62	9.637656	2.504036	3.344919	13.9371
Nco2	62	7.855855	1.643189	3.654266	9.697285
Sco2	62	7.085903	2.028588	3.441777	11.47449
Dgdp	62	39.74343	11.91156	18.10738	58.58551
Fgdp	62	30.09122	11.41384	11.42529	46.47136
Ngdp	62	51.39205	19.80321	19.13406	77.54403
Sgdp	62	35.31101	11.14294	16.52536	53.69253
Dexp	56	88.78768	56.83647	19.25105	199.2201
Fexp	52	48.65149	31.58857	10.54346	101.658
Nexp	52	98.26711	44.44948	27.40531	154.961
Sexp	62	101.0447	78.76335	13.74721	267.0621
Dimp	56	75.15466	49.72051	17.1989	178.5358
Fimp	52	48.26801	29.27444	13.99095	100.7072
Nimp	52	69.73418	35.39681	26.41476	137.8699
Simp	62	96.34511	66.515	19.60385	241.9843
Oilprice	62	44.27268	28.36446	10.17336	108.6027

This table shows descriptive statistics for the input variables. Where: *Xco2* is CO_2 per capita in metric tons. *Xgdp* is GDP per capita in thousands of 2015 US Dollars, *Xexp* is exports in billions of 2015 USD, *Ximp* is imports in billions of 2015 USD, for Denmark, Finland, Norway, and Sweden (e.g., Dgdp = Danish GDP). *Oilprice* is the price per barrel of Brent Crude in 2015 US Dollars.

Table C-1 (Descriptive statistics)

Appendix D

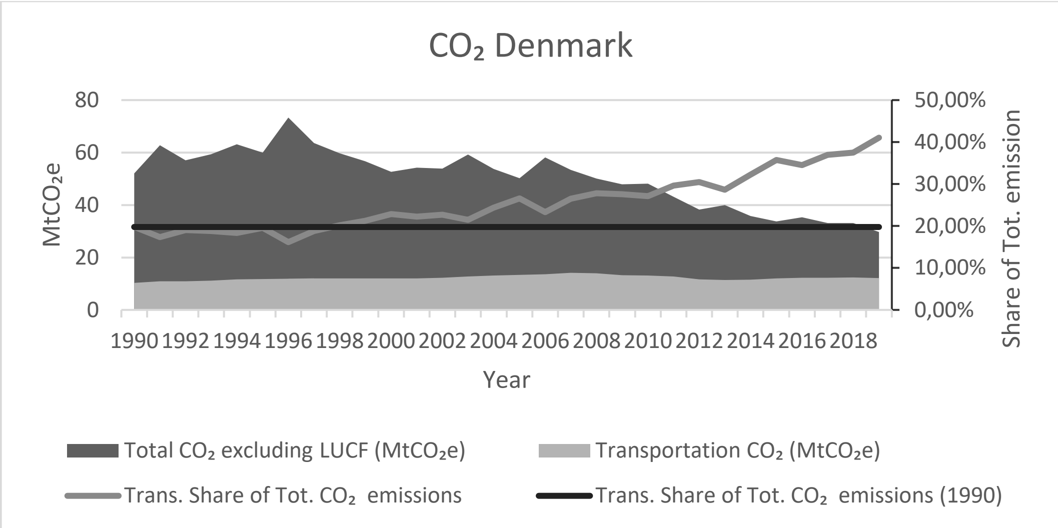

Figure D-1 (CO_2 Emissions breakdown, Denmark)

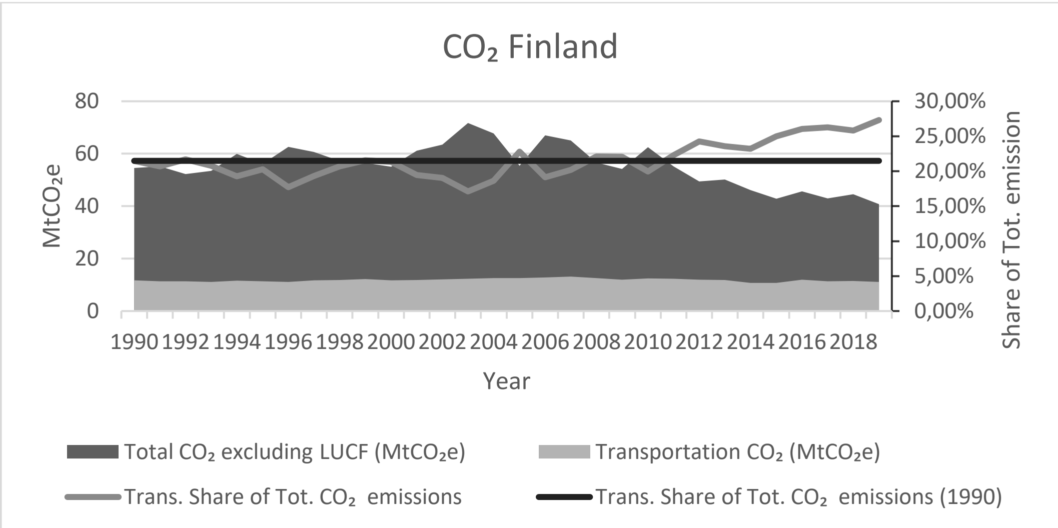

Figure D-2 (CO_2 Emissions breakdown, Finland)

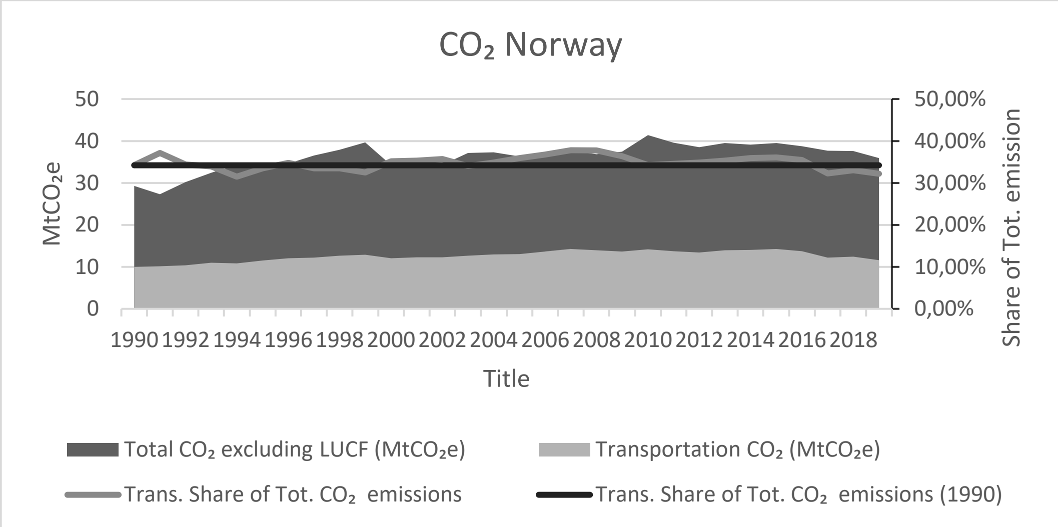

Figure D-3 (CO_2 Emissions breakdown, Norway)

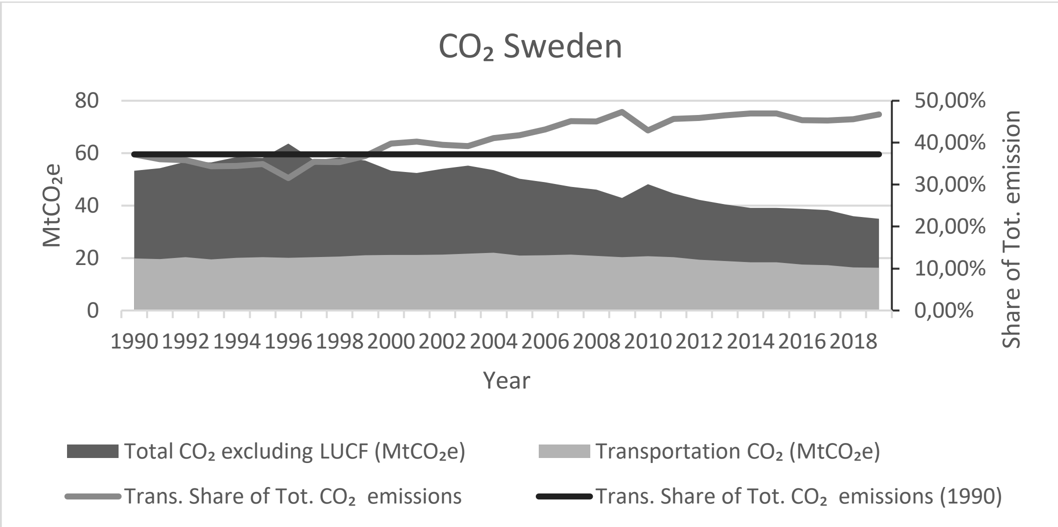

Figure D- 4 (CO_2 Emissions breakdown, Sweden)