Assessing the Impact of Pollution Permits:
An Effective Solution or an Environmental Illusion?

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Foreword

The master thesis completes the Master of Science in Public Administrations at Leiden University. The thesis has been written in the specialisation of Economics and Governance, more specifically in a capstone focused on environmental economics. The master has aimed at providing an interdisciplinary view on current challenges developing all over the world. Embedded in the research on fundamental changes like globalisation, the master's outlook goes hand in hand with the research of this thesis. In the widest sense, this thesis deals with the global challenge of climate change.

Global warming needs to be addressed not only on an international scale, but also on a local and regional level. Thus, the thesis fits very well in the multi-level perspective the master tried to incorporate. The thesis is directly based on courses like *Economics of Regulation* and *Research Methods: Applied Empirical Economics*. The thesis relates to the broader context of other courses like *Public Institutions* which has dealt with major societal problems and how they can be addressed; the problem the thesis is focusing on is how carbon prices tackle the problem of excess pollution and climate change respectively.

The chosen topic has gained increased popularity since the Kyoto Protocol. Carbon prices have been introduced in different places worldwide, again on a local, regional, national or even supra-national level. In a time where global warming becomes increasingly visible and threatening, research about the effectiveness of specific policies tackling the problem of excess greenhouse gases is essential. Therefore, the thesis made the best use possible of publicly available sources to assess the impact of the stringency of cap-and-trade systems. The thesis contains skills that have been acquired specifically in the courses of this master's programme, especially an in-depth analysis and application of economic theory and the performance of a statistical analysis. The results can now be found in the final version of this thesis.

Saskia Dietz | The Hague, June 2018

Abstract

After the Kyoto Protocol has been adopted in 1997, different cap-and-trade systems were developed on local, regional, national and supranational levels. Empirical research has already focused on individual cap-and-trade systems, like the Regional Greenhouse Gas Initiative (RGGI) in the United States (e.g. Hibbard & Tirney, 2011; Schutt, 2016). Nonetheless, a profound panel regression that includes various states and cap-and-trade systems has been missing so far. As cap-and-trade systems are still being introduced, like the Chinese cap-and-trade systems in December 2017, the assessment of the effectiveness of carbon prices in a cross-country framework is highly relevant: Can the levels of CO_2 emissions per capita in OECD and BRIICS countries be explained by the stringency of CO_2 permits in these countries?

The stringency of permits is defined by the permit cost (per ton of emissions) relative to the price of electricity (per megawatt hour). The higher the additional cost imposed by the permit relative to the price of electricity, the higher the level of stringency. The thesis makes use of the OECD's indicator of Environmental Policy Stringency, to determine whether CO_2 emissions per capita decrease if permit regulation is more stringent. Via a comparative ordinary least squares and two-stage least squares analysis, the thesis finds a robust significant negative correlation between stringency and CO_2 permits in 34 countries, being in line with the theory of externalities that increased costs for pollution lead to a lower level of pollution in practice.

Key words: Cap-and-trade systems, environmental economics, theory of externalities

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1. Introduction

> The cap-and-trade approach combines the efficiency of the carbon tax with easier enforcement. For that reason we believe it should sit at the heart of any successful global climate agreement.
>
> -Christian Gollier and Jean Tirole, *The Economist*, 2015

The Paris Agreement entered into force on November 4th, 2016 and currently comprises 174 out of the 192 Member States of the United Nations (UN, n.d.). Article 2 of the Paris Agreement (2015) aims at "holding the increase in the global average temperature to well below 2°C above pre-industrial levels". The Paris Agreement acknowledges that the reduction of greenhouse gases plays a significant role in combating climate change (Article 4). Nonetheless, the Paris Agreement has not been the first international agreement on climate. The Kyoto Protocol had been signed about twenty years earlier, setting binding emission reduction targets (1998). The enforcement of the Kyoto Protocol led to many different measures in different countries, aiming at the reduction of greenhouse gases. The measures mainly resulted in the introduction of taxes or tradeable pollution permits (International Carbon Action Partnership [ICAP], 2017).

The reduction of greenhouse gases has gained global attention due to its potential devastating consequences. Global warming leads to a rise of the sea level which threatens coastal areas and causes extreme weather events. Extreme weather events include heat waves, droughts and floods (European Commission, 2018). They cause high economic and societal costs due to environmental damages. These costs go beyond directly measurable costs caused by extreme weather conditions. They include indirect costs for weather-dependent economic sectors, such as tourism and agriculture (European Commission, 2018). The potentially high direct and indirect costs of climate change make the issue of greenhouse gases one of high societal relevance.

In the light of a catastrophic future outlook, China joined the efforts to combat climate change and launched the world's largest cap-and-trade system in December 2017 (Harvey & Min, December 19, 2017). Even though the cap-and-trade system only covers power generation in the first phase, the emissions that are targeted are almost twice as high as the ones targeted under the EU ETS (Harvey & Min, December 19, 2017). After seven regional cap-and-trade system pilot programmes have been tested in China, the newly established cap-and-trade system is the first national one in the aftermath of the Paris Agreement. It demonstrates the practical relevance of pollution permits for governments. Next to an increase in regional and national cap-and-trade systems, an increasing number of firms are introducing internal carbon prices. The firms want to “stress-test investments for a world of government-mandated levies” (The Economist, 2018, January 11). The introduction of internal carbon prices is no new phenomenon, but the speed at which the introduction of internal carbon prices is currently taking place suggests the development of a new trend (The Economist, 2013, December 14). It underlines that the question about the effectiveness of carbon pricing is highly relevant. Effectiveness is defined as the extent to which a certain goal can be achieved. In the case of CO_2 permits and other climate policies the overall goal is to reduce emissions.

The academic literature has focused on many related issues in the past. The Kyoto Protocol, the Paris Agreement and the sustainable development goals have been analysed in depth (e.g. Dagoumas, Papagiannis, & Dokopoulas, 2004; Liobikien & Bhutas, 2017). Furthermore, the functioning of different environmental policies, such as pollution permits, environmental taxes and environmental standards have been analysed (e.g. Brink, Vollebergh, & van der Werf, 2016; Turner, Pearce, & Bateman, 2014; Rose & Stevens, 1993). Nevertheless, the academic gap that can be identified lies in cross-national comparisons assessing the effectiveness of carbon pricing.

This thesis’ academic relevance lies in advancing the literature in this field by applying the relatively new Organisation for Economic Co-operation and Development (OECD) indicator of Environmental Policy Stringency that has only been used in relation to economic productivity so far (Botta & Kozluk, 2014). The analysis is embedded in the field of environmental economics and based on the economic theory of externalities. Theory assumes that the more the costs of creating pollution are reflected in the price, the fewer products should be produced for a given demand in the polluting sector. Making use of a dataset that combines OECD and BRIICS (Brazil, Russia, India, Indonesia, China and South Africa) countries, the thesis addresses the following research question: Can the levels of carbon dioxide (CO_2) emissions per capita in OECD and BRIICS countries be explained by the stringency of CO_2 permits in these countries?

The stringency of permits is defined by the permit cost (per ton of emissions) relative to the price of electricity (per megawatt hour (MWh)). The higher the additional cost imposed by the permit relative to the price of electricity, the higher the level of stringency. There are two other terms in the research question that require some discussion. CO_2 permits will be referred to as allowances and permits interchangeably. CO_2 emissions will be called pollution and emissions throughout the thesis. Furthermore, permits create cap-and-trade systems which will be analysed in depth. Emission trading systems, carbon markets and cap-and-trade-systems refer to the same concept:

> A system for controlling carbon emissions and other forms of atmospheric pollution by which an upper limit is set on the amount a given business or other organization may produce but which allows further capacity to be bought from other organizations that have not used their full allowance. (Oxford University Press, n.d.)

For ease of readability, the thesis will use the term cap-and-trade system for this concept throughout the paper. Merely focusing on CO_2 emissions does not decrease the academic relevance of this thesis with regard to overall greenhouse gas levels. Figure 1 has been taken from the United States Environmental Protection Agency (EPA) and shows that the level of carbon dioxide has by far the highest share of greenhouse gas emissions.

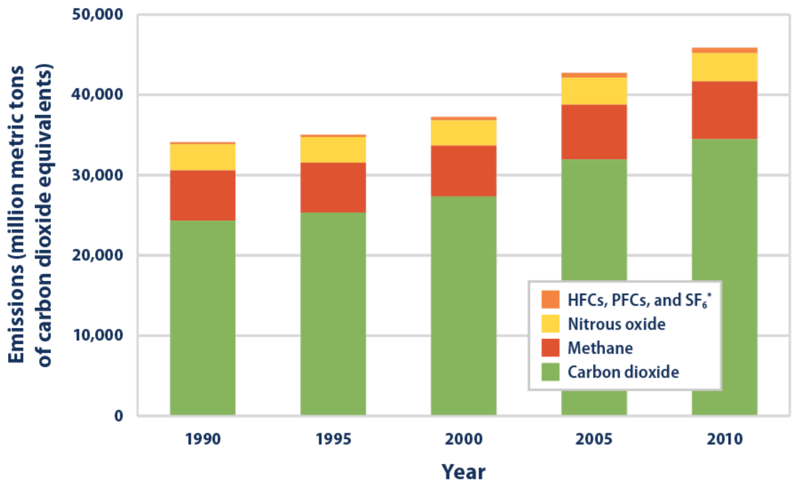

Figure 1: Global greenhouse gas emissions by gas, 1990-2010 (EPA, 2014)

The structure of this thesis is as follows. Chapter 2 discusses the theoretical background to put the topic into the context of the academic literature. This includes the theories that have already been mentioned in this introduction. Chapter 3 compares the four different trading schemes that are included in the thesis and reviews the academic findings in this area. The research design is presented in Chapter 4 concurrently with the data collection and data analysing method. This part focusses in-depth on the OECD Environmental Stringency Index, which is used in the statistical part of the thesis.

Following the operationalisation part, the statistical analysis in Chapter 5 is divided into two parts: Firstly, descriptive statistics will visualise the data and examine common trends and observable characteristics in the data. Secondly, inferential statistics will aim at answering the research question by using a cross-country panel regression. The analysis is completed by the conclusion in Chapter 6. After the list of references and list of sources, the appendices provide additional insight into the results of the statistical analysis.

2. Theoretical Framework and Literature Review

This chapter sets the thesis into the international context of the Kyoto Protocol, the Paris Agreement and the sustainable development goals. The theoretical framework embeds the thesis in the literature of environmental economics and the theory of externalities. Furthermore, the theoretical part focusses in detail on the different policies that can internalise externalities, their advantages and disadvantages.

2.1 International Context

It is important to take the international context into consideration when studying the effect of CO_2 permits in a global context. The next section discusses the Kyoto Protocol and the Paris Agreement and the current insights related to both treaties. Additionally, the analysis will take into account the United Nation's (UN) sustainable development goals and their applicability to the thesis' topic. The implications following from the discussed studies for the thesis' own analysis will be highlighted.

2.1.1 Kyoto Protocol

The Kyoto Protocol was signed as the first binding international treaty on climate change on December 11, 1997 in the city of Kyoto in Japan (United Nations Framework Convention on Climate Change [UNFCCC], n.d.-a). The treaty is linked to the United Nations Framework Convention on Climate Change (UNFCCC). The details concerning the implementation of the Kyoto Protocol were decided in Marrakesh in 2001, known as the Marrakesh Accords. The Kyoto Protocol entered into force in 2005 and the first commitment period ran from 2008 until 2012 (UNFCCC, n.d.-a; UNFCCC, n.d.-b). In 2012, the Doha Amendment changed articles of the Kyoto Protocol, revised the list of greenhouse gases, and added new commitments for Annex I countries for the second commitment period. The second commitment period takes place between 2013 and 2020 (UNFCCC, n.d.-b).

The treaty has been signed by 191 countries and the European Union (EU). In the United States of America (USA) the treaty did not enter into force, even though they belong to the 83 signatories which showed their support for a global climate agreement in the first place (UNFCCC, n.d.-a). The countries have been split in two groups: Annex I countries are industrialised nations and non-Annex I countries are developing and emerging countries (Bhatti, Lindskow, & Pedersen, 2010, p. 132). The threshold for Annex I parties has been set at a reduction of five percent of the greenhouse gases in the first commitment period and eighteen percent in the second commitment period compared to 1990 levels (UNFCCC, n.d-b). Compliance is ensured by a registry system in which parties report their annual greenhouse gas emissions. Additionally, a compliance system and an adaptation assistance have been installed to support countries in meeting their targets (UNFCCC, n.d.-b).

The international treaty consists of three different mechanisms: international emission trading, the Clean Development Mechanism (CDM) and Joint Implementation (JI). The three mechanisms aim at achieving the Kyoto targets in a cost-effective way and creating incentives for investment (see Chapter 2.3 for a discussion of cost-effectiveness; UNFCCC, n.d.-b). International emission trading refers to the assigned quantities of emissions that every country is allowed to produce within a given period (UNFCCC, n.d.-c).

The Kyoto Protocol offers the possibility to trade spare emission quantities or to buy additional permits to pollute, creating a cap-and-trade system. Through the CDM, countries can gain certified emission reduction (CER) credits by investing in projects that reduce emissions in developing countries (UNFCCC, n.d.-d). Credits from the CDM will be credited to the respective countries to ease the compliance with the emission targets. Joint Implementation (JI) functions in the same way as CDM with the difference that Annex I countries can earn emission reduction units (ERUs) by investing in emission-reduction projects in other industrialised countries (UNFCCC, n.d.-a).

The Kyoto Protocol attracted a lot of research. This research focused not only on the negotiations of the Kyoto Protocol, but also on the compliance with the Kyoto Protocol's targets. Before assessing the effectiveness of the treaty, the way in which targets were set and agreements reached needs to be addressed. Bhatti, Lindskow and Pedersen (2010) analysed why countries were willing to accept burden-sharing in the context of the Kyoto negotiations. The paper examined different hypotheses with regard to particular country characteristics, such as previous emission reductions or future growth rates (pp. 136-137). The targets were distributed among the participating countries in 1997 for the years between 2008 and 2012 (p. 143).

Using an ordinary least squares model, the results show that the more a country reduced its greenhouse gas emissions between 1990 and 1997, the more lenient were its target in the Kyoto Protocol (Bhatti, Lindskow, & Pedersen, 2010, p. 140; p. 143). While fast-growing and poor countries received more lenient targets, countries with high levels of greenhouse gas emission per capita received the most stringent targets (p. 143). Thus, the authors found that the targets of the Kyoto Protocol varied based on country-specific characteristics (p. 144). Other research showed that the level of democracy positively influences the probability of ratification, while countries are not influenced by the decisions of their neighbouring states (Sauquet, 2012, pp. 152-153). The research shows that there are observable reasons why different countries are treated or behave differently on a global level. To achieve generalisable results, it is necessary to include as many countries as possible in an analysis that is embedded in a global context. Further, the measure of stringency should be more accurate than the mere inclusion of the permit price, because it is a relative measure, based on national prices of electricity. A relative measure ensures that cross-country differences are captured.

The application of the Kyoto targets and their impact will be assessed next. Analysing 66 regions and 57 sectors, Dagoumas, Papagiannis and Dokopoulos (2004) compared various policies to a reference scenario (pp. 27-28). They found that national climate policies cause negative consequences for developed countries. Despite this, trading mechanisms and the introduction of carbon sinks might reduce compliance costs. Carbon sinks refer to actions that increase the CO_2 reduction through specific land management, for example through forestation (p. 37).

The reduction of CO_2 in the atmosphere through carbon sinks can be referred to as negative emissions. Negative emissions follow the aim of overall carbon dioxide removal (CDR) to decrease the already existent CO_2 in the atmosphere (European Academies Science Advisory Council [EASAC], 2018, p. 5). Research has focused more concretely on the extent of reduced CO_2 emissions through the Kyoto Protocol (Almer & Winkler, 2016). It finds that the reduction of CO_2 emissions in the 15 Annex I countries has not been significant since the introduction of targets (p. 139). It follows that a simple reduction in emissions cannot always be linked to a certain policy and that a causal link has to be established to assess the reasons for fewer emissions.

Another analysis of the impact of the Kyoto Protocol on all greenhouse gases found, in contrast to the previous study, a significant reduction of CO_2 and CH_4, but not a decrease of the other greenhouse gases (Iwata & Okada, 2012, p. 333). The different results show how debated the issue of the effectiveness of the Kyoto Protocol still is and how different models lead to different findings. When the effectiveness of the Kyoto Protocol as such remains unclear, the analysis of a more specific policy that arose from the Kyoto Protocol might be more meaningful.

While the direct impact of the protocol remains debatable, Shishlov, Morel and Bellassen (2016) found that nine countries exceeded the Kyoto targets in the first commitment period (p. 770). In contrast to the other papers, they analysed why so many countries complied with the targets: The collapse of the Soviet Union led to a large drop of CO_2 emissions in the respective countries which left a large quantity of pollution available to comply with the targets. Additionally, the global and financial crisis, the introduction of environmental policies, and that Canada and the US were not participating, made it easier to comply with the targets (pp. 771-772). Thus, external causes were highly relevant in this context. It highlights again that the assessment of the effectiveness of the treaty cannot solely rely on the overall implementation of the protocol. An analysis has to be focused on specific policies. It has to take into account time trends to capture external trends. To create reliable results, other variables need to be considered, including for example the gross domestic product (GDP) which largely dropped during the global and financial crisis.

The different ways in which the Kyoto Protocol has been analysed has shown different implications for an analysis in the area of pollution. When dealing with global issues, it is necessary to perform cross-country analyses, to derive generalisable results. Furthermore, to capture the real cause of emission reductions, time trends and other important variables have to be taken into account, as external causes might bias the results. The difficulty in analysing the real impact of the Kyoto Protocol shows that an assessment of pollution permits might be more likely to capture the effect of changed pollution policies in a global context.

2.1.2. Paris Agreement

The Paris Agreement entered into force on November 4, 2016 (UNFCCC, n.d.-e). Since then, 174 parties ratified the treaty. All industrialised nations ratified the treaty, even though the President of the United States of America, Donald Trump, declared the withdrawal from the agreement in June 2017 (Trump, June 1, 2017). The Paris Agreement aims at keeping “the increase in the global average temperature to well below 2°C above pre-industrial levels” (Paris Agreement, 2015, Article 2). It favours an even lower temperature rise of maximum 1.5 degrees Celsius (UNFCCC, n.d.-e). Additionally, the agreement aims at supporting the countries that are suffering from climate change to pursue the goals of the treaty. To achieve that, the Paris Agreement is supposed to be more transparent than the Kyoto Protocol. Nevertheless, countries remain nationally responsible to install suitable measures (UNFCCC, n.d.-e).

The Paris Agreement has been the subject of academic research since its conclusion. Not only has the Paris Agreement been analysed in depth, but it has also been set in the context of previous global warming agreements such as the United Nations Convention of Climate Change (UNFCCC) and the previously analysed Kyoto Protocol. Unlike the Kyoto

Protocol, the Paris Agreement no longer divides countries into Annex I and non-Annex I countries. Research has shown that the distinction in two different blocks has not provided justice to the actual situation where some non-Annex I countries "have higher responsibilities than many of the Annex I countries" (Ari & Sari, 2017, p. 179). As the previous separation in developed and developing countries has been inaccurate when it comes to climate change policies, the inclusion of all countries in the Paris Agreement has been interpreted as the right approach (p. 179).

Falkner (2016) assesses the Paris Agreement in the light of previous international treaties as "a more realistic approach", acknowledging the importance of national sovereignty and international oversight (pp. 1107- 1108). Nevertheless, it remains open whether international oversight over nationally pursued policies can generate enough pressure to create significant changes (p. 1108). Falkner highlights that the reviews, which are supposed to take place every five years, are a substantial factor and will only be effective if they are transparent and reliable (p. 1125).

Another strand of literature has made predictions about whether the targets will be achieved in the future. The analysis focused on the CO_2 emissions of the ten highest emitting countries in the treaty, namely China, the USA, India, Russia, Japan, Germany, South Korea, Iran, Saudi Arabia and Indonesia, by taking into account their emissions between 1991 and 2015 (C. Dong, X. Dong, Jiang, K. Dong, & Liu, 2017, p. 1294). With a small error probability, the model predicts an increase of emission output between 26.5 and 36.5% until 2030, compared to their 2005 emissions. The analysis of the ten highest emitting countries is based on their previous trends (p. 1300). The model does not incorporate any additional policies. Based on these trends, the potential increase in emission output for the US, Japan, Germany and South Korea implies that they are unlikely to meet their nationally determined targets in accordance with the Paris Agreement (p. 1300). To what extent countries will be able to comply with the Paris Agreement is dependent on different factors in the model, such as economic growth and the growth of renewable energy (C. Dong et al., 2017, p. 1300).

Analysing EU Member States more specifically, it becomes clear that only half of the EU countries will achieve their targets by 2020, based on trends between 1990 and 2012 (Liobikienė & Butkus, 2017, p. 302). Taking the EU as a whole into account, the EU will achieve its emission targets even in a scenario with fast economic growth (p. 302). Both predictions are based on a baseline scenario where no additional policies are introduced. Their accuracy is thus dependent on whether new policies are introduced in the future as new policies would change the trend. The trends that have been used in the analyses cover the time period that this thesis is dealing with. They suggest that current policies are not enough to achieve the targets of the Paris Agreement. However, the trends do not show which policies would be effective to influence future outcomes. The conclusions that can be drawn from the discussed analyses are therefore limited.

Another relevant factor of whether the targets can be achieved is the capacity of financial investment (Peake & Ekins, 2017, p. 849). The Paris Agreement's success is dependent on the creation of "non-carbon energy sources that are cheaper, cleaner . . . and more convenient than fossil fuels" (p. 849). Carbon prices and subsidies play an important role when predicting the effectiveness of the treaty. The negative externality can be removed only if subsidies on fossil fuels are removed and carbon prices are introduced to reflect the full environmental costs of fossil fuels in the price. (p. 847). At this point the thesis sets in. As the trends suggest that the Paris Agreement's targets will not be met in the current context, the assessment of existing policies is essential. The Paris Agreement is dependent on binding policies to be enforced. Therefore, legally binding cap-and-trade systems provide an important tool to combat climate change.

2.1.3. UN Sustainable Development Goals

The Kyoto Protocol and the Paris Agreement were both created to deal with climate change in particular. Moreover, greenhouse gas emissions can be viewed in the context of the sustainable development goals. The sustainable development goals were adopted in 2015 to guide the global development until 2030. They highlight anew the relevance of tackling pollution (UN, 2015a). The issue of pollution can be directly linked to the goals of affordable and clean energy, responsible consumption, production, and climate action.

Greenhouse gas emissions have indirect effects on other development goals such as marine life under water and life on land or good health and well-being. All of the mentioned goals might be threatened by climate change or negatively impacted by excess pollution. The goal which is most relevant for the thesis is goal 13 on climate action: "Take urgent action to combat climate change and its impacts" (UN, 2015b).

The sustainable development goals follow the Millennium Goals which were guiding the global community between 2000 and 2015. It has previously been highlighted that the model of sustainability unites the environmental, economic and social sphere. Even though definitions of sustainability vary, the global community recognises the urgency of sustainable development (Sachs, 2012, p. 2207). Both the millennium goals and the sustainable development goals aim at maximising social welfare. The means that are available for their achievement are, however, different. On the one hand, the Millennium Goals can be achieved by bringing relevant technologies to less developed countries. One measure to tackle extreme poverty is for example the introduction of electricity. On the other hand, the new sustainable development goals can only be achieved by developing new technologies, for example low-carbon technologies (p. 2211). The need for new technologies means that the new global goals require new inventions to make additional progress, also in the developed world. If current policies are not enough to achieve the sustainable development goals, it is necessary to critically assess how the effectiveness of policies that have already been implemented can be increased.

In the context of the sustainable development goals, research tried to evaluate ex ante whether the goals will be achieved. One macroeconomic ex-ante analysis made use of a sustainability index to predict future sustainability (Campagnolo et al., 2018). In comparison to a baseline scenario the analysis took into account different policy options (p. 97). There are no clear benchmarks indicating whether the goals will be achieved or not. Instead, an index is created to rank to what extent the development of countries will be sustainable. The index includes factors related to the sustainable development goals like energy security, education, CO_2 intensity and public debt (p. 105). The multi-scenario analysis discovered that the implementation of policies that enhance sustainability will increase budgetary pressure compared to the baseline scenario. The benefits of increased sustainability and well-being will, nonetheless, outweigh the budgetary costs (p. 98).

The sustainable development goals also led to criticism. In particular, accountability and compliance remain debated issues:

> The UN 2030 Agenda for Sustainable Development declaration (Oct 25, 2015) launches a double-duty paradox: sustainable development is about both committing oneself to a promise and committing others to an obligation. Responsibility becomes both all-encompassing and non-existent. The SDGs become everyone’s business but no-one’s major responsibility. (Engebretsen, Heggen, & Ottersen, 2017, p. 365)

This quote shows that relevant indicators are missing. Missing relevant indicators have also been criticised by Hák, Janousková and Moldan (2015). Even though the sustainable development goals include goals, targets and indicators, the operationalisation of the indicators remains highly unclear (p. 565). The review indicates that measuring the effectiveness of certain actions is problematic with regard to the sustainable development goals. Therefore, a cross-country comparison of cap-and-trade systems will enhance the assessment of current climate policies, in particular relating to the goal of climate action.

2.2 Environmental Economics and the Theory of Externalities

In this section the subfield of environmental economics will be described in more detail. Environmental economics is concerned with the theory of externalities. It explains why pollution and environmental damage is problematic in the light of economic theory.

2.2.1 Environmental Economics

Even though the thesis is based on economic theory and will rely on a statistical analysis, the topic it deals with is an environmental one. The sub-field of environmental economics focusses particularly on the intersection of economic and environmental thinking. To show the connection between the theory of externalities and the broader context of environmental economics, the next part will focus on the definition of environmental economics and its relevant concepts.

The core of environmental economics is described by Turner, Pearce and Batemen (1994): "Its essence lies in a sequence of logical steps: assessing the *economic* importance of environmental degradation; looking for the e*conomic* causes of degradation; and designing *economic* [emphases in original] incentives to slow, halt and reverse that degradation" (p. vii). Degradation of the environment refers to the situation where economic activity harms the environment, for example through the exploitation of natural resources. Environmental economics has its roots in the 1960s movement of environmentalism. The movement represents the first modern movement towards the inclusion of the environment in economic thinking (Turner, Pearce, & Batemen, 1994, p. 1). It views the economy as an open system, in contrast to classical economics that describes it as a closed and linear system (p. 15).

Viewing the economy as an open system is related to the concept of environmental resources. In opposition to classical economic theory that includes capital, labour and land as resources, Sullivan and Arias (1972) argue that "the combination of the available means in the production, distribution and consumption of goods as well as the complex of climatic, edaphic and biotic factors" needs to be included (p. 598). The inclusion of additional factors extends the classical definition by factors that are directly or indirectly included in the production process, for example climate (p. 598).

There are two different approaches when it comes to environmental resource management: property rights and material balance (Pearce & Turner, 1990, p. 16). First of all, the debate about property rights has been shaped by the Coase theorem. A detailed analysis of the theorem and its practical application can be found in Chapter 2.3.3. Secondly, the material balance approach acknowledges that the laws of thermodynamics state that production and consumption necessarily lead to some pollution. It is the task of the regulators to find a cost-effective way to reduce pollution or environmental damage to a socially acceptable limit (p. 19). Cost-effectiveness is one of the criteria that will be used in to evaluate different tools of government intervention.

Why is environmental resource management so important? Andersen (2007) describes four functions of the environment that can be threatened by economic activities. Firstly, the environment is a "life-support system" for all living beings on the planet which can be influenced by economic activity (p. 135). Secondly, the environment can be seen as "resource base" that provides resources and raw materials for the economy. Thirdly, the environment works as a waste bin for waste produced as a by-product of the production process. Fourthly, the environment increases the utility of people per se, which is for example based on "the beauty of landscapes" which is referred to as amenity value (p. 135).

The four different functions overlap and they show the importance of protecting the environment in the long-term (Andersen, 2007, p. 135). In a classical linear economy, negative consumption and production externalities arise, which are covered more in depth in Chapter 2.2.2. Andersen (2007) points out that production and consumption can lead to a decrease of the amenity values, exploitation of natural resources, and a decrease of the environmental capacity to function as a waste bin and as a life-support system (p. 136). When examining the problems that environmental economics addresses, it is important to mention the problems that arise from designing and implementing environmental policies. Environmental policies face a high level of uncertainty concerning the effects of a certain policy (Turner, Pearce, & Batemen, 1994, p. 129).

Many different environmental sub-fields highlight different aspects. Overall, three common features have been identified by Turner, Pearce and Bateman (1994, p. 29). Firstly, the economic system should not purely function as a tool to satisfy the needs of individual rational human beings, but rather the needs of society as a whole. Secondly, economic development should be sustainable in the long-run. Thirdly, the economy should lower its impact on the environment in the long-run, for example by technological innovation (p. 30).

Environmental economics analyses the consequences of different policy options in the light of the intended goals. Welfare is used as a measurement to assess the effectiveness of policies in the field of environmental economics. Because welfare takes into account social objectives, it makes sustainability a part of environmental economics. When all three dimensions are included, namely the economic, environmental and social one, something can be called sustainable, which is presented in Figure 2.

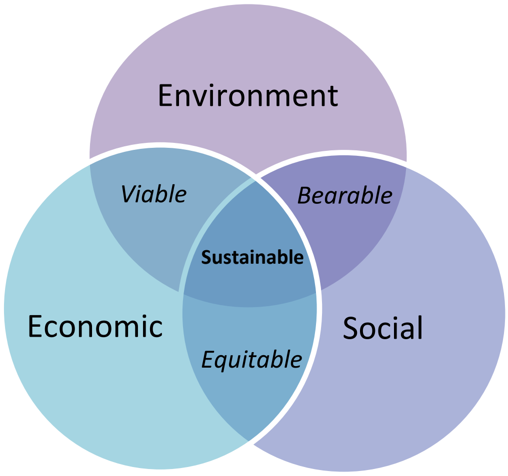

Figure 2: Model of Sustainability. Based on Flint (2013, p. 35)

The model shows that only when all three dimensions are considered, the term sustainability becomes applicable. The more dimensions are added, the more government policies are restricted in their design, making it harder to tackle certain problems. Taking into account two out of the three dimensions leads to viable, bearable or equitable results, but not to sustainable ones. Sustainability has been defined in many different ways from weak definitions to very strong ones (Turner, Pearce, & Bateman, 1994, p. 61). All the different definitions are united in the need for operationalisation, which is strongly connected to the economic and environmental sphere. Thus, sustainable economics does not only concern the economy or the environment, but society as a whole.

2.2.2 Theory of Externalities

To understand the theory of externalities, it is necessary to take an intermediate step and to briefly discuss the notion of a perfectly competitive market. Economic theory suggests that a perfectly competitive market achieves a Pareto efficient allocation of goods (Veljanovski, 2010, p. 21). Economic efficiency or Pareto efficiency "is about making the best use of limited resources given people's tastes" (Barr, 2012, p. 43). The Pareto efficient point is a point where no party can be made better off without making some person worse off, yielding the highest possible utility (satisfaction) for everyone (p. 46).

Pareto efficient markets exist where demand and supply are in equilibrium. In the case of environmental damage and pollution the market failure that distorts the market equilibrium is an externality. According to economic theory “externalities arise whenever the actions of one party make another party worse or better off, yet the first party neither bears the costs nor receives the benefits of doing so” (Gruber, 2009, p. 122). To understand the problem of externalities it is important to introduce some relevant economic terms at this point.

The thesis uses the definitions applied by Gruber (2009): First of all, every model involves private marginal cost (PMC) and social marginal cost (SMC). Private marginal cost is “the direct cost to producers of producing one additional unit of a good” (p. 124). Social marginal cost refers to the cost to society that arises with the production of an additional unit (p. 124). The additional cost margin of the damage others have to bear is the so-called marginal damage (MD). Secondly, the model involves private marginal benefit (PMB) and social marginal benefit (SMB). Private marginal benefit refers to the “direct benefit to consumers of consuming an additional unit of good” (Gruber, 2009, p. 125). Social marginal benefit includes the benefit to all other people in the relevant market.

If the market supplies goods at equilibrium of social marginal cost and social marginal benefits, the situation is socially optimal. Then producers or consumers that are active in the relevant market face the full costs and benefits of their consumption/ production choices. However, consumers and producers do not rationally decide how much to produce/ consume on the basis of the overall social welfare, but they make self-interested decisions, leading to a production/ consumption at the point where private marginal cost and private marginal benefit are in equilibrium (Gruber, 2009, p. 124). There are positive and negative externalities (p. 123). For this thesis solely negative externalities are relevant, because we are dealing with negative effects arising from private consumption and production.

First of all, a negative consumption externality is presented in Figure 3. The consumer consumes at the point where PMB equals PMC at Q_2. In this case the socially optimal level of consumption would be Q_1, because SMB is lower than PMB. An example of a negative consumption externality is the use of diesel-powered cars. The individual that is using his or her car derives utility from it, because he or she can travel by car and diesel is cheaper than petrol. But diesels are particularly polluting and yield therefore a much lower SMB. The individual’s behaviour will lead to the overproduction between Q_1 and Q_2. Deadweight loss occurs when goods are not produced where SMB equals SMC. Thus, deadweight loss refers to the cost imposed on the society due to inefficient markets (p. 125). The deadweight loss that occurs from overconsumption is highlighted by the shaded area.

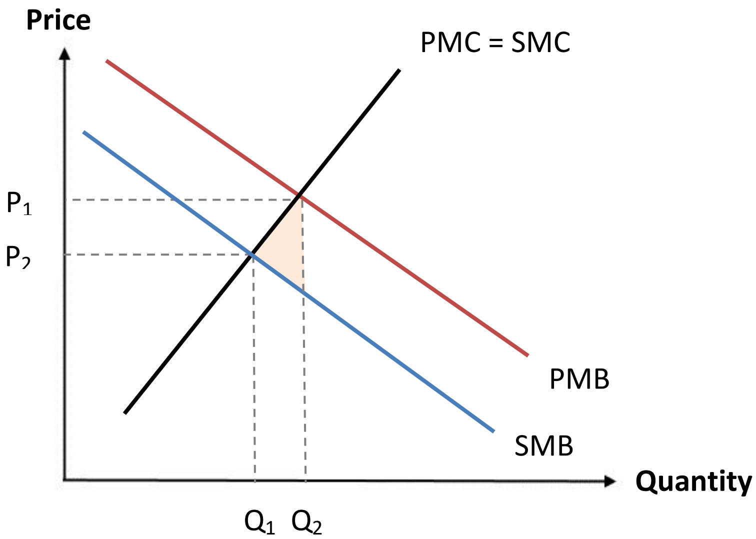

Figure 3: Negative consumption externality

A negative production externality, which is presented in Figure 4, arises from the production of goods. The socially optimal level would be produced at Q_1 where the SMC curve intersects with the SMB curve. Nonetheless, the PMC lies below the SMC and the production will take place at Q_2, reflecting an oversupply between Q_1 and Q_2. Every production process that creates pollution and whose social costs are not included in the price can be taken as an example for a negative production externality. Pollution leads to environmental damages such as climate change, for whose negative consequences society has to pay. As long as this damage is not included in the price that the producer has to pay the overproduction will not be reduced, because production is more profitable for the private producer at Q_2. This imposes a deadweight loss of the shaded area on society.

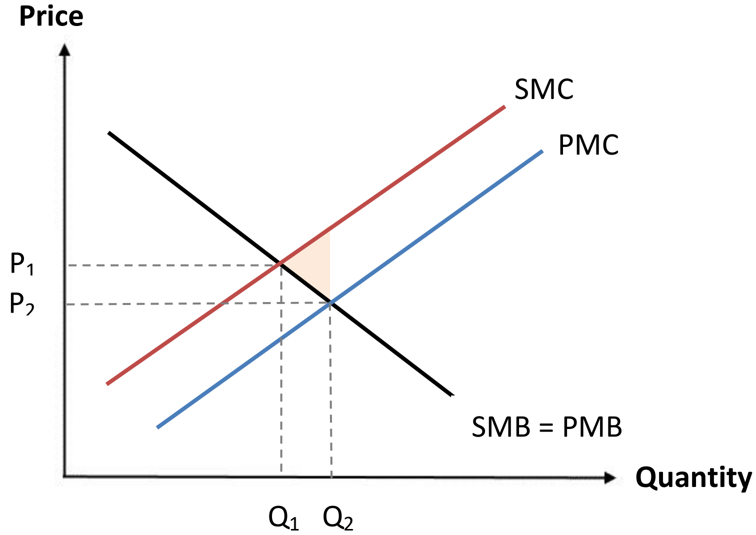

Figure 4: Negative production externality

The introduction of pollution permits, which aims at reducing CO_2 output, can be classified as a tool to deal with negative externalities. In the next part, the different policies to address externalities will be presented. There is already one conclusion that can be drawn from the theory of externalities at this point: Negative externalities exist because social marginal costs exceed private marginal costs. The closer the private marginal cost curve gets to the social marginal cost curve, the more deadweight loss decreases. More concretely, in theory, if a price is put on environmental damage or pollution, the damage is internalised and production/ consumption will decrease due to higher private marginal costs, increasing welfare. One important implication for the analysis can be derived from this discussion: The more the private marginal cost curve shifts towards the social marginal cost curve, the smaller society's welfare loss will be.

2.3 Policies to Internalise Externalities

In this section, the thesis discusses the different policies that can be adopted by governments in order to internalise (environmental) externalities. When focusing on one specific policy, it is important to compare it to other existing policies. The comparison helps to understand the peculiarities of the different approaches. Environmental externalities are used as a fundamental justification for government intervention (Stavins, 2007, p. 1). A good example for this kind of justification is provided by the Australian government for the introduction of the cap-and-trade system:

> Greenhouse gas emissions are a form of pollution - carbon pollution. The consequent economic cost is not currently reflected in the costs of business or the price of goods and services - because firms face no cost from increasing emissions, the level of emissions is too great. Unless businesses and individuals bear the full responsibility for their consumption and production decisions, the level of carbon pollution will remain too high. The Carbon Pollution Reduction Scheme is designed to redress this market failure. (Australian Government, 2008, p. 26)

Theoretically, if perfect information exists, all instruments can lead to the governmental goal of internalising the externality (Smith, 2015 p. 727). The different instruments can be split in two different categories: command-and-control and market-based instruments (Stavins, 2007, p. 9). Market-based instruments set incentives by internalising external costs, while command-and-control policies make use of regulations. Market-based instruments include for example taxes, permit trading schemes or liability rules. Command-and-control policies can be further divided into setting technology or performance standards (p. 9).

2.3.1 Standards

Command-and-control instruments, like standards, are considered to be less cost-effective than market-based instruments. To illustrate the economic principles underlying this assumption, another economic concept has to be introduced, namely marginal abatement costs (MAC). Abatement costs are the compliance costs that a firm faces when adopting governmental regulations (Field & Field, 2013, p. 206). Different firms face different costs for abating, presented in the figure below.

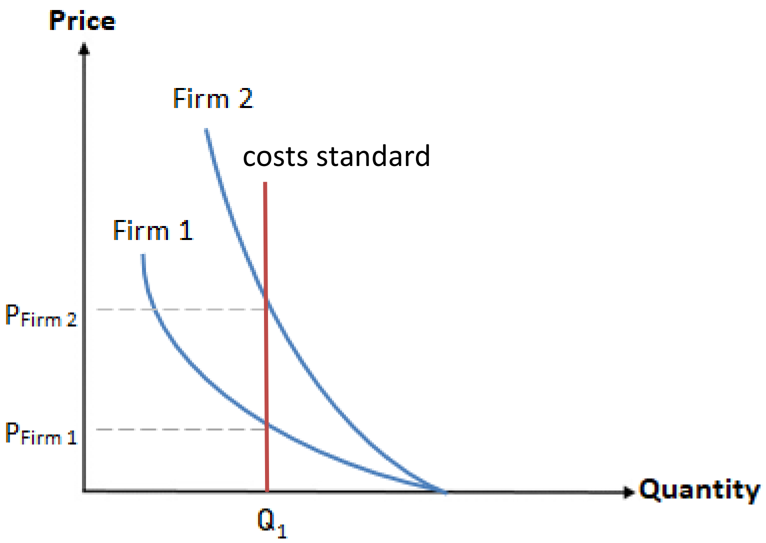

Figure 5: Standards and marginal abatement costs. Based on Field and Field (2013, p. 215)

Figure 5 shows the simplest economic model where two firms produce the same quantity in the same market. The blue lines represent the marginal abatement costs of the firms. The steeper curve of Firm 2 indicates that it is more expensive for the firm to comply with the regulation. That Firm 2 faces higher costs is highlighted in a scenario where both firms face a quantity restriction of at Q_1. The price for Firm 2 is higher than it is for Firm 1, indicated by the difference between P_{Firm2} and P_{Firm1}. Even though the same regulation for all firms in a market seems to be fair, it is not cost-effective (Field and Field, 2013, p. 215). Standards do not take into account the different abatement costs of firms. Therefore, some firms are comparatively disadvantaged, in this case Firm 2.

For policies to be cost-effective, the equimarginal principle has to be taken into account: “To get the greatest reduction in total emissions for a given total abatement cost, the different sources of emissions must be controlled in such a way that they have the same marginal abatement cost” (p. 214). The total amount of emission reduction will be lower if standards are applied uniformly (p. 216). Another negative aspect of standards is that they do not incentivise innovation beyond the point of compliance (Field & Field, 2013, p. 217; Turner, Pearce, & Bateman, 1994, p. 191). As soon as firms comply with the targets there will be no additional value for them to cut pollution further. Thus, standards produce the least innovative incentives.

According to Field and Field (2013) there are in particular three different kinds of environmental standards: ambient standards, emission standards and technology standards. Firstly, ambient standards define the quality of a regulated good. In the case of pollution the air quality could be defined by setting limits on certain greenhouse gases in the polluted air (p. 207). Ambient standards are mostly designed as "average concentration levels over some period of time" (p. 208). Secondly, emission standards regulate the quantity of emissions produced which is referred to as performance standard (pp. 208-209). There is a large variation of how to apply emission standards, from total quantity restrictions to restrictions of the quantity per input or output (p. 209). Thirdly, technology standards do regulate the technologies that should be used. Thus, technology standards leave no freedom how the standard is achieved (p. 209).

Despite their presented cost-ineffectiveness, standards have often been favoured (Turner, Pearce, & Bateman, 1994, p. 190). Standards automatically achieve the set targets, as they leave no flexibility to comply with the rule (p. 190). Their high level of certainty leads to the political approval of standards (p. 200). Standards might even be favoured by the industry itself, when there is the potential of regulatory capture. Regulatory capture refers to a situation where the polluters find a common ground with the regulator to apply regulation less sharply (p. 191).

The last aspect that has to be taken into account is the enforcement of standards. Enforcement mainly takes place via monitoring and sanctioning (Field & Field, 2013, p. 221). Field and Field (2013) introduce another concept, namely the "marginal penalty function" (p. 221). Businesses will only comply with the set standards if the marginal penalty function exceeds the marginal abatement cost curve; otherwise paying the penalty is cheaper. The penalty function can be raised by increasing monitoring activities or by increasing the level of the penalty (pp. 221-222). The penalty function is likely to be unknown to the government, making an adequate introduction of standards even more difficult.

The penalty function is similar to liability law that ensures that individuals are compensated by a harming entity, if damage occurs (Field & Field, 2013, p. 189). A firm will cause harm until liability costs exceed marginal abatement costs (p. 191). The success of liability law is dependent on the following criteria: (a) not too many people are involved (b) harm can be causally traced back to its origin (c) there is certainty about the amount of damage that occurred (Field & Field, 2013, p. 193). These criteria show that in practice the effectiveness of liability law is much more limited than in theory, especially when it comes to complex global environmental problems. Therefore, liability costs will not be analysed more in depth.

2.3.2 Taxes

Taxes in the environmental sphere can be traced back to Pigou's idea to tax polluters according to the damage they make, the so-called Pigouvian tax (Turner, Pearce, & Bateman, 1994, p. 170). When referring back to the graph of negative production externalities, ideally the tax would be set at such a level that it accounts for the difference between private marginal costs and social marginal costs. The situation is depicted in Figure 6. The PMC curve shifts upwards and the price producers have to face rises from $P_{no\ tax}$ to P_{tax}, where the tax is represented by the distance between the two points. In theory, the upward shift of the PMC curve leads to a situation where producers face full costs and consequently pollute the social optimal level at Q_1.

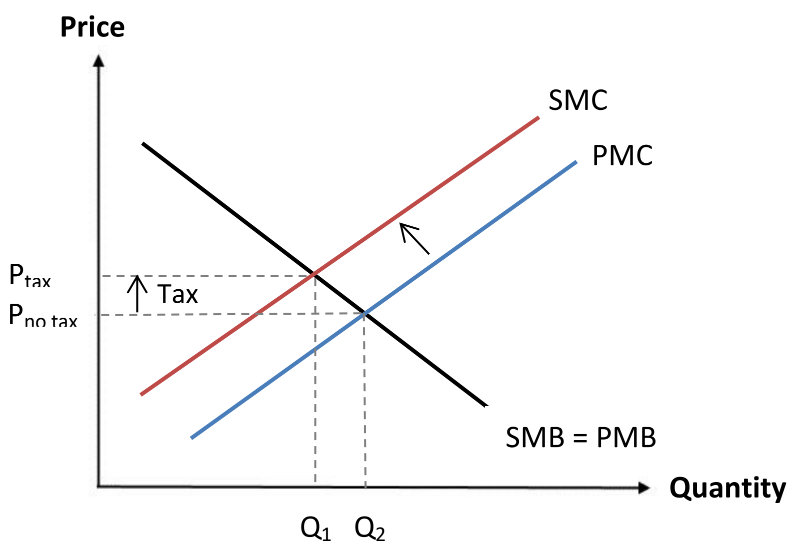

Figure 6: Optimal taxation on negative production externalities

There are certain advantages when applying taxes. Turner, Pearce and Bateman (1994) point out that environmental taxes fall within the national frame of taxation which makes it easy to administer its implementation. Taxes are imposed on every unit of pollution and therefore provide a continuous incentive to reduce pollution. A decreasing tax burden increases the incentive to invest in research and development to foster technological innovation that leads to a lower emission output (p. 170). Taxes are considered to obtain the "'Polluter Pays Principle' (PPP), the principle that those who generate pollution (producers and/ or consumers) should be the ones liable to pay the damage cost" (p. 171).

Another factor is striking when it comes to the practicability of the Pigouvian tax: Marginal abatement costs play a decisive role (Pearce & Turner, 1990, p. 88-89).

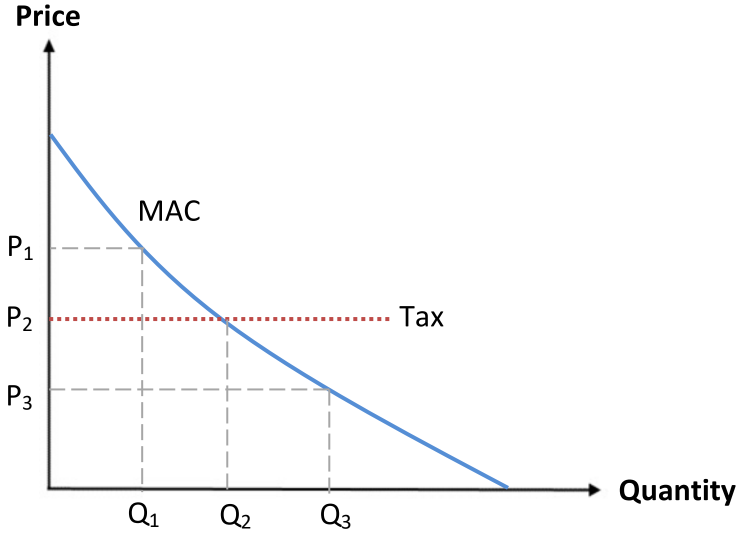

Figure 7: The relation between taxes and marginal abatement costs

In Figure 7, similar to the mechanism behind standards and liability rules, firms will abate pollution up to the point where the MAC curve cuts the tax line. If cutting pollution is more expensive than paying the tax, producers will keep on polluting. If the tax level is too low, the tax will not lead to the intended results and reduce pollution to a socially optimal level. At point Q_1 marginal abatement costs are higher than the tax and firms are more likely to maintain their level of pollution and to pay the tax. At Q_3 the opposite case can be seen where the tax leads to less pollution. At Q_2 the firm is indifferent between abating and paying the tax. A problem arises when the tax is set too high, for example by setting the tax at P_1 when the producer already faces full social marginal costs at P_2. Then the tax will lead to inefficiencies in the economy (Pearce & Turner, 1990, pp. 168-169).

Facing higher costs provides an incentive to reduce pollution for producers. Apart from that, producers might pass the additional costs of the tax on to the consumers. To what extent the price will be passed on depends on the consumer's elasticity of demand. Elasticity depends on the consumers' willingness to switch products when prices increase. If their demand is inelastic, producers can pass the price increase to the consumer which will still buy the good while facing reduced welfare (Pearce & Turner, 1990, p. 174). Besides, if taxes are only implemented nationally, they disadvantage the respective industry relative to international competition (p. 178). The analysis shows that Pigouvian taxes are theoretically a powerful tool, but face several uncertainties and risks in their practical application.

2.3.3 Cap-and-Trade Systems

The last section of this chapter deals with cap-and-trade systems. The analysis of the thesis is based on the theory behind cap-and-trade systems. After analysing standards and taxes in depth, the question arises why cap-and-trade systems are chosen as the main focus of the thesis instead of the other instruments. In theory, which will be demonstrated below, cap-and-trade systems combine the cost-effectiveness of a tax with the certainty of standards.

One opponent of the application of the Pigouvian tax, which has been introduced in the last section, has been Coase (Coase, 1960, p. 2). According to Coase, in a case where the entity causing harm cannot be held liable for the harm it causes, another solution is necessary to achieve an economic optimal outcome (p. 8). The two parts of the Coase theorem can be summarised as follows:

> When there are well-defined property rights and costless bargaining, then negotiations between the party creating the externality and the party affected by the externality can bring about the socially optimal market quantity. The efficient solution to an externality does not depend on which party is assigned the property rights, as long as someone is assigned those rights. (Gruber, 2009, p. 131)

The underlying conditions of the Coase theorem show why its practical applicability is problematic. First of all, if a large number of people are involved, costless bargaining is hardly a feasible concept. With an increasing number of involved actors, bargaining might not be feasible at all (Gruber, 2009, p. 132). Secondly, property rights are not always clearly defined. If they are shared, actors might use their property rights to exert power over the other actors, referring to the so-called holdout problem (p. 133). Thirdly, it is not always possible to straight-forwardly identify the party causing the externality. Especially with regard to wider problems, such as global warming, holding the respective actors responsible is difficult if not impossible (p. 132).

In a complex world the Coase theorem does not hold. In practice, as negotiations between a large number of actors are not feasible, negotiations become the responsibility of a third party, namely the state. Nonetheless, the essential concept that the Coase theorem introduces are property rights as a solution to environmental problems. Pollution permits can be defined as property rights, giving the holder of the permit the right to pollute the air as part of his property. Property rights are solely applicable in areas where the externality is measurable. If the externality is not measurable, it is not possible to monitor whether the regulated party purchased enough property rights in comparison to the damage it causes. In the case of pollution permits, states are able to monitor emission outputs of firms. Permits provide a high level of certainty. Certainty is achieved through the pollution cap that is enforced by distributing a limited quantity of property rights in the market.

The introduction of property rights also affects the existence of the externality. The externality in Figure 8 is internalised if the societal costs are included in the price. The costs society has to bear are resulting from excess pollution. With the introduction of a cap-and-trade system, permit prices are added to the PMC, indicated by the black arrows.

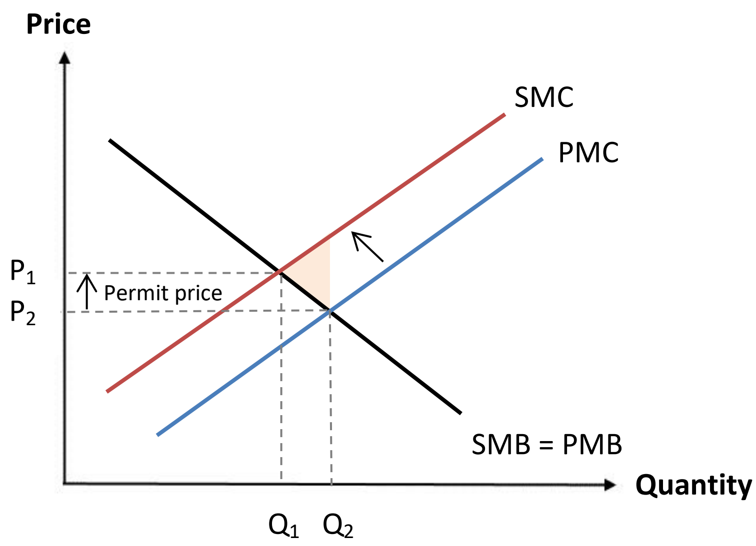

Figure 8: The effect of pollution permits on a negative production externality

The impact of the increased price depends on its relative share of PMC. The stringency of permits is defined by the permit cost (per ton of emissions) relative to the price of electricity (per MWh). The price of electricity is assumed to be part of the PMC. The higher the additional cost imposed by the permit relative to the price of electricity, the higher the level of stringency. The higher the level of stringency, the more the PMC curve shifts towards the SMC curve, decreasing welfare loss caused by overproduction. In Chapter 2.2.2 the analysis showed that the more the private marginal cost curve shifts towards the social marginal cost curve, the smaller society's welfare loss will be. The hypothesis that can be derived from this assumption for this thesis is the following:

H_1: The more stringent CO_2 permits are, the lower CO_2 output will be.

Cap-and-trade programmes start their operation with the allocation of permits. There are different ways on how to allocate permits. Permits can be given away for free, auctioned, sold or distributed through a hybrid system that gives a certain amount of allowances away for free and sells the rest of the permits in auctions (Field & Field, 2013, p. 255). In theory, as the quantity-based instrument would forbid pollution above the quantity-restriction and businesses can allocate the permits according to their marginal abatement costs, permits will be distributed efficiently. The mechanism behind pollution permits can be depicted in the marginal abatement cost model.

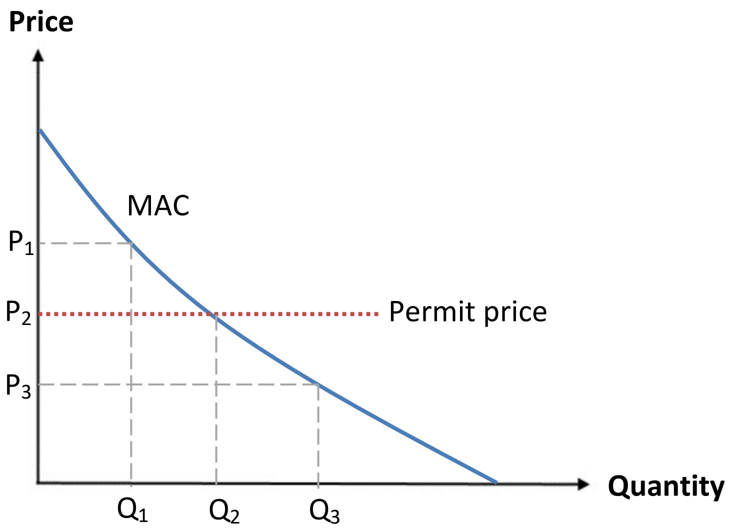

Figure 9: Marginal abatement costs with permits. Based on Field and Field (2013, p. 252)

In Figure 9, the blue line represents the marginal abatement cost curve; the red line indicates the permit price. There are three different scenarios: (a) the marginal abatement costs are more expensive than pollution permits (b) the permit price equals the marginal abatement costs (c) the permit price is higher than marginal abatement costs. The permit price is always set at P_2. In the first scenario the MAC of the firm is set at P_1 when the quantity of emissions is produced at Q_1. Abatement is more expensive than buying additional permits which illustrated by the difference between P_1 and $P_{2.}$ The firm buys additional permits at the point of Q_1. In the second scenario the firm produces at Q_2 where the permit price equals the MAC price of P_2. At the point of Q_2 the firm is indifferent towards buying permits or abatement.

The third scenario with the production point Q_3 shows that the price for abating, namely P_3 is lower than permit price at $P_{2.}$ The firm chooses to abate instead of using its permits. At point Q_3 the firm will sell permits to other firms. It will sell the permits to firms which have a different abatement cost curve and which want to buy permits, because their MAC are higher than the permit price at the quantity they produce.

The explanation of the marginal abatement cost model shows that pollution permits are cost-effective. There is only a limited quantity of emissions that is allowed in the market, which gives firms the option either to abate emissions or to buy additional permits. As different firms have different marginal abatement costs, a uniform standard would disregard that cutting emissions is more expensive for some firms than for others. Cap-and-trade programmes set incentives for the abatement of pollution for firms that have lower abatement costs (Field & Field, 2013, p. 253). Firms facing proportionally higher costs if they cut emissions can buy additional permits from other firms or on auctions. To conclude, cap-and-trade systems can be considered as fair with regard to the individual abatement costs. Firms either face additional costs via buying permits or via abating their emissions.

Even if permits are traded in accordance with individual abatement costs, auctioning has some advantages. Additional revenue will be created when the state auctions permits. Revenues from the auctions can be reinvested by the state, improving overall welfare (Field & Field, 2013, p. 255). Next to that, the free allocation poses some additional questions: Who should receive permits for free, to guarantee a competitive market in the future? Large companies or rather small and medium-sized enterprises? How can the government protect itself against lobbyism? Is free allocation of permits functioning as a barrier of entry to the market, when already established businesses receive free allowances and new ones do not? Due to the pitfalls of free distribution, auctioning or at least a hybrid system seems to be the socially best option (p. 255; p. 261).

Some cap-and-trade systems include options to bank or to borrow permits. On the one hand, "'banking' provisions allow entities to hold surplus allowances from previous trading periods, when mitigation may have been easier, and to surrender them in future compliance periods" (ICAP, n.d.). On the other hand, regulated entities "may 'borrow' allowances to surrender in the present, which are then deducted from their future budgets" (ICAP, n.d.). Banking of permits can be profitable for firms if future prices are expected to rise or if fines for exceeding the carbon cap are particularly high. Then firms may want to store additional permits, in case their pollution limits unexpectedly exceed the pre-defined level.

An effective trading market needs enforceable trading rules that are at the same time not too burdensome (Field & Field, 2013, p. 256). Apart from that, a functioning market requires an administering agency that has oversight over how the permits are distributed in the market and who emits which amount of pollution (p. 260). Another aspect that must be considered in a cap-and-trade system is the reduction of the quantity of permits. In the case where the government wants to apply a stricter cap, for example due to new technological standards, the government can either buy permits back or hand out temporal allowances which expire over time (p. 256). After their expiration, the government could decide to hand out fewer permits in the next period to decrease total emission (p. 257). One potential problem, when tightening the cap, is carbon leakage where production is outsourced to countries without a cap-and-trade system or to sectors that are not included in the trading scheme. Thus, sometimes the costs may outweigh the benefits of introducing an even tighter cap.

Another issue is the existence of additional subsidies. In a market with excess pollution an underconsumption of green energy is likely to be found. Especially when energy with a negative externality is subsidised, this kind of energy is used in excess and the externality increases. If governments want to reinforce the decrease of pollution or guarantee the compliance with the set targets, the combination of certain policies can be useful. For example the cutback of subsidies supporting so-called dirty energy would be useful, to indirectly support green energy consumption.

The permit price plays a role in the functioning of the market. In general, a cap-and-trade system is a quantity-based instrument. The number of permits restricts the number of emissions that are allowed. How the price in the market is created depends on the specific set-up of the cap-and-trade programme. Even though the price does not define the amount of emissions that are allowed in the market, the price of the allowances sends a price signal. If the permit price is too low, the price will not adequately stimulate investment in low-carbon technologies (Brink, Vollebergh, & van der Werf, 2016, p. 603). The stimulation of the investment in environmental technologies is important, because market failures exist in the area of environmental innovation. Amongst others, positive production externalities and economies of scale create disincentives for businesses to invest (OECD, 2010, pp.19-20). Cleaner technology does decrease the costs, because less permits need to be bought. Therefore, a strong price signal can foster innovation that cuts emission output.

The price level is also linked to uncertainty. Permits decrease future uncertainty by quantifying the level of emissions in the future. In contrast to that, uncertainty about the future price of emissions exists (Field & Field, 2013, p. 264). The previous paragraph already discussed the negative effect on innovation if the price is set too low. If the price is set too high, it can have significant effects on the economy, leading in the worst case to “economic disruption and volatile permit markets" (p. 264). When the price is stable and at an adequate level, cap-and-trade programmes decrease uncertainty more than taxes as the quantities in the future are fixed.

In conclusion, the abatement cost model shows that cap-and-trade systems offer the possibility for firms to reduce emissions in accordance to the previously introduced equimarginal principle. Economically, whether permits are auctioned, allocated for free or a hybrid system exists does not make a difference. In practice, however, free allocation yields some concerns about competitiveness and fairness and auctions should be used preferably. Furthermore, the cap-and-trade system needs to have enforceable rules. An adequate price level is necessary to send a strong signal that providing incentives for innovation and decreasing uncertainty. Overall, the restriction of the quantity leads to a high level of certainty.

The academic debate about cap-and-trade systems revolves around the previously discussed issues. In particular, the cost-effectiveness of permits, transaction costs and the allocation of permits gained attention. For example Rose and Stevens (1993) found that cap-and-trade systems guarantee significant abatement cost savings, no matter how permits are initially distributed (p. 142). Overall, trading leads to the same equilibrium which means that "post-trading abatement costs for any country will always be the same . . . no matter what the initial allocation of permits", causing net welfare benefits (pp. 142-143).

More critical is Stavins' (1995) analysis who claims that economic analysis does not sufficiently take into account transaction costs (p. 133). The higher transaction costs are, the lower the cost-effectiveness of cap-and-trade systems (p. 144). Initial allocation should take transaction costs into account and try to distribute permits in a way that decreases transaction and monitoring costs (p. 145). The thesis includes four cap-and-trade systems in the analysis, which partly differ in the initial allocation of permits. Chapter 3.1 will show how these four cap-and-trade systems function in practice. The literature dealing particularly with the four cap-and-trade systems will be presented in Chapter 3.2, to provide additional insight into the academic debate.

3. Empirical Assessment of the Cap-and-Trade Systems

The next chapter starts with an empirical analysis. It presents individually the cases of the Australian Carbon Pollution Scheme, the United States Regional Greenhouse Gas Initiative, the Danish Emission Trading System and the European Union Emission Trading System. Every analysis starts with an overview of the functioning of the cap-and-trade systems, following the same pattern of briefly describing its history, scope, targets, distribution of permits, banking and borrowing possibilities as well as the price mechanisms, the use of revenues and compliance mechanisms. Afterwards, the thesis turns to the academic debate on the cap-and-trade systems to highlight where previous findings can be complemented by the statistical analysis.

3.1 Empirics

The Australian Carbon Pollution Reduction Scheme (CPRS) follows the cap-and-trade model laid out in Chapter 2.3.3 (Australian Government, 2008, p. 27). The law introducing the CPRS was voted down twice, before finally passing the parliament as part of the Clean Energy Futures Package in 2011 (Parliament of Australia, 2016). In July 2012 carbon prices became effective in Australia. After parliamentary elections in 2013, the new government decided to abolish the CPRS and reversed the cap-and-trade programme by July 2014. The voting on the bill had to be repeated three times to receive the required majority.

The cap-and-trade system included around 75% of Australia's emissions accounting for around 1,000 businesses (Australian Government, 2008, p. 29). The CPRS was applied for all greenhouse gases targeted under the Kyoto Protocol, namely CO_2, methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). The sectors that were covered included "stationary energy, transport, fugitive, industrial processes, waste and forestry sectors" (Australian Government, 2008, p. 29). Australia aimed at a carbon pollution reduction of 15% in 2020 compared to 2005 levels and 60% until 2050 (p. xxi).

The allocation system was a hybrid system where permits were auctioned by the government and allocated for free; most of the permits were auctioned (Australian Government, 2008, p. 34). The firms had to hand in one permit per ton of emissions produced at the end of every calendar year (p. 27). Permits could be used as of a specified date without an expiration date (p. 30). To increase the certainty in the market, the cap was announced a minimum of five years in advance (p. 32). The permits were tradeable and the price was determined by demand and supply in the market (p. 31). Banking and borrowing was allowed to stabilise prices (p. 31). The first years of the scheme prohibited the export of permits and implemented a “transitional cap” to prevent major price increases (Australian Government, 2008, p. 31).

Another mechanism in the system was the use of offset credits which refers to emission reductions by one party that can be used by another party to pollute more (Australian Government, 2008, p. 30). The offset credits work similar to the CDM developed under the Kyoto Protocol (see p. 9). The difference is that they are generated within the same country, not in third countries. Offset credits can for example be created by sectors that are not covered in the CPRS. One hundred percent of the revenues from the auctions were reinvested into clean energy and in programmes to support businesses and individuals to comply with the new cap-and-trade system (Australian Government, 2008, p. 34). The CPRS aimed at steering research and innovation through the introduction of a carbon price. According to the Australian government (2008), particularly the sectors that are facing high abatement costs have an incentive to reduce their greenhouse gases through technological innovation. The cap addresses both consumer and producer externalities, by highlighting that for example an increase in electricity costs will incentivise consumers to save energy (p. 27).

The regulated businesses had to monitor and report their pollution levels. If the regulated entities did not comply with the rules set out under the CPRS, they faced penalties (p. 28). The Australian Securities and Investments Commission (ASIC) furthermore monitored the market with regard to market manipulation (p. 31)

The Regional Greenhouse Gas Initiative (RGGI) in the United States is a union of nine Northeast and Mid-Atlantic States. The nine states in the RGGI are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island and Vermont (RGGI, n.d.-a). The discussion over a regional cap-and-trade system covering CO_2 emissions started in 2003 (RGGI, n.d.-b). The first agreement was signed by seven states in the end of 2005, followed by Massachusetts, Rhode Island and Maryland in 2007. The programme began in 2009 with auctions starting in 2008 (RGGI, n.d.-c). In the beginning of 2012, New Jersey effectively withdrew from the programme (RGGI, n.d.-b). Moreover, the programme has been reviewed in 2012 and the rules have been amended as of 2013 (RGGI, n.d.-b).

The organisation of the programme is left to the individual States via CO_2 Budget Trading Programs. The states are united in the aim to cut CO_2 emissions by setting a cap on the emissions of electric power plants and enforcing the cap by creating a system of CO_2 permits (RGGI, n.d.-a). More specifically, the scope of the first mandatory programme in the

United States is limited to “fossil-fuel-fired electric power generators with a capacity of 25 megawatts (MW) or greater” (RGGI, n.d.-a). The targets in the programme are set at 50% of CO_2 emissions in the electric power generators sector, compared to 2005 greenhouse gas (GHG) levels. Another reduction of 30% compared to the previous cap is intended until 2030 (ICAP, 2018, p. 1). The targets are set out by the individual states and are not defined by the RGGI.

The allowance auctions take place every three months on a regional level. It is compulsory for the regulated entities to have CO_2 permits equivalent to the CO_2 emissions they produce within the three-year control period. Every permit equals one ton of CO_2 and can be used in all of the participating states (RGGI, n.d-a). The auctions are “sealed-bid, uniform price auctions, which are open to all qualified participants”, which leads to adjusted prices on a quarterly base (RGGI, n.d.-a). The adjusted prices imply that the price is fluctuating over time, having had its lowest value at 1.86 US dollar, and reaching the highest value of 7.50 US dollar in 2015, running up to the latest auctions in March 2018, being 3.79 US dollars (RGGI, n.d.-c).

The RGGI works with a Cost Containment Reserve (CCR), keeping additional permits in reserve. The permits are supplied on the market if the market price, defined by demand and supply, exceeds the predefined price. The reserve of the CCR is filled up in the beginning of every calendar year to its original size of 10 million permits. The price at which the CCR is set free increases by 2.5% every year until 2020. After that, the price increase will get steeper (RGGI, n.d-a). Next to the price ceiling through the CCR, the RGGI works with a price floor which increases by 2.5% every year (ICAP, 2018, p. 3). Trading over a secondary market is possible through over-the-counter trades or exchanges. Banking is allowed to an unlimited extent (p. 3).

The profits from the auctions are reinvested in programmes which improve consumer welfare, for example by improving energy efficiency or supporting the development of renewable energy. The monitoring of the market includes monitoring of its performance, to see whether prices are manipulated, whether the efficiency could be improved and whether auctions comply with the specified criteria. The RGGI COATS tracking system keeps track of the CO_2 emissions and the trading of CO_2 permits (RGGI, n.d.-a). Fines for non-compliance are defined by the individual states. Additionally, the amount of missing permits that has to be purchased is multiplied by three. For example, if a firm exceeded its emission cap by one ton/ permit, the firm has to by three additional permits as penalty (ICAP, 2018, p. 3). As the additionally purchased permits can be used in the future, buying permits does not harm firms per se. Nonetheless, the penalty sends the signal that purchasing fewer permits than required is not profitable in the long term, especially if prices rise over time.

The Danish Emission Trading System (ETS) has been active between 2001 and 2003, covering the CO_2 output of the Danish electricity producing sector. The law was enforced after the Danish Parliament voted in favour of the Act on CO_2 quotas for electricity production in 1999. The act originally covered the years 2001 until 2003 and in the light of the introduction of a European-wide quota system, no new act had been enforced (Danish Environmental Protection Agency, 2003, p. 18). Its targets were set at an emission reduction of 20% of 1988 levels until 2005 (Pedersen, 2003, p. 223). The initial allocation followed the so-called "grandfathering" principle. Grandfathering refers to a situation where permits are allocated for free to already existing emitting plants, according to their previous emissions (p. 227). After they have been allocated for free, demand and supply defined the price of permits in the market of tradable permits.

The free allocation implies that the system does not generate revenues that can be reinvested. Nonetheless, the penalties for non-compliance which were fixed at 40 Danish kroner (DKK) per ton of CO_2 had to be reinvested in energy savings (Pedersen, 2003, p. 226). Continuous monitoring of the fuel consumption of electricity- and heat-producing plants assured compliance (p. 226). Limited banking was allowed, but banked permits could merely be used until 2003 (p. 226). The Danish ETS had been developed before international trading schemes started operating, which had been criticised by the industry (p. 230). The Danish cap-and-trade-system was replaced by the European Emission Trading System (EU ETS) in 2009.

The EU ETS consists of 31 countries including all 28 EU Member States, Iceland, Liechtenstein and Norway. The EU ETS started its first trading period with national caps in 2005 which lasted until 2007 (p. 2). At the beginning of the second phase from 2008 until 2012, Iceland, Norway and Liechtenstein joined the EU ETS. The third trading period from 2013 until 2020 is characterised by the reform of the EU ETS to an EU-wide cap and to a more auction-based system. The fourth trading period will start in 2021 and last until 2030 (p. 2).

The cap-and-trade system accounts for around 45% of the greenhouse gases produced in the EU, applying for over 11,000 heavy energy-using installations and airlines (European Commission, 2016, p. 1). Every company can buy pollution permits, even if they are not part of the EU ETS (p. 5). Further, governments are able to exclude smaller plants from the trading scheme (p. 3). The targets are set in relation to 1990 greenhouse gas emission levels with a reduction of 20% until 2020 and a reduction of a minimum of 40% until 2030 (p. 3).

The cap-and-trade system makes use of a hybrid system, where a certain quantity of allowances is handed out for free and the rest is auctioned (European Commission, 2016, p. 2). One pollution permit accounts for one ton of CO_2 or an equivalent amount of N_2O or PFCs. Polluters must hand in permits for every ton emitted in the previous year (p. 2). Further, the regulated entities have to hold enough permits to cover their total pollution at least until the 30th of April of the following year (p. 4). Polluters have the possibility to use the permit surpluses from previous compliance periods; thus, banking is allowed (p. 3). The amount of auctions is continuously increasing since 2013, being around 60% in the third trading period (p. 3). Auctions take place on platforms which are available to all buyers from the participating states (European Commission, 2016, p. 3). In the EU ETS auctions, the price is defined by market demand and supply (p. 5).

The accounting of permits is monitored by one single Union registry (p. 4). The emissions need to be monitored and reported by the businesses and investigated by an “accredited verifier” every calendar year (European Commission, 2016, p. 4). The trading of allowances is recoded in the Community Independent Transaction Log (CITL). The compliance mechanism includes fines of 100 euros per ton of pollution in 2013 if the business did not buy enough allowances; the price increases according to the European consumer price index. Further, the business exceeding its pollution cap is “named and shamed” (p. 4).

The legislative framework lays out that a minimum of half of the profits from the auctions in general and all profits from the aviation sector should be used to fight climate change (European Commission, 2016, p. 4). The European Commission (2016) states that the inclusion of important economic sectors incentivises businesses to invest in new low-carbon technologies. The incentive to invest is reinforced by investing the auction revenues in low-carbon and renewable energy technologies (p. 5). Additionally, firms are motivated to invest in projects in third countries that lower emissions to receive credits which can be used under the EU ETS (p. 5). This mechanism combines the CDM and JI mechanisms introduced in the Kyoto Protocol.

The empirical analysis has shown that cap-and-trade systems can be implemented in different ways. When focusing on the individual characteristics of the CPRS, the RGGI, the Danish ETS and the EU ETS, it becomes clear that they differ in various aspects. None of the analysed categories, namely time period, geographic scope, targets, greenhouse gases, sectors, distribution of allowances, prices, revenues, compliance and banking and borrowing, had the same results for all cap-and-trade systems. The variety between the cap-and-trade systems broadens the generalisability of the findings. The heterogeneity between the systems will be eliminated by using the index in the statistical part. To contrast the different cap-and-trade systems, Table 1 summarises the previous section, before moving on to the literature review which is already indicated in the table.

Table 1: Comparison of the Australian, American, Danish and EU cap-and-trade systems

Characteristics	CPRS (AUS)	RGGI (US)	Danish ETS	EU ETS
Time Period	2012-2014	2005 – today	2001-2003	2005 - today
Geographic Scope	Australia	9 Northeast and Mid-Atlantic US States	Denmark	28 EU MS, Norway, Liechtenstein, Iceland
Targets 2020	Minus 15% CO_2 emissions (2000 levels)	Minus 50% CO_2 from electricity generation (2005 levels)	Minus 20% CO_2 in 2005 (1988 levels)	Minus 20% GHG (1990 levels)
Greenhouse Gases	CO_2, N_2O, PFCs, CH_4, HFCs, SF_6	CO_2	CO_2	CO_2, N_2O and PFCs
Sectors	Stationary energy, transport, fugitive, industrial processes waste and forestry	Electricity generation	Electricity generation	Power stations, industrial plants and airlines operating between the countries
Distribution Allowances	Hybrid system	Auctions	Grandfathering	Hybrid system
Price	Demand and supply	Price floor and price ceiling	Demand and supply	Demand and supply
Revenues	100% reinvested	100% reinvested	Revenues from penalties invested in energy savings	Reinvested min. 50% and 100% for aviation
Compliance	Penalties for non-compliance	- Penalties for non-compliance (set by individual states) - Three times the amount of missing permits has to be purchased	- Fixed fine of 40 DKK per ton of additional emissions	- Fine of 100€ in 2013 per ton of additional emission (inflation adjusted) - Naming and shaming - Additional national penalties
Banking and Borrowing	Both allowed	Unlimited banking allowed	Limited banking allowed until 2003	Unlimited banking allowed (since 2008)
Previous Empirical Analyses	- Information about CPRS has influence on electricity spot prices - Mainly political analyses	- Decreases emissions - Positive economic impact - Limited in its regional set-up	- Concerned with the set-up of the Danish ETS in comparison to other cap-and-trade systems	- Very low permit price sending a bad signal - Price is sensitive to political announcement

3.2. Literature Review

The economic impact of the CPRS has not been analysed extensively. Research has focused more on ex ante studies that analysed the potential effects of the CPRS (e.g. Chapple, Clarkson, & Gold, 2013). Chevallier (2010) analysed the impact of announcements concerning the CPRS in the news and their impact on spot prices of electricity. In the period of 1998 to 2009, two results have been found: Additional information about the functioning of the cap-and-trade system decreased uncertainty and respectively decreased electricity spot prices (p. 3921). In contrast, reports about high regulatory costs increased the spot price (p. 3291). This suggests that even before their introduction, cap-and-trade systems can have immediate short-term effects on the price of electricity.

The CPRS has received more attention on the political development compared to its economic implications. Bailey, MacGill, Passey and Compston (2012) show how the legislative process developed. Another paper analyses the decision-making process with regards to the cap-and-trade system, focusing on the Labour Government that implemented the scheme (Marensi, Maroulis, & Cockfield, 2009). Additionally, the politics behind the CPRS are set in the context of previous climate policy (Firsova, Strezov, & Taplin, 2012). The summary shows that an empirical economic analysis will contribute to the literature, as sufficient ex post analyses about the effectiveness are missing.

An econometric analysis of the RGGI already investigated why emissions in the participating states dropped since the introduction of the scheme. While a major switch from coal to gas accounts for the decrease of emissions, the economic crisis also played an important role, reinforced by a general increase in climate policies (Murray & Maniloff, 2015, p. 588). Despite the general trend of lower emissions, the RGGI states observed the strongest decrease in emissions in the included electric power sector, compared to the rest of the country (p. 588). The RGGI accounts for almost 24% of the emission reduction in the participating states (p. 558). The results show that the inclusion of GDP plays an important role in the analysis to achieve reliable results.

While cap-and-trade programmes aim at having a positive environmental impact, economic impacts play an important role to politically justify their existence. The research by Hibbard and Tierney (2011) hints at a positive economic impact of the RGGI (p. 30). They discovered a net benefit in the participating states in the first three years (p. 34). The main part of the measured benefits comes from the auction revenues that are reinvested by the RGGI. Additionally, the findings suggest that the investment of auction revenues resulted in lower consumer demands in electricity. Lower consumer demands in electricity can be traced back to increased energy efficiency which increased consumer welfare in return (p. 34). At the same time, producers of power generators were facing a net loss, due to higher costs and lower consumption (p. 36).

All in all, the analysis proposes that the reinvestment capacities of the RGGI helped to support the economy and did prevent distortions (Hibbard & Tierney, 2011, p. 39). The findings are in line with the predictions by Ruth et al. (2008) focusing on the State of Maryland (p. 2279). Their analysis showed that the RGGI is likely to result in a decrease in emissions and a net positive economic effect (p. 2288). Additionally, the study highlights that the investment of auction revenues plays an important role when assessing the effectiveness of the scheme (p. 2288).

The RGGI has been described as a potential role model for a nationwide scheme due to its positive environmental and economic effects (Shutt, 2016). Nonetheless, the RGGI is a regional scheme that has to be taken into account into the wider frame of the US for the cross-country analysis following. Looking at the global externality cap-and-trade systems are dealing with, national efforts are already limited in their global effectiveness, but regional efforts are even more restricted (Wiener, 2007). Compared to smaller systems like the Danish cap-and-trade system, its scope is nonetheless quite significant. The thesis will contribute to the analysis of the RGGI's effectiveness by analysing the cap-and-trade system as part of the United States.

Due to the short duration of the Danish cap-and-trade system and its existence before cap-and-trade systems developed as an international trend, the academic literature about its functioning is quite limited. Research in the early 2000s has dealt with the set-up of the Danish ETS (Haites & Mullins, 2001). The relatively early introduction of the cap-and-trade system encouraged comparative analyses of the Danish scheme with other previously introduced systems (Boemare & Quiron, 2002; Mez & Piening, 2000). The analyses of the Danish ETS have been preceded by a case study of Denmark before the introduction of the ETS, to advice how the cap-and-trade systems should have been designed (Svendsen, 1998). Concluding, previous analysis has mainly dealt with the set-up of the Danish cap-and-trade system. Therefore, any research which tests the efficiency of the scheme provides added-value.

Moving on to the evaluation of the EU ETS, it becomes apparent that so far the academic literature has been quite critical of the effectiveness of the EU ETS, especially with regards to the price mechanism. A low permit price led Brink, Vollebergh and van der Werf (2016) to the conclusion that the price sends a "bad signal" to the industry, because a low price does not carry enough incentives for them to cut emissions (p. 613). The problems can be traced back to a low demand relative to the supply which was intensified by the financial crisis (p. 604). Another factor that led to a "lack of scarcity" is the option of banking (p. 604). If there are many banked permits, scarcity will solely be created in the market as soon as firms have no other option than to buy new ones in the market. Additionally, the use of carbon offsets and other climate policies like the promotion of renewable energy have been found to be crucial factors for the lack of scarcity (de Perthuis & Trotignon, 2014, p. 102). Carbon offsets refer to a situation where saved emissions in one place can be used in another place, which has been described as part of the Kyoto mechanism in Chapter 2.1.1.

Ways to increase prices could be the introduction of a tighter cap, setting aside permits that were scheduled for auctions, additional taxes on CO_2 or an auction reserve price (Brink, Vollebergh, & van der Werf, 106, p. 605). A price floor would decrease price uncertainty and consequently incentivising investments in low-carbon technologies (p. 613). Prices are however not only dependent on demand and supply. Cretí and Joëts (2017) found in their analysis that various bubbles existed in the different compliance periods (p. 121). They trace the bubbles back to an announcement effect, where speculative bubbles arise after environmentally related political announcements at the EU level which is in line with previous academic findings (p. 121). Another destabilising factor has been found in a large excess supply in the first trading period, where the market had been classified as "relatively illiquid" (Sanin, Violante, & Mansanet-Bataller, 2015, p. 330).

The question that remains and to which the thesis will contribute to is, whether the CO_2 permits did nevertheless achieve a reduction in CO_2 emissions. Overall, the literature review emphasises that the RGGI has been characterised as the most successful cap-and-trade system, leading to a decrease in emissions and generating a positive economic impact. Despite this, the EU ETS has been criticised for a low permit price while the CPRS and Danish ETS literature shows a clear lack of economic analyses. The gap in the academic literature will be addressed in the following chapters.

4. Research Design and Data Collection

After having introduced the theoretical framework of the thesis, the following two sub-chapters will present the research design and the data collection method of the analysis. To measure the introduced cap-and-trade systems, the thesis will employ the OECD stringency index that is discussed in detail in Chapter 4.1. The second sub-chapter will continue with the research design, discussing in detail how the stringency index will be employed as explanatory variable (the X-variable or the independent variable). Afterwards, the chapter presents which other variables are included and how the dataset has been composed, to ensure the replicability of the findings.

4.1 Main Explanatory Variable: The Stringency of CO_2 Permits

The analysis focuses on emission output as the unit of analysis (the Y- variable or the dependent variable). The main explanatory variable is the stringency of CO_2 permits. Indexes as such imply several advantages and disadvantages. Firstly, indexes do lead to a loss of the heterogeneity of underlying policies, undermining the possibility to examine why something happened. In this thesis, the heterogeneity between the cap-and-trade systems like the inclusion of different sectors, varying targets and the inclusion of different greenhouse gases will not be accounted for. Secondly, an index makes it difficult to assess what the measured coefficients imply for future government policies. Thirdly, indexes are less precise than actual measurements and might make the data less accessible.

In contrast, an index summarises the data and provides the advantage of less data that needs to be analysed. The data presents differences and a development in a single number which eases the interpretation. Finally, an index increases the general comparability of different countries. By neglecting the heterogeneity, the findings will remain to a certain extent generalisable because of the large-N approach of the study. This thesis acknowledges the mentioned limitations, but chooses the application of the index due to the increased comparability. Still, in order to increase the generalisability of the findings the thesis will alternatively include the permit price in a robustness test.

Since the thesis seeks to empirically test economic theory, the OECD index has been chosen as independent variable. Policy stringency "is defined as a higher, explicit or implicit, cost of polluting on environmentally harmful behavior" (p. 24). On the one hand, an explicit increase in costs refers for example to taxes, where higher taxes increase the marginal costs. On the other hand, an implicit increase in costs can be found in subsidies where a higher subsidy increases the opportunity costs for polluting, which is taken into account by the index

(p. 24). Opportunity costs refer to the benefit that an individual did not receive because the individual chose another strategy. In this context firms can make use of the subsidy and pollute less at a lower cost than without the subsidy. Or they cannot take the subsidy and not receive the benefit which they would have gotten through the subsidy.

The thesis will focus on a single policy within this index, namely CO_2 Emission Trading Schemes. Nonetheless, as it is embedded in the overall stringency index, it is important to provide an overview over the whole index. The OECD index has been developed for the energy sector and as an economy wide indicator (p. 14). The index for the energy sector focuses on electricity generation and is limited to "selected activities that pertain to the production, transmission and distribution of electricity, gas and steam" (p. 14). The economy-wide index additionally includes policies with regard to the transport sector and data on the existence of deposit and refund schemes (p. 15). The index does not include more data, because then the complete time period could not have been covered (p. 15). The index therefore faces some limitations. It index does not include soft policy instruments like voluntary approaches or land use regulations due to the high level of heterogeneity which would make a comparative approach across countries very difficult (p. 16).

The index includes two different kinds of policy instruments that have been introduced in Chapter 2.3 as command-and-control and market-based instruments. The table below gives an overview of the fourteen included environmental policies, mainly related to climate and air pollution and how their stringency in measured.

Table 2: Policies included in the Environmental Stringency Index. Adapted from Botta and Koźluk (2014, pp. 18-19)

Kind of Policy	Policy	Measurement
Market-Based	CO_2 Tax	Tax rate in EUR/ton
	NO_x Tax	Tax rate in EUR/ton
	SO_x Tax	Tax rate in EUR/ton
	Tax on diesel for industry	Total tax for one liter of diesel used in transport
	Feed In Tariff for wind	EUR/kWh
	Feed In Premium for wind	EUR/kWh
	Feed In Tariff for solar	EUR/kWh
	Feed In Premium for solar	EUR/kWh
	Government R&D expenditures for renewable energy technologies	% of GDP
	Emission Trading Scheme CO_2	Price of one CO_2 allowance
	Emission Trading Scheme SO_2	Price of one SO_2 allowance
	Renewable Energy Certificates Trading Scheme	% of renewable electricity that has to be procured annually
Command-and-Control	Energy Certificate Emission Trading Scheme	% of electricity saving that has to be delivered annually
	Particulate Matter Emission Limit (newly built coal-fired plant)	Value of Emission Limit in mg/m^3
	SO_x Emission Limit Value (newly built coal-fired plant)	Value of Emission Limit in mg/m^3
	NO_x Emission Limit Value (newly built coal-fired plant)	Value of Emission Limit in mg/m^3
	Deposit and Refund Scheme	Dummy for presence of a deposit refund scheme
	Sulphur Content Limit in Diesel	Value dictated by the standard

The calculation of the overall Environmental Stringency Index is presented in Figure 10 below, which has been taken from Botta and Koźluk (2014, p. 22).

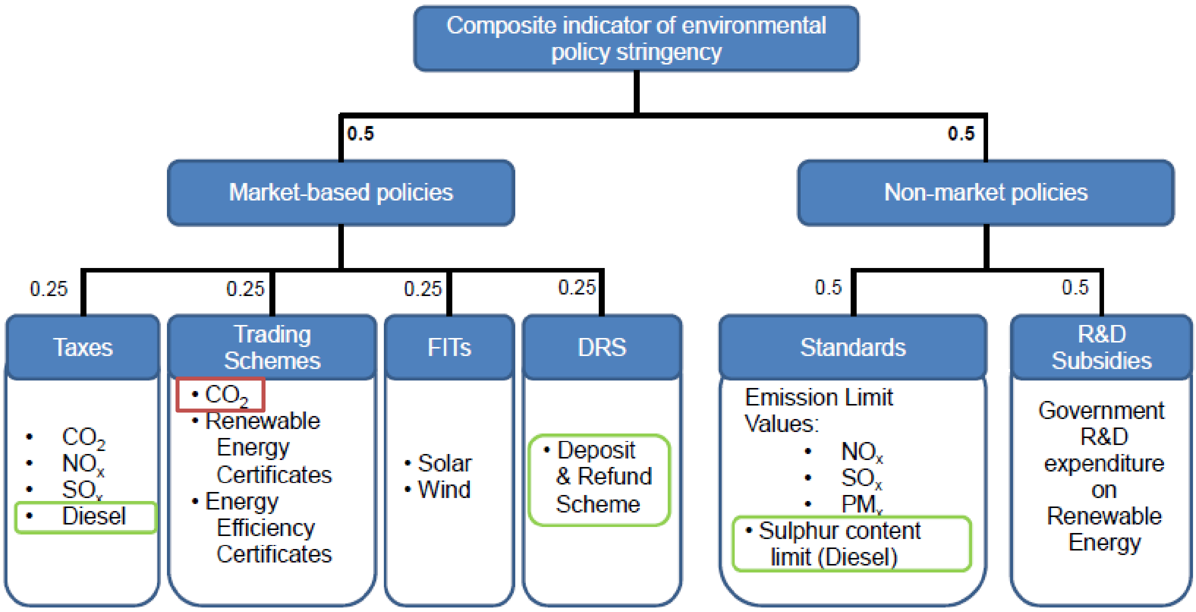

Figure 10: Structure of the economy-wide indicator (Botta & Koźluk, 2014, p. 22)

The green edging highlights the policies that are additionally included in the economy-wide index, while the red edging highlights the part of the index which is used in the analysis. The overall stringency index is calculated by making use of an aggregation method. The indicators that are created for a specific instrument are aggregated into "mid-level indicators" which are divided into market-based and non-market based instruments, leading to an overall indicator (p. 20). Every indicator is developed on a scale from 0 to 6, where 0 is not stringent/ existent and 6 very stringent (p. 22). The statistical analysis includes only the index of the stringency of permits and not the overall index, because the overall stringency index lacks a control group.

To create the relevant index for CO_2 cap-and-trade systems, "the simple yearly average of allowance prices has been used" (p. 18). More precisely "nominal values of market instruments for the energy sector have been normalised using the electricity price paid by industrial users in order to account for the different impact of nominal tax rates across countries" which has been applied to the permit price (p. 19). The formula summarises the way of measurement:

$$\frac{Permit\ price}{Price\ of\ electricity} = \frac{€/_{ton}}{€/_{MWh}} = \frac{MWh}{ton}$$

Thus, not the direct price of permits has been used, but their value related to the price of electricity. The index of CO_2 permits was created in a way that stringency increases when the measured values increase (p. 19). Table 3 shows the impact of a varying price of electricity on relative stringency, assuming that all countries introduced the same permit price.

Table 3: Example of calculating the price of permits relative to the price of electricity

	Permit Price	Price of Electricity	Relative Stringency (MWh/ton)
Country A	4	0.1	40
Country B	4	0.5	8
Country C	4	1	4
Country D	4	4	1

The result shows that the higher the permit price is in comparison to the price of electricity, the higher the relative price will be, using the formula above. Formulated differently, the higher the permit price is in comparison to the price of electricity, the higher the relative stringency will be. In this model all countries introduced the same permit price. Country A turns out to have the relatively highest permit price. For the price of one ton of emissions (one permit), 40 MWh of electricity can be produced. Country D faces the relatively lowest stringency with 1 MWh/ton. The measure is supposed to more accurately reflect the stringency of permits (Botta & Koźluk, 2014, p. 19). If the relative permit price is higher, abating becomes relatively cheaper compared to buying permits. The threshold for buying permits instead of abating shifts upwards and incentivises firms to additionally cut pollutions (see p. 27, Figure 9).

Based on the distribution within the respective sample, thresholds were created to create the indicator between 0 and 6. The calculation of the stringency levels takes into account that "the cross country (and time) ranges of policies are standardised across instruments" (p. 19). Yearly performance is then compared to the designated categories to classify the stringency for each year and country, creating a "relative stringency" level (p. 20). For regional cap-and-trade systems, like the RGGI, the results "have been weighted by the state's share of a country's total generation", to provide a more accurate level of stringency (p. 19).

Before the Environmental Stringency Index of the OECD has been established, various methods have been used to calculate environmental stringency in the past, including the following ones:

> policy change measures; composite measures of environmental regulation; surveys on the perceptions of stringency; survey-based data on firm or plant-level pollution abatement expenditures; estimated "shadow prices" of pollution; and environmental or

related performance data . . . international environmental treaties ratified or [the] number of environment-related inspections. (Botta & Koźluk, 2014, p. 8)

However, all indexes have an important shortcoming. Even if some of them created comparable cross-country data, there is a "lack of a sufficient time-series dimension" limiting the "empirical application". The inclusion of different sectors in some indexes makes a complementary use impossible (p. 8). The thesis will not highlight the weaknesses of every single way of measurement as it would exceed the scope of this chapter. Nonetheless, it remains to be highlighted that the composite indicator of environmental stringency by the OECD does fill the gap of indicators that are empirically applicable by providing cross-country data from 1990 to 2015 for 34 countries, 28 OECD countries and 6 BRIICS countries (p. 15).

As composite indicators have proven to be valuable in other areas, the goal of the index is to create "reliable, comparable measures of the stringency of environmental policies" (Botta & Koźluk, 2014, p. 3; p. 15). Table 4 shows that environmental stringency is correlated with other indexes that try to measure the stringency of environmental policies. It confirms that the OECD index can be regarded as an optimised version of previous indexes (p. 32). Due to the heterogeneity of indexes, Botta and Koźluk (2014) were only able to make a direct comparison with the Climate Laws, Institutions and Measures Index (CLMI) and an index by the World Economic Forum (WEF). Both differ slightly, as the WEF "assesses the perception of *de facto* environmental stringency in all domains . . . while the latter [CLMI index] focuses only on *de jure* climate policies" (p. 8). The WEF and CLMI index correlate with each other (p. 8).

Table 4: Correlations with other measures of stringency (Botta & Koźluk, 2014, p. 31)

Energy Sector									
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Over the period**
Perceived stringency (WEF)	.45 (.02)	.29 (.16)	.24 (.25)	.22 (.29)	.29 (.15)	.40 (.04)	.28 (.19)	.35 (.09)	.26 (.00)
CLIMI							.54 (.01)		
Economy-wide indicator									
Perceived stringency (WEF)	.60 (.00)	.51 (.01)	.49 (.01)	.49 (.01)	.45 (.02)	.53 (.00)	.44 (.03)	.45 (.03)	.44 (.00)
CLIMI							.56 (.01)		

Note: Significance levels reported in brackets

With regard to the energy sector, the correlation with the CLIMI in Table 4 is higher. The correlation can be traced back to the fact that the WEF index covers all sectors while the CLIMI is limited to climate policies including to a large extent the energy sector (p. 30). Therefore, the economy-wide stringency indicator, which covers more sectors, might yield a higher correlation with the WEF index (p. 31). Apart from that, the CLIMI makes use of policy data while the WEF uses surveys to calculate the perception. The difference between the two indexes might explain the variation between the two indexes more deeply (p. 30). There is only a minor change in the correlation between the CLIMI and the stringency index in the economy-wide indicator.

4.2 Research Design and Data Collection

By using the stringency index, the thesis answers the following question: Can the levels of CO_2 emissions per capita in OECD and BRIICS countries be explained by the stringency of CO_2 permits in these countries? The developed hypothesis suggests that the more stringent permits are the lower CO_2 output will be. To test this hypothesis, the analysis includes a population of cases. The thesis selects all countries that have observations in the employed stringency index in the time period between 1990 and 2012.

The research approach is a large-N observational research which means that the hypotheses are tested in a macroeconomic panel regression. A large-N framework is chosen, because such frameworks offer the possibility to generalise the findings and to compare many countries at different time periods (Toshkov, 2016, pp. 200-201). While qualitative research in the area of cap-and-trade systems can account for different policies in different countries, quantitative data is necessary to measure the actual impact on emissions. The set-up of the macroeconomic panel regression is depicted in the figure below.

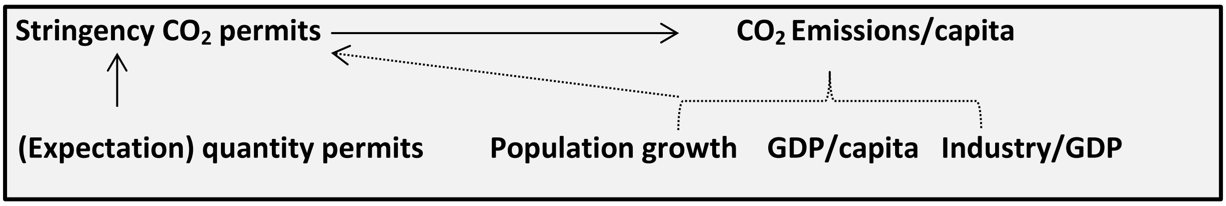

Figure 11: The set-up of the statistical analysis

The dependent variable of the analysis is the output of CO_2 emissions. It is assumed that emissions depend on the stringency of CO_2 permits. Thus, the explanatory variable of the analysis is the stringency of CO_2 permits. The inclusion of the stringency of permits raises the problem of endogeneity. While a higher stringency can lower greenhouse gas emissions, less greenhouse gas emissions can lead to less demand which lowers the stringency. Equilibrium price and equilibrium quantity are determined simultaneously.

The instrumental variable of the quantity of CO_2 permits and the expected future developments are used to overcome the problem of reversed causality. Instrumental variables have to fulfill three criteria. They have to (a) impact the independent variable (b) influence the dependent variable only through the treatment variable and (c) be as-good-as randomly assigned which means being unrelated to the omitted variable the analysis controls for (Angrist & Pischke, 2015, p. 106).

The quantity of permits influences the stringency of permits by impacting the supply of permits. When the permit price is defined by demand and supply in the market, the quantity of permits affects the price and respectively influences the level of stringency. Furthermore, the instrumental variable affects greenhouse gas emissions through the stringency. CO_2 permits per se will not lead to less greenhouse gas emissions. Only if there are fewer permits than the quantity produced, which means if the policy is stringent enough, CO_2 emissions will decrease. This is also the added-value of using the stringency instead of the quantity of permits, as the quantity of permits does not directly reflect the demand. The stringency measures not only potential but actual effectiveness. Lastly, the supply of allowances per se does not define emission output, but solely the use of pollution permits does. In this specific dataset, the descriptive statistics and a simple regression showed that CO_2 emissions do not have a clear relationship with the quantities of permits. The regression used the quantity of permits as dependent variable and CO_2 emissions as explanatory variable. Thus, the independence assumption that the instrumental variable is not correlated with the omitted variable holds in this dataset (see Appendix 1, Figure 1; Appendix 1, Table 1).

Randomness is addressed by making use of statistical tests. The analysis includes control variables to address the problem of confounding variables and to examine whether other factors might lead to a decrease of the greenhouse gases. Omitted variable bias occurs when a variable is correlated with both the explanatory and the dependent variable. If the control variable is not included, the effect of the control variable will be picked up by the explanatory variable. The impact that is measured is then biased because the measurement does not only include the effect of the explanatory variable but also other missing variables.

Sohag, Mamun, Uddin and Ahmed (2017) reviewed existing literature that analyses CO_2 emission output and the control variables included in those analyses. They establish

GDP, industrial value added in GDP and energy use as the most important control variables, complemented by the control variable population growth (p. 9757). The importance of including control variables has already been highlighted in the literature review. The control variables can impact CO_2 per capita and the stringency of permits. For example a higher share of industry cannot only lead to more emissions but might also make the introduction of a higher stringency level necessary, because of increased industrial activity. Energy use is excluded in the data, because energy is included in CO_2 permit schemes and might partly capture the effect of their effectiveness. In order to reveal the relative changes, the data is measured as per capita or growth data.

The analysis will be described in detail in Chapter 5.2 on inferential statistics. The thesis makes use of a two-stage least squares (2SLS) and an ordinary least squares analysis (OLS). 2SLS is appropriate if the stringency index is an endogenous variable. If the stringency index is found to be exogenous, OLS can provide good estimates. In order to see which method should be used, the results of 2SLS and OLS will be compared with each other. If the results are very similar, the variables are likely to be exogenous, because otherwise the results would differ noticeable. The quantity of permits will solely be used in the IV analysis. The basic regression equation is presented in the following formula:

$$co2\_c_i = \alpha + \beta psi\_co2_i + \gamma_1 gdp\_c_i + \gamma_2 pop\_g_i + \gamma_3 gdp\_ind_i + \varepsilon_i$$

The dependent variable is the measurement of CO_2 emissions per capita on the left side of the equation (co2_c), while the right side consists of α representing the constant and β the treatment effect with the treatment variable of the stringency of permits (psi_co2). The effect of the different control variables are defined as γ_1, γ_2 and γ_3, namely GDP per capita (gdp_c), population growth (pop_g) and the share of industry of the GDP (gdp_ind). The error term ε is the amount of variation for which the model does not account for.

The instrumental variable effect will be represented by ρ with the variable of the quantity of permits (q_permits). The instrument q_permits will be complemented by two leads, namely lead 1 (lead1) and lead 2 (lead2). Lead 1 includes the quantity of permits one year before their introduction and lead 2 includes the quantity two years in advance. In this way the future expectation of permit prices can be taken into account. A 2SLS model has the advantage of including both the instrument and the different covariates (Angrist & Pischke, 2015, p. 132). The 2SLS analysis has two stages. First, it uses a reduced form model to estimate the strength of the instrument:

(1) $co2\_c_i = \alpha_0 + \beta psi\_co2_i + \rho q\_permits\ lead1\ lead2 + \gamma_0 gdp\_c_i + \gamma_0 pop\_g_i + \gamma_0 gdp\_ind_i + \varepsilon_{0i}$

Afterwards, it measures the effect of the instrument on the treatment variable (step 1):

(2) $psi\_co2 = \alpha_1 + \beta_1 psi\_co2_i + \Theta q\_permits\ lead1\ lead2 + \gamma_1 gdp\_c_i + \gamma_1 pop\_g_i + \gamma_1 gdp\_ind_i + \varepsilon_{1i}$

Lastly, the value from the previous regression is used in the second stage equation (step 2):

(3) $co2\_c_i = \alpha_2 + \lambda_{2SLS}\widehat{psi\_co2_i} + \gamma_2 gdp\_c_i + \gamma_2 pop\_g_i + \gamma_2 gdp\_ind_i + \gamma_2 energy\_c_i + \varepsilon_{2i}$

The thesis makes use of the statistics programme Stata to perform the analysis. The analysis consists of the 34 countries presented in the table below, split into a control and a treatment group. The control group is the group of countries that never had a cap-and-trade system within the investigated period. The treatment group is the group of countries that did have such a system.

Table 5: Control and treatment group in the statistical analysis

Control group	**Treatment Group** (Treatment Period)
Brazil, Canada, China, India, Indonesia, Japan, Korea, Mexico, Russia, South Africa, Switzerland, Turkey	Australia (2012-2014), Austria (2005-2012), Belgium (2005-2012), Czech Republic (2005-2012), Denmark (2001-2003, 2005-2012), Finland (2005-2012), France (2005-2012), Germany (2005-2012), Great Britain (2005-2012), Greece (2005-2012), Hungary (2005-2012), Ireland (2005-2012), Italy (2005-2012), Netherlands (2005-2012), Norway (2005-2012), Portugal (2005-2012), Poland (2005-2012), Slovenia (2005-2012), Slovakia (2005-2012), Spain (2005-2012), USA (2008-2012)

For the analysis, only the years between 1990 and 2012 have been considered. First of all, the CO_2 per capita data had been missing for the year 2015 at the point of the analysis, which automatically excludes that year from the analysis. Secondly, the share of missing data with respect to the stringency of permits increased noticeable after 2012, which makes an analysis until 2012 more accurate.

4.2.1 Instrumental Variable

The research design in the previous section shows that the analysis will make use of an instrumental variable, namely the quantity of distributed pollution permits. The data for the

EU ETS is taken from the European Union Transaction Log (EUTL) which is presented in the EU ETS data viewer (European Environment Agency, 2017). Under the field emissions by sector, all allowances of stationary plants, referring to power stations and industrial plants, and aviation is selected to get the total amount of allocated emission permits. As they are measured separately, the two fields are added to get the total amount of allocated allowances, which is the cap that has been introduced by the governments. The database includes all EU countries, Norway and Iceland from 2005 until 2016. Thus, the relevant EU Member States and Norway are selected for the period 2005 until 2012.

The data on the Member States is complemented by the quotas of the Danish CO_2 trading system which already started in 2001. The data is taken from the Danish Act on CO_2 quotas for electricity production (Danish Energy Agency, 2001). The creation of leads requires the inclusion of the quantity of permits of the Canadian and Chinese cap-and-trade systems introduced after 2012, because their stringency is included in the database. The Canadian data has been taken from the website of the International Carbon Action Partnership (ICAP, n.d.). The variety of Chinese regional and local programmes has made it impossible to find a reliable number of all existing Chinese permits and has therefore been reported as missing data in the dataset.

The quantity of Australian carbon credit units (ACCUs) from the Carbon Pollution Reduction Scheme (CPRS) in Australia is taken from the website of the Australian government (2018). ACCUs are measured per financial year and one financial year in Australia has the duration from the 1st of July until the 30th of June (Australian Government, n.d.). Thus, the quantity for the year 2012 consists partly of the financial year 2011-2012 and partly of the year 2012-2013. In order to make use of the given quantities, it is assumed that quantities were equally distributed throughout the year. Thus, the quantities of the financial years were divided by two and then added together to create the total sum of ACCUs for the year 2012 which has been rounded, as permits are available in full units. For the RGGI, the data of the actual amount of issued allowances was taken from the official website of the RGGI (n.d.). The data for the RGGI has only been reported as of 2009.

4.2.2 Robustness Test: Prices Instead of the Stringency of Permits

Next to the quantities, the thesis uses the direct prices of the permits in a robustness test as a substitute for the stringency index. The average prices per year for the RGGI have been taken from the respective website by adding the prices of every year and dividing them by the number of auctions, creating a weighted average (RGGI, 2018). Nevertheless, prices are only directly included in the dataset, without weighing them compared to the whole US, like the stringency index did before. The Australian carbon price was defined on the website of the Australian government (2015). While data on prices in the Danish Emission Trading System were unavailable, data on prices in the EU Emission Trading System were taken from the European Energy Exchange AG (n.d.). As average prices were not available, the prices used in the dataset are the settled prices on the last working day of June, the mid-point of the year. Furthermore, the prices are solely the ones in the secondary market. The data is available between 2009 and 2015, generating missing values between 2005 and 2008.

4.2.3 Dependent Variable and Control Variables

The OECD database on greenhouse gas emissions does not include the per capita emissions of CO_2 specifically, but only the per capita values of all greenhouse gases. The same database on total CO_2 emissions lacks sufficient data on the countries of China, India, Indonesia and South Africa which are part of the control group. The respective World Bank database is chosen instead, because it is available until 2014, thus, covering the whole period of investigation (World Bank, 2018a). The dependent variable is defined as CO_2 in metric tons per capita. The database consists of more countries than the OECD Environmental Stringency Index. Therefore, the respective 34 countries from the Index are retrieved from the database for the time period between 1990 and 2012. Even though the US RGGI covers a limited amount of states, national emissions are used, because (a) the level of stringency as explanatory variable is provided for the whole country (b) the control variables are available on a country-level and (c) the quantities of permits as instrumental variable are not available per individual state.

The thesis includes control variables. GDP per capita data is taken from the World Bank which publishes the relevant data as GDP per capita in current US dollars (World Bank, 2018b). Furthermore, population growth is used as a control variable. Population growth data is taken from the World Bank database (World Bank, 2018c). Another control variable is industrial value added to the GDP in percentage (World Bank, 2018d). The above mentioned data has been downloaded individually from the respective websites and has then been merged into one single database. This database forms the basis for the statistical analysis in the following chapter. An overview of the dataset can be found in Appendix 1, Table 2.

5. Analysis and Results

5.1 Descriptive Statistics

The following chapter gives an overview over the descriptive statistics of the created database. Through the use of graphs the thesis visualises the data and presents the trends that become visible from looking at the data. The visualisation helps to get a first impression of the data. The statistical analysis only includes the index of the stringency of permits. Nonetheless, having a look at the descriptive statistics of overall policy stringency places the specific stringency of pollution permits in the general context of environmental policies. The graph below shows the development of policy stringency over time. Each dot represents the location of one or more countries in the given year. It becomes visible where on the scale most countries are located.

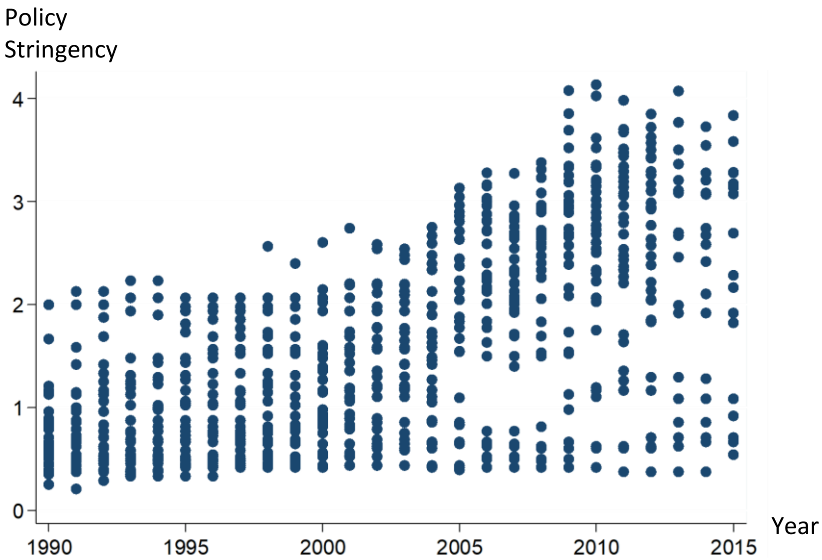

Figure 12: The development of policy stringency over time

The Environmental Stringency Index scale goes up to 6 (very stringent), but the data shows that the maximum point reached lies at 4.13 and the lowest point at 0.21. Not only does the highest point increase over time, but the density of countries reaching higher stringency levels increases. The trend does not visibly continue between 2010 and 2015. The data shows a long-term increase in policy stringency, with fewer countries reaching low stringency levels. It has to be mentioned that the data between 2012 and 2015 has not yet been completed for all countries, which might influence the graph in the last three years.

The same time trend of the stringency of permits does provide a less clear picture. Figure 13 shows that the stringency started to be above 0 in the 2001 when the Danish ETS was introduced. The first time a stringency of 6 was reached was in the year 2005 with the introduction of the EU ETS and the RGGI. In the last years between 2012 and 2015 the dataset seems to comprise less medium-levels of stringency. The missing of medium-levels might however be related to a high amount of missing data in these years.

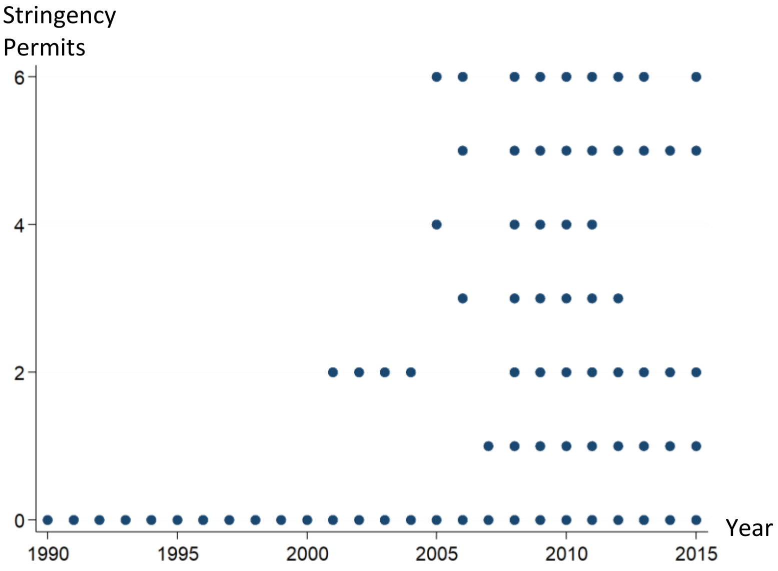

Figure 13: The development of the stringency of permits over time

When studying environmental stringency separately from the stringency of permits, the question arises how the two variables interact. The scatterplot below shows their relationship. Figure 14 does not provide any data on the development of the relationship, but takes into account the data from all years to identify the relationship between the two variables. The graph shows that countries with a higher stringency of permits have a higher level of environmental stringency. All of the countries that have a stringency level above zero do have a policy stringency level above one. The 95% confidence interval shows that there is a 95% chance that the actual population value is laying within the grey area.

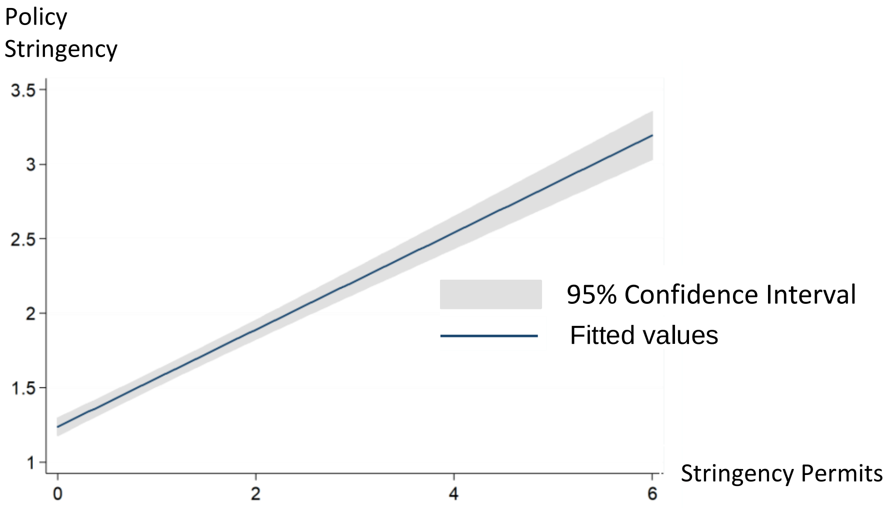

Figure 14: The relationship between policy stringency and the stringency of permits

Another interesting aspect is that the distribution of the stringency of permits varies over time and between countries, even between members of the same system, in this case of the EU ETS. In the US, the CO_2 caps are set by centralised auctions on a single platform, while the EU ETS started off with a national allocation and caps of permits until 2013 (see p. 37).

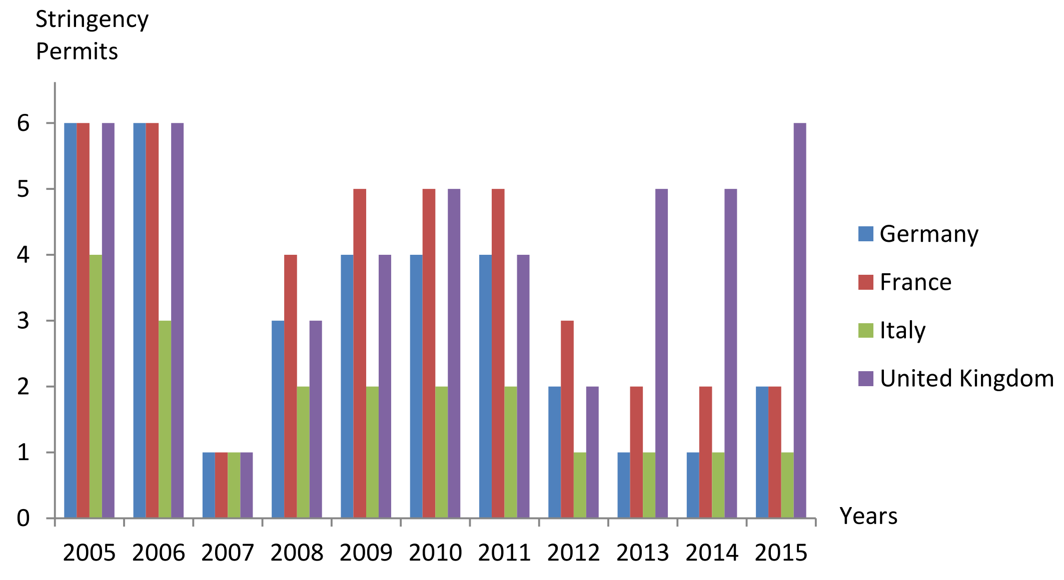

Figure 15: The stringency of permits over time in the EU ETS

Figure 15 shows the stringency of permits in Germany, France, Italy and the United Kingdom, to represent the fluctuation of permit stringency. Germany, France, Italy and the United Kingdrom have been the highest emitting countries in the EU according to Eurostat (2015). France, Germany and the United Kingdom start off with a higher stringency as Italy, but in all four countries the stringency drops significantly in 2007 to a stringency level of one.

Afterwards, the stringency seems to develop individually in the different countries. The complete data suggests an increase after 2007, followed by another decrease in 2011. Solely the stringency in the United Kingdom increases noticeable after 2013. Like previously discussed, the stringency levels are developed as a cross-country and cross-time measurement. The stringency of 6 indicates that it has been the highest level of stringency across time and across countries. Further, the varying stringency can be explained by a varying national price of electricity (see p. 44).

The quantities of permits in the two long-term cap-and-trade systems of the RGGI and the EU ETS in Figure 16 and Figure 17, shows an overall decrease in permits over time. Note that the quantity of permits for the RGGI is only available as of 2009.

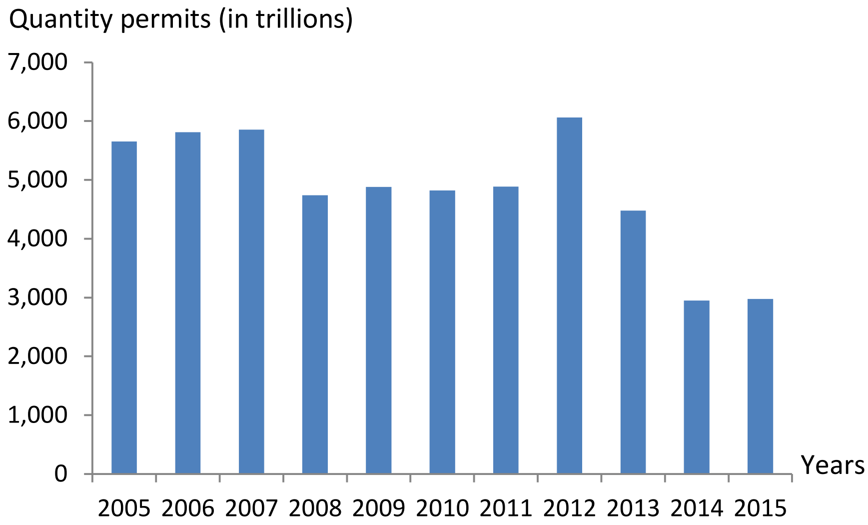

Figure 16: Total quantity permits EU ETS

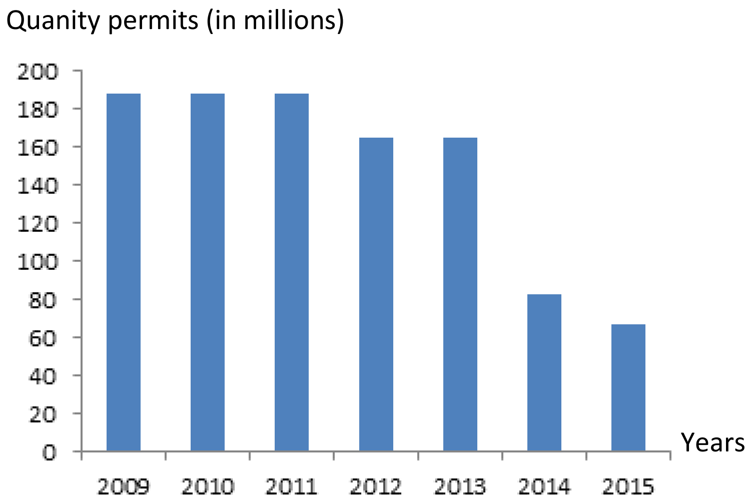

Figure 17: Total quantity pollution permits RGGI

The thesis aims to explain the impact the stringency of permits on CO_2 emissions. Therefore, it is crucial to have a look at the development of CO_2 emissions.

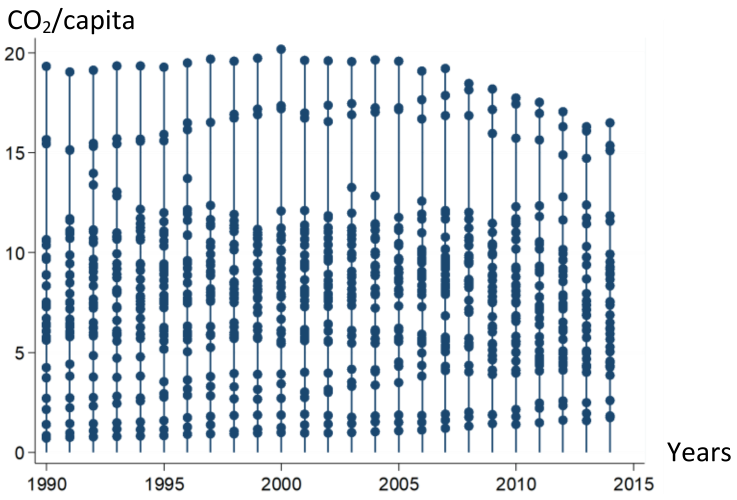

Figure 18: The development of CO_2 per capita over time

The graph represents the CO_2 per capita emissions over time until 2014, as the 2015 World Bank data is missing. The graph does not display a clear trend, but a few things are visible. Firstly, the highest data points seem to be decreasing in the last years and the lowest data points seem to be increasing. This increase means that the lowest emitting countries in the database increased their emissions per capita in the last years. Secondly, more countries seem to fall below the threshold of 10 metric tons per capita in the last years. But is there a relationship between CO_2 per capita and the policy stringency of permits in the data?

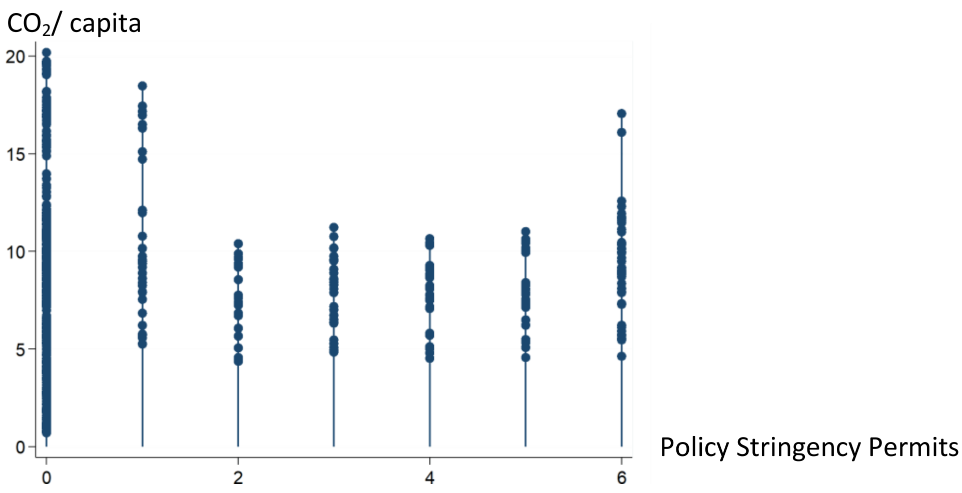

Figure 19: The relationship between CO_2 per capita and the policy stringency of permits

Figure 19 shows that the policy stringency of permits lies above one in countries where CO_2 per capita lies around and above five tons per capita. As Australia, the United States and the European Union Member States and Norway introduced permits in the analysis, it shows that only more industrialised states introduced permits in this dataset. The data shows that the highest emitting countries are more likely to achieve a low permit stringency level of one. With regard to medium-emitting countries there is no clear trend visible. The graph highlights the limitations of descriptive statistics. While higher stringency should lead to lower emissions, higher emissions might lead to higher stringency due to political pressure. It is however impossible to derive causality from the graph. Chapter 4.2 highlighted that the problem of endogeneity will be controlled for by making use of an instrumental variable. It has to be noted that the graph does not present a time trend.

It is important to look for time trends in the data, to see whether the inferential statistics should control for time. With regard to the control variables which have been introduced in Chapter 4.2, the descriptive statistics show the following results, where years are reported on the x-axes.

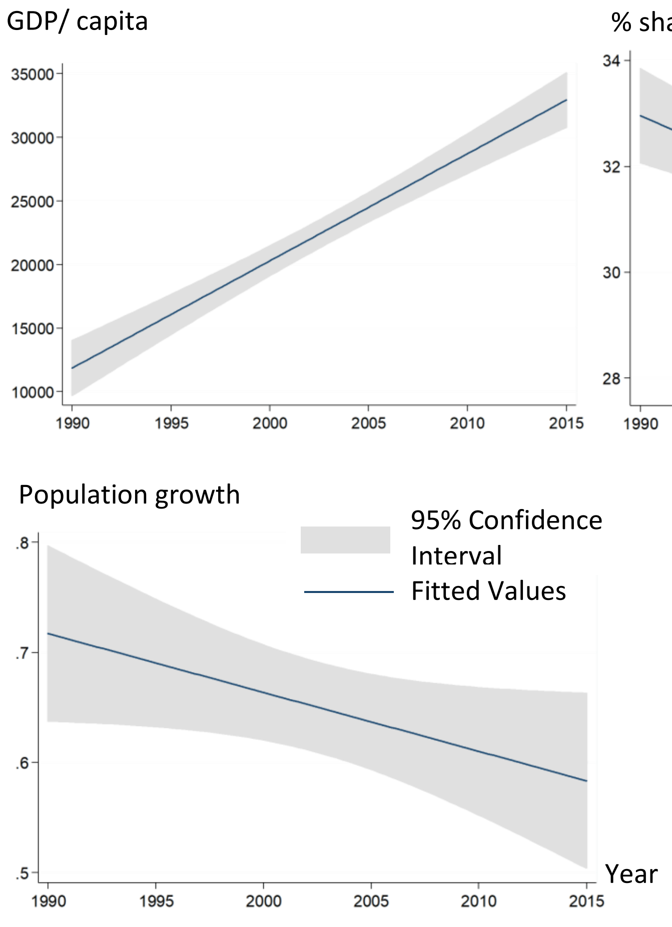

Figure 20: Time trends of GDP per capita, industry share of GDP and population growth

GDP per capita increases over time, while the industry share of GDP decreases over time. The descriptive statistics are in line with research that focuses on deindustrialisation and the move from a manufacturing and an industrial economy to a service economy (see e.g. Iversen & Cusack, 2000). Population growth decreases over time, but the values are spread widely, shown by the width of the confidence interval. Population is still growing, but slower than in the 1990s. The findings show clear trends in the data. Therefore, the statistical analysis will take time into account. Before moving on to the inferential statistics, it is interesting to see the connection between the dependent variable CO_2 per capita and the three control variables; CO_2 per capita is presented on the x-axes.

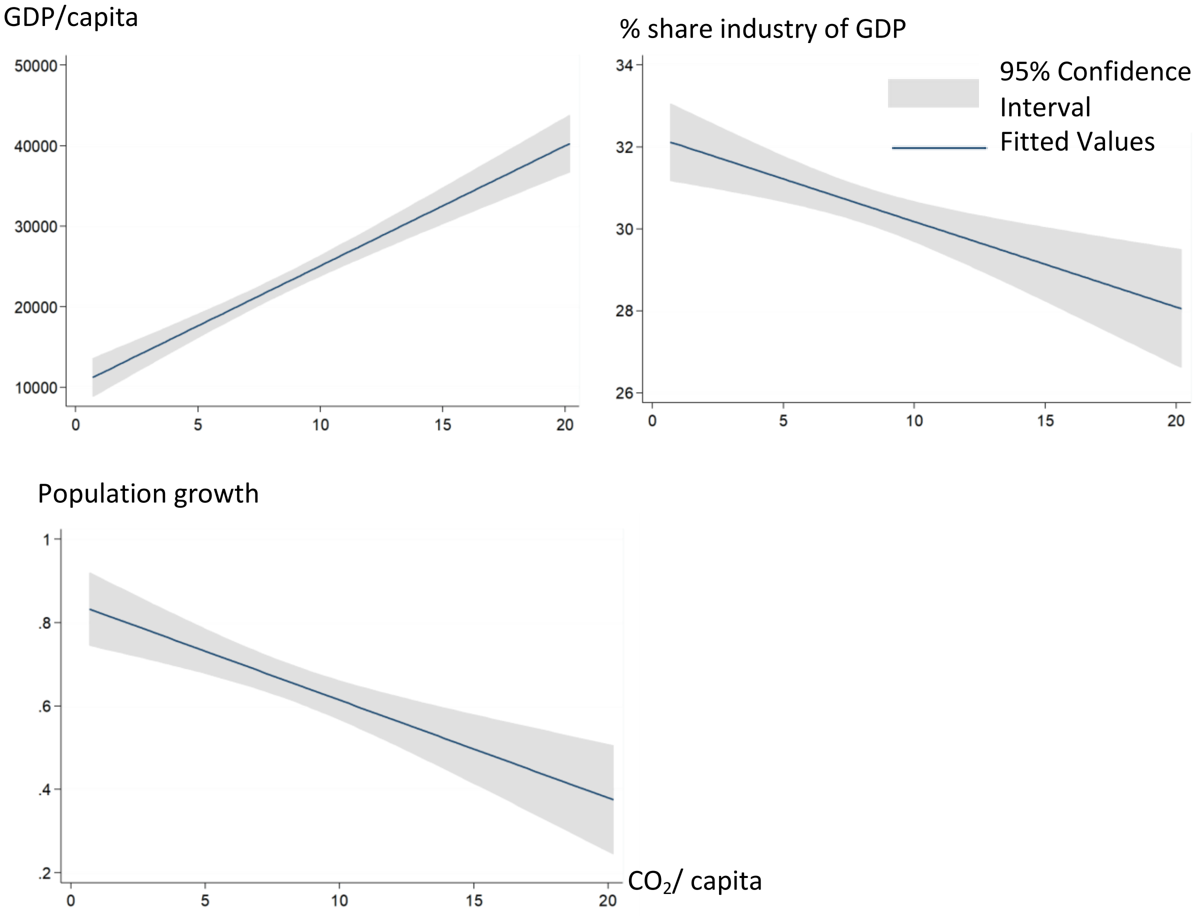

Figure 21: Relationship between CO_2 per capita and GDP per capita, industry share of GDP and population growth

The descriptive statistics show that there seems to be a correlation between the control variables and the CO_2 output per capita. The correlation confirms our assumption that the three variables should be taken into account when analysing the change of CO_2 emissions.

The descriptive statistics have provided an overview over the dataset. The dataset will now be employed to examine the effectiveness of CO_2 permits based on their stringency.

5.2 Inferential Statistics

The statistical analysis of the thesis is now addressed. The employed data has been described in detail in Chapter 4. It has been outlined that the analysis includes both an instrumental variable model and an OLS model due to the potential problem of endogeneity. Whether the assumption that an instrumental variable analysis might be more precise was correct will be elaborated below. The first part of this chapter uses the stringency index as explanatory variable. The second part will test the robustness of these results with the use of price as explanatory variable.

5.2.1 The Impact of the Stringency of Permits on CO_2 Emissions

Besides using the quantity of permits, the thesis created two leads: In lead 1 the quantities of permits are used as an instrument one year in advance and in lead 2 the quantities are used two years in advance. The inclusion of leads is based on the theoretical assumption that the spot market might react to the quantities that are issued in the future. The different schemes make data on quantities available before they are sold, underlining this argument (e.g. European Commission, n.d.).

Pre-estimation results showed a significant impact of the chosen instruments on the instrumented variable of stringency, influencing on average over 20% of the variation of the stringency of permits (Appendix 1, Table 3). Even though the coefficient of the results is very small, it has to be noticed that the results show the increase of stringency from one additional unit of permits. One single unit is very small compared to the total amount of millions of permits while one higher level of stringency is comparably high in an index of 0 to 6. Therefore, the significance of the results sufficiently highlights the relevance of the instrumental variable.

The analysis is mainly based on four different types: OLS analysis, OLS with fixed effects, IV and IV with fixed effects. The fixed effects analyses include both country fixed effects and time fixed effects. Fixed effects control for the heterogeneity within the different units, in this case within countries, and over time. The descriptive statistics part has already suggested that there are time trends in the data which need to be controlled. The statistical output confirms that the inclusion of fixed effects is relevant, as the variance within countries and time is higher than between countries and over time.

The findings are reported in Table 6 and Table 7. The first table reports the IV results and the second table the OLS results. Both tables report the results for different models. First of all, the analyses have been performed without control variables. Afterwards, one control variable was added per analysis. Then all control variables are included before excluding the ones that are not significant. An analysis with fixed effects and significant variables of the fixed effects analysis completes the table.

Significant results are marked with stars and highlighted in bold. Significance signals that the results of the analysis are unlikely to be random or by chance, but that there is a correlation and a potential causal mechanism behind the relation of the emission output and the variables (Angrist & Pischke, 2015, p. 14). The table notes standard errors in brackets, which measures the extent to which the mean in the specific sample differs from the mean of the whole population. Standard errors determine the preciseness in which this specific sample reflects the outcomes in the whole population, referred to as sampling error (p. 26).

The sample in the analysis consists of the 34 OECD and BRIICS countries while the population refers to all countries in the world. Lastly, the reported r^2 and adjusted r^2 shows to what extent the variance in the dependent variable can be explained by the independent variables, which is called the coefficient of determination (Everitt, 2002, p. 78). The adjusted r^2 measurement is slightly more accurate, because if measures the influence of the independent variables on the dependent variable, affecting the dependent variable in practice and are not just theoretically.

Table 6: Results instrumental variable analysis

	No Control	**Only one Control (gdp_c)**	**Only one Control (gdp_ind)**	**Only one Control (pop_g)**	**All Controls**	**Only Significant Controls**	**Controls & Fixed Effects**	**Only Significant Controls & Fixed Effects**
Stringency Permits	0.1657 (0.1585)	**- 0.3482*** (0.1784)	0.0672 (0.1600)	0.0227 (0.1613)	**-0.3864**** (0.1727)	**-0.4825***** (0.1802)	**- 0.1484***** (0.2831)	**-0.1645***** (0.0263)
GDP/Capita		**0.0001***** (0.0000)			**0.0001***** (0.0000)	**0.0001***** (0.0001)	-0.0000 (0.0000)	
Industry/GDP			**-0.0943***** (0.0267)		-0.0282 (0.2445)		**0.1289***** (0.1427)	**0.1246***** (0.0140)
Population Growth				**-1.1317***** (0.2441)	**-1.1488***** (0.8597)	**-1.0240***** (0.2261)	**0.2408**** (0.1077)	**0.1983*** (0.1041)
Constant	**8.072***** (0.1992)	**6.2570***** (0.2226)	**10.9604***** (0.8992)	**8.9462***** (0.2789)	**8.6560***** (0.8599)	**7.0313***** (0.2261)	**3.3019***** (0.4882)	**3.3464***** (0.4879)
R^2		0.1560	0.0222	0.0295	0.1707	0.1774	0.0343	0.0173
Observations	769	765	679	769	679	765	679	679

*** p-value <0.01 ** p-value <0.05 * p-value <0.1

Note: Numbers in brackets are the reported standard errors

Table 7: Results ordinary least squares analysis

	No control	**Only one Control (gdp_c)**	**Only one Control (gdp_ind)**	**Only one Control (pop_g)**	**All Controls**	**Only Significant Controls**	**Controls & Fixed Effects**	**Only Significant Controls & Fixed Effects**
Stringency Permits	0.0466 (0.8302)	**-0.3730***** (0.0842)	0.0108 (0.0787)	-0.0092 (0.0827)	**-0.3132***** (0.7858)	**-0.4123***** (0.0836)	**-0.1499***** (0.2890)	**-0.1676***** (0.0268)
GDP/Capita		**0.0001***** (0.0000)			**0.0001***** (8.87e-06)	**0.0001***** (0.0000)	-0.0000 (0.1321)	
Industry/GDP			**-0.0974***** (0.0251)		-0.0264 (-1.132)		**0.0145***** (0.1099)	**0.1274***** (0.0143)
Population Growth				**-1.1440***** (0.23781)	**-1.1320***** (0.2164)	**-1.0048***** (0.2221)	**0.2289**** (0.1099)	**0.1821*** (0.1063)
Constant	8.1708*** (0.1639)	**6.2556***** (0.2220)	**11.1103***** (0.8033)	**8.9798***** (0.2332)	**8.0970***** (0.8507)	**7.0250***** (0.2774)	**3.206***** (0.4983)	**3.2547***** (0.4981)
Adjusted R^2	-0.0009	0.1539	0.0201	0.0272	0.1669	0.1750	0.0355	0.0172
Observations	770	766	680	770	680	766	680	680

*** p-value <0.01 ** p-value <0.05 * p-value <0.1

Note: Numbers in brackets are the reported standard errors

Both tables show that a model without control variables does not lead to significant results with regard to the explanatory variable. The explanatory variable has a positive coefficient in that case which would reject the hypothesis that a higher level of stringency decreases CO_2 emissions and would suggest the opposite. When the IV analysis adds only the industry share of GDP or population growth the result does not change. The same applies to the OLS regression when including the share of the industry. If GDP per capita is added individually, the results become significant. The change to significant results suggests that GDP is the most important control variable in this case. GDP seems to be able to capture parts of the time and country variation that are controlled for in the fixed effects model. In practice the result means that GDP has a strong influence on emission output and that the effect of policies is dependent on the economic growth. Economic growth has to be taken into account when designing policies, which is particularly relevant for fast-growing countries.

When the model controls for fixed effects in the IV analysis, the coefficient of the stringency of permits decreases from -0.3864 to -0.1484 and becomes significant at the 1% level. The results show that in the IV analysis with fixed effects, a higher level of stringency means a decrease of 0.1484 metric tons of CO_2 per capita. It is essential to highlight that fixed effects changes the negative coefficient of population growth to a positive coefficient. A positive coefficient shows that higher population growth increases CO_2 output. The change in the coefficient can probably be traced back to the control of the time effects. R^2 decreases from 0.1707 to 0.0343, when including fixed effects. This translates into 3.43% in the specified model instead of 17.07% without fixed effects. On a scale of 0 to 100%, 3.43% is a relatively low measure. The decrease of r^2 shows that a lower extent of the variation in the dependent variable is explained by the explanatory variable in the specified model. Nonetheless, the results are statistically significant.

The OLS analysis shows similar results. Fixed effects decrease the coefficient from -0.3132 to -0.1499 of metric tons of CO_2 per capita. The decrease in both analyses shows that the model becomes more accurate and the explanatory power increases, bringing the coefficient closer to the real value. The lower values are more likely to explain the real impact of the stringency of permits than the values that do not control for unobserved time and country-heterogeneity. Fixed effects in the OLS analysis also decreases r^2. R^2 decreases from 0.1669 in the model with all controls to 0.0355 in the fixed effects model with all controls. This accounts for a decrease from 16.69% to 3.55%.

Before interpreting the results, the thesis has to readdress the issue of endogeneity. The two tables show that the values of the OLS and IV regression, just as the fixed effects analyses, are very similar. If there would have been endogeneity, the results would vary to a high extent. The application of the Hausman test confirms the assumption (see Appendix 1, Table 4). The variables are exogenous and not endogenous which means that an IV regression has not been necessary and OLS analysis is a suitable way of measurement. Other statistical tests confirm the validity of the results. The instruments that have been used for the IV regression have been found to be sufficiently strong in the post-estimation (Appendix 1, Table 5; Appendix 1, Table 6). Moreover, the model has been correctly specified and there were no over-identifying variables (Appendix 1, Table 7).

The summary of the results below shows their robustness and the variation between models. All analyses show that an increased level of stringency reduces CO_2 emissions. It has been found that there is a high level of within country variation and time trends. Hence, the fixed effect models seem to be more accurate. As the variables are exogenous, an IV regression is not necessary and the thesis concludes that the OLS fixed effects- model is the best way of measurement. Endogeneity might not be that strong, because of the construction of the index. The index does not use direct prices of permits but uses a weighted value of prices in relation to the price of electricity. Therefore, the indirect value diminishes endogeneity and an OLS model can be applied.

Table 8: Comparison Results OLS and IV analysis

	OLS	**OLS, Fixed Effects**	**IV**	**IV, Fixed Effects**
Stringency Permits	**-0.3132***** (0.7858)	**-0.1499***** (0.2890)	**-0.3864**** (0.1730)	**- 0.1484***** (0.2831)
GDP/Capita	**0.0001***** (0.0000)	-0.0000 (0.1321)	**0.0001***** (0.0000)	-0.0000 (0.0000)
Industry/ GDP	-0.0264 (-1.132)	**0.0145***** (0.1099)	-0.0282 (0.2445)	**0.1289***** (0.1427)
Population Growth	**-1.1320***** (0.2164)	**0.2289**** (0.1099)	**-1.1522***** (0.8599)	**0.2408**** (0.1077)
Constant	**8.0970***** (0.8507)	**3.206***** (0.4983)	**8.1656***** (0.8599)	**3.3019***** (0.4882)
R^2	0.1718 (adjusted)	0.0355	0.1707	0.0343
Observations	680	680	679	679

*** p-value <0.01 ** p-value <0.05 * p-value <0.1
Note: Numbers in brackets are the reported standard errors

The dependent variable that has been used is measured as CO_2 in metric tons per capita. Focusing on the OLS fixed effects model, the results show that an increase of the stringency level by one decreases CO_2 emissions in metric tons per capita by 0.1499. The results do not reject the hypothesis that a higher level of stringency leads to lower CO_2 emission per capita.

In contrast, a higher share of the industry and population growth increases pollution while GDP has an insignificantly minor negative impact. The relatively low impact of GDP in the analysis might be explained by relatively more advanced low-carbon technologies in industrialised countries. When interpreting the results one disadvantage of the use of indexes that has previously been described becomes apparent. An increase in stringency does decrease emissions, but how the stringency can be translated to real, applicable values remains unclear.

Up to this point, the analysis has taken all cap-and-trade schemes into account. The empirical part has however highlighted that the four included trading schemes differ in their functioning. The following table summarises the results for the individual trading schemes, when excluding the other three cap-and-trade systems from the analysis, keeping the control group constant.

Table 9: Results different cap-and-trade systems (OLS, fixed effects)

	RGGI (US)	CPRS (AUS)	EU ETS[1]	Danish ETS[2]	All
Stringency Permits	**-2.9851*** (0.43776)	-0.1408 (0.1387)	**-0.1546*** (0.0287)	**-1.0832*** (0.2224)	**-0.1499*** (0.2890)
GDP/Capita	-0.0000 (0.0000)	**-0.0000*** (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	-0.0000 (0.1321)
Industry/GDP	**0.0601*** (0.0214)	**0.0590*** (0.0213)	**0.1336*** (0.0136)	0.0313 (0.0231)	**0.0145*** (0.1099)
Population Growth	**-0.5807*** (0.2982)	-0.1528 (0.2374)	0.07553 (0.1064)	0.7414 (0.4288)	**0.2289**** (0.1099)
Constant	**4.0587*** (0.9100)	**4.4783*** (0.8792)	**2.3695*** (0.4755)	**3.4959*** (1.0717)	**3.206*** (0.4983)
R^2	0.0195	0.0144	0.0011	0.0027	0.0355
Observations	249	256	618	159	680

[1] EU ETS without Denmark to exclude the effects of the Danish ETS
[2] Analysis without the years 2005 until 2012 to isolate the effect of the Danish ETS
*** p-value <0.01 ** p-value <0.05 * p-value <0.1
Note: Numbers in brackets are the reported standard errors

Linking the empirical analysis of the four different systems with the statistical analysis, the results show that the set-up seems to play a role. The RGGI which has been evaluated as very efficient by previous studies yields a higher negative correlation. Thus, stringency might play a more important role in the RGGI than in the other cap-and-trade systems. The table shows that the Australian CPRS system is the only one that does not yield individual significant results. In the other cases the assumption that a higher level of stringency decreases CO_2 emissions holds. In particular, the RGGI with a coefficient of almost minus three seems to have a high correlation between stringency and emissions. The Danish ETS shows the second highest correlation, followed by the EU ETS. The results for the EU ETS are the closest to the overall results. To sum it up, the set-up of cap-and-trade systems and their performance might play an important role which policy-makers should not underestimate.

5.2.2 Robustness of the Results

The OECD Index on policy and permit stringency suggested that it provides a better comparable measurement for analysis. What happens if the analysis uses simple prices in the regression, without accounting for exchange rates, purchasing power or anything else? Table 10 shows the results in contrast to the previous findings. A few methodological issues have to be highlighted before interpreting the results. First of all, the Danish trading scheme is not included, as no prices could be found because permits were allocated for free and no governmental agency recorded secondary market trading. Secondly, for the RGGI average prices were taken, while the Australian price was set at a single point for the two included years. For the EU ETS, no average values could be obtained, and the price data is therefore derived from the last working day of June between 2009 and 2015, lacking the years 2005 to 2008. Prices are only available for the secondary market. To conclude, the data is not complete and has to be regarded with caution.

Table 10: Comparison between the stringency index and permit price as explanatory variable

	Stringency: OLS	**Stringency : OLS, Fixed Effects**	**Price : OLS**	**Price: OLS, Fixed Effects**
Explanatory Variable	**-0.3132***** (0.7858)[1]	**-0.1499***** (0.2890)	**-0.1483***** (0.0342)	**-0.0855***** (0.0131)
GDP/Capita	**0.0001***** (0.0000)	-0.0000 (0.1321)	**0.0001***** (0.0000)	**-0.0000*** (0.0000)
Industry/GDP	-0.0264 (-1.132)	**0.0145***** (0.1099)	-0.0333 (0.0260)	**0.1419***** (0.1245)
Population Growth	**-1.1320***** (0.2164)	**0.2289**** (0.1099)	**-1.0783***** (0.2307)	0.0796 (0.1245)
Constant	**8.0970***** (0.8507)	**3.206***** (0.4983)	**8.3283***** (0.2306)	**2.9243***** (0.5699)
R^2	0.1718 (adjusted)	0.0355	0.1544 (adjusted)	0.0230
Observations	680	680	662	662

*** p-value <0.01   ** p-value <0.05   * p-value <0.1

Note: Numbers in brackets are the reported standard errors

The use of price as explanatory variable still yields significant results, showing a negative correlation between permit price and CO_2 output. When including price as an explanatory variable, the OLS fixed effects model provides again the most reliable results (see Appendix 2, Table 1). The advantage of the results is that they are easier to interpret than the results from the inclusion of the index. Instead of having less accurate levels of stringency, the price refers to an actual value. Nonetheless, the included prices were measured in different currencies.

Overlooking the mentioned shortcomings, the results in the fixed effects model show that an increase of price by one unit leads to a decrease in CO_2 output per capita of 0.0855 in metric tons, with an output of r^2 of 2.3%. The obvious conclusion is that an increase in the price of permits will lower emission output and increase the effectiveness of cap-and-trade systems. Table 11 contrasts the individual effects for the RGGI and the EU ETS as the two longest cap-and-trade systems. An overview of all results can be found in Appendix 2, Table 2.

Table 11: Comparison results permit stringency and price for different cap-and-trade systems (OLS, fixed effects)

	RGGI (US) Stringency	**RGGI (US) Price**	**EU ETS[1] Stringency**	**EU ETS[1] Price**
Permits	**-2.9851***** (0.4378)	**-1.1170***** (0.1881)	**-0.1546***** (0.0287)	**-0.1085***** (0.0130)
GDP/ Capita	-0.0000 (0.0000)	-0.0000 (0.0000)	0.0000 (0.0000)	**0.0000*** (0.0000)
Industry/GDP	**0.0601***** (0.0214)	**0.0612***** (0.0220)	**0.1336***** (0.0136)	**0.1200***** (0.0145)
Population Growth	**-0.5807*** (0.2982)	-0.5049 (0.3039)	0.07553 (0.1064)	-0.0184 (0.1201)
Constant	**4.0587***** (0.9100)	**4.8418***** (0.9298)	**2.3695***** (0.4755)	**2.6930***** (0.5034)
R^2	0.0195	0.0319	0.0011	0.0124
Observations	249	249	618	541

[1]EU ETS without Denmark to control for the Danish cap-and-trade system
*** p-value <0.01 ** p-value <0.05 * p-value <0.1
Note: Numbers in brackets are the reported standard errors

The comparison shows that the impact of permits on CO_2 emissions in the individual schemes decreases, when using the price as explanatory variable. For the RGGI the difference accounts for around 1.87 metric tons per capita, while the emissions per capita for the EU ETS are around 0.05 less. The varying strength of the change suggests that the difference between the price of permits and the price of electricity might have been relatively higher in the RGGI. If the stringency was previously higher due to relatively lower electricity prices and not due to relatively higher permit prices, the decrease will be steeper, when only including the price. Despite the decrease in the coefficient of the explanatory variable, the outcome leads for the RGGI and the EU ETS to individually significant results.

The robustness test and the previous results have shown that the stringency of cap-and-trade systems and the price affect emission output. If the stringency or price goes up, emissions per capita decrease. The results do not reject the hypothesis that has been based on the theory of externalities. The pollution externality will decrease if the private marginal cost curve shifts upwards. The results suggest that policy makers can rely on the theoretical assumption in practice and that an increased stringency or price of permits will make cap-and-trade systems more effective. Nonetheless, the strength of the impact varies between individual systems while the overall conclusion seems to be generalisable.

The theoretical discussion of cap-and-trade systems has shown that prices can increase if (a) price floors are introduced (b) scarcity is introduced in the market by buying permits back or (c) scarcity naturally arises if permits are temporally valid and less permits are issued in the future (see p. 40). Policy recommendations therefore involve the introduction of one of the discussed measures to increase the price or the stringency level. The introduction of a price floor yields the lowest uncertainty, because a certain minimum price is guaranteed.

6. Conclusion

Embedded in the framework of environmental economics and more specifically in the theory of externalities, the thesis analysed the effect of pollution permits on CO_2 output. Can the levels of CO_2 emissions per capita in OECD and BRIICS countries be explained by the stringency of CO_2 permits in these countries? The theory of externalities would affirm this question. The mechanism suggests that a higher stringency increases private marginal costs. An increase in PMC internalises the externality and decreases the externality/ pollution. The stringency of permits is defined by the permit cost (per ton of emissions) relative to the price of electricity (per MWh). The higher the additional cost imposed by the permit relative to the price of electricity, the higher the level of stringency. The assumption has been tested on 34 countries which include four different trading schemes, namely the US RGGI, Australian CPRS, Danish ETS and EU ETS.

The analysis has been split in three parts, namely in an analytical assessment of the four different cap-and-trade systems, a descriptive and an inferential statistical part. The analytical assessment laid open the different characteristics and previous findings on the four cap-and-trade systems. The descriptive statistics highlighted different trends in the data and a correlation between the included variables. The inferential statistics employed the OECD's indicator of Environmental Policy Stringency to test the hypothesis.

The macroeconomic panel regression included all countries from the index. The comparative results include an ordinary least squares and two-stage least squares analysis. The results highlight that a fixed effects OLS model, fixing time and unit (country), including GDP per capita, the percentage share of the industry on GDP and population growth as control variables, is the best model. The analysis found a robust significant negative correlation between stringency and CO_2 pollution. The results are in line with the hypothesis and the theory of externalities respectively: An increase of the level of stringency by one reduces CO_2 output in metric tons per capita by 0.1499. The results have been reaffirmed in another robustness test which used prices instead of stringency levels as explanatory variable. The statistical analysis found that a price increase by one unit reduces emissions by 0.0855. The degree of the negative correlation varied between the different cap-and-trade systems, highlighting that their individual characteristics may play an important role.

The findings provide an added-value for the academic debate, because previous analyses have mainly focused on single case study and not an overall generalisable large-N assessment of cap-and-trade systems. The findings emphasise the importance of stringency and that policy makers can indeed improve the impact of cap-and-trade systems if they increase the stringency of permits. Thus, an increase of the (relative) permit prices seems not only to decrease CO_2 output in theory, but also in practice. Referring back of the theoretical discussion of this thesis, policy recommendations can be derived from the given results. A higher stringency can be achieved by (a) tightening the cap by buying back allowances (b) issuing temporal allowances in the future (c) the introduction of a floor price, or a combination of the three measures. The introduction of floor prices is the policy instrument with the lowest uncertainty. If the price or the stringency level is sufficiently high, pollution permits can function as an effective solution to combat climate change and are more than an environmental illusion.

The stringency index, which only included OECD and BRIICS countries, limits the generalisability of the findings, especially to less developed countries. Additionally, the difference in the strength of the correlation for different trading schemes might be associated with the different set-ups, but no causation can be derived from this assumption. Evaluating the difference in the outcomes more in depth would be an important point for further research. Methodologically, the creation of a dataset that includes more reliable and comparable data on the price of permits might provide added-value.

The analysis used the quantity of permits as instrumental variable to control for endogeneity and no endogeneity could be found. However, there are other factors that could be relevant. For example political pressure can influence the stringency of permits in cap-and-trade systems, but does not directly influence CO_2 output (see e.g. Bryant, 2016). Due to the scope of the thesis, such a qualitative measurement could not be included and remains for future research. Lastly, the index only included four cap-and-trade systems. Due to data availability the included variables have all been measured on a national level. Research on a more local or regional level could provide additional insight into the effectiveness of cap-and-trade systems.

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Appendices

Appendix 1: Pre- and Post-Estimations Statistical Analysis

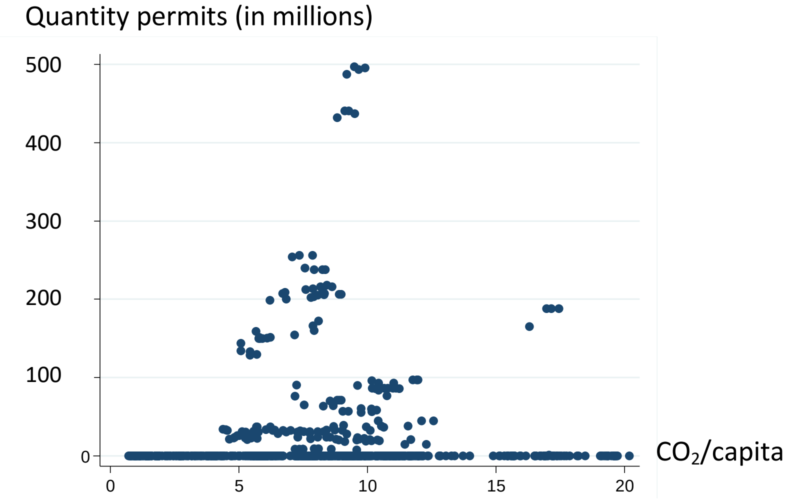

Figure 1: Relationship between CO_2 emissions and the instrumental variable

Table 1: Regression results of the impact of CO_2 emissions on the instrumental variable

	OLS
CO_2/Capita	583788.1 (57317.1)
Constant	**16800000***** (5244503)
R^2 (adjusted)	0.0001
Observations	773

Note: Numbers in brackets are the reported standard errors
*** p-value <0.01 ** p-value <0.05 * p-value <0.1

Table 2: Overview dataset

Variable	Observations	Mean	Lowest Value	Highest Value
Year	782	2001	1990	2012
GDP/Capita	776	21358.46	298.22	101668.2
CO_2/Capita	773	8.21	0.71	20.18
Population Growth	782	0.66	-1.85	2.89
Industry/GDP	685	30.82	15.57	48.35
Policy Stringency	751	1.51	0.21	4.13
Stringency Permits	779	0.8	0	6
Quantity Permits	782	21,400,000	0	497,000,000
Lead 1	782	23,900,000	0	497,000,000
Lead 2	781	25,700,000	0	497,000,000
Price	694	1.56	0	24.15

Table 3: Regression results of the quantity on stringency permits. Strength of the instruments

	Quantity Permits	Lead 1	Lead 2
Stringency Permits	**0.0000*** (0.0000)	**0.0000*** (0.0000)	**0.0000*** (0.0000)
Constant	**0.5176*** (0.0573)	**0.5151*** (0.0596)	**0.5280*** (0.0611)
Adjusted R^2	0.2744	0.2398	0.1975
Observations	779	779	778

*** p-value <0.01   ** p-value <0.05   * p-value <0.1

Note: Numbers in brackets are the reported standard errors

Table 4: Post-estimation. Test of endogeneity – H_0: variables are exogenous

	Value	P-Value
Durbin (Score) Chi2(1)	0.1585	0.6905
Wu-Hausman F(1,673)	0.1571	0.6919

Table 5: Post-estimation. First-stage regression statistics

R^2	Adjusted R^2	Partial R^2	F (3,672)	Probability > F
0.2492	0.3434	0.2060	58.1312	0.0000

Table 6: Critical Values - H_0: Instruments are weak

	5%	10%	20%	30%
2SLS relative bias	13.91	9.08	6.46	5.39
	10%	**15%**	**20%**	**25%**
2SLS Size of nominal 5% Wald test	22.30	12.83	9.54	7.80
LIML Size of nominal 5% Wald test	6.46	4.36	3.69	3.32

Table 7: Post-estimation. Test over-identification

	Value	P-Value
Sargan (Score) Chi2 (2)	0.1257	0.9391
Basmann Chi2 (2)	0.1244	0.9397

Appendix 2: Additional Results

Table 1: Comparison results OLS and IV analysis with price as explanatory variable

	OLS	OLS, Fixed Effects	IV	IV, Fixed Effects
Price Permits	**-0.1483***** (0.0342)	**-0.0855***** (0.0131)	-0.1368 (0.1567)	**0.0827***** (0.0126)
GDP/Capita	**0.0001***** (0.0000)	**-0.0000*** (0.0000)	**0.0001***** (0.0000)	-0.0000 (0.0000)
Industry/ GDP	-0.0333 (0.0260)	**0.1419***** (0.1245)	-0.4868 (0.0302)	**0.1208***** (0.0154)
Population Growth	**-1.0783***** (0.2307)	0.0796 (0.1245)	**-1.2000***** (0.2718)	0.1856 (0.1229)
Constant	**8.3283***** (0.2306)	**2.9243***** (0.5699)	**8.1840***** (1.4111)	**3.5068***** (0.5271)
R^2	0.1544 (adjusted)	0.0230	0.2027	0.0261
Observations	662	662	594	594

*** p-value <0.01 ** p-value <0.05 * p-value <0.1

Note: Numbers in brackets are the reported standard errors

Table 2: Results different cap-and-trade systems with price as explanatory variable (OLS, fixed effects)

	RGGI (US)	CPRS (AUS)	EU ETS[1]	All
Price Permits	**-1.1170***** (0.1881)	-0.0350 (0.0344)	**-0.1085***** (0.0130)	**-0.0855***** (0.0131)
GDP/Capita	-0.0000 (0.0000)	**-0.0000*** (0.0000)	**0.0000*** (0.0000)	**-0.0000*** (0.0000)
Industry/GDP	**0.0612***** (0.0220)	**0.0590***** (0.0213)	**0.1200***** (0.0145)	**0.1419***** (0.1245)
Population Growth	-0.5049 (0.3039)	-0.1528 (0.2374)	-0.0184 (0.1201)	0.0796 (0.1245)
Constant	**4.8418***** (0.9298)	**4.4783***** (0.8792)	**2.6930***** (0.5034)	**2.9243***** (0.5699)
R^2	0.0319	0.0114	0.0124	0.0230
Observations	249	256	541	662

[1] EU ETS without Denmark to control for the Danish cap-and-trade system

*** p-value <0.01 ** p-value <0.05 * p-value <0.1

Note: Numbers in brackets are the reported standard errors