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The effectiveness of carbon taxing in mitigating climate change

Master thesis

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Abstract

It is well acknowledged that addressing climate change effectively should be of highest importance in the 21st century. Various approaches have emerged in response to the challenges posed by climate change and global warming. Market-based instruments in particular aim to provide a cost-effective approach in curbing CO_2 emissions and thus mitigating climate change. Even though various studies have come to the conclusion that emission trading systems are not successful in mitigating the large-scale consequences of climate change, the overall effectiveness of another market-based instrument, namely carbon taxing, is still under consideration. This thesis aims to contribute to the existing pool of literature by evaluating to what extent carbon taxing is successful in reducing per capita CO_2 emissions and thus mitigating climate change. Consequently, this thesis has analized 54 (high-income) countries over a 28 year-long period to establish whether countries with implemented carbon taxing initiatives have significantly lower levels of per capita CO_2 emissions. The results of the panel regression indicate that the presence of a carbon tax leads to an overall 14.5% decrease in per capita emissions among high-income countries. Therefore the conclusion can be drawn that carbon taxing can serve as an important and effective policy-instrument in addressing climate change.

Key words: climate change, market-based instrument, carbon taxing, CO_2 emissions, high-income countries, green growth, de-growth

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List of Abbreviations

CDIAC	Carbon Dioxide Information Analysis Centre
CDM	Clean Development Mechanism
CGE	Computable General Equilibrium
CO_2	Carbon Dioxide
DID	Difference-in-Difference method
EIA	Electric Industries Association
EU-ETS	European Union Emission Trading Scheme
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GNI	Gross National Income
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
MBIs	Market-based Instruments
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Squares
PPP	Purchasing Power Parity
R&D	Research and Development
SD	Standard Deviation
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization

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Chapter 1.

1. Introduction

Ice caps are melting, sea levels, global air, and ocean temperatures are rising, oceans are acidifying, and natural disasters such as drought, hurricanes, and tsunamis are occurring more frequently with increasing intensity (IPCC, 2007). According to IPCC (2007), the rising heat is caused by the increasing concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs). These, in turn, are the results of decades of fossil fuel combustion and the Earth's declining capacity to absorb these human-induced emissions. As reported by the IPCC (2019) human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels. When increasing at current rates, global warming is likely to reach 1.5°C between 2030 and 2052. If unabated, our climate system will reach a point beyond which global warming becomes irreversible (Storm, 2009). Such warming is likely to result in large-scale adverse consequences, which will affect not only our ecosystem but most of the species and our infrastructures (Worldwatch Institute, 2009). Moreover, poor societies who are the least responsible for loading the air with heat-trapping gases and the most vulnerable to climate-induced changes will be affected by global warming's effects first.

Essentially all humans that have ever lived contributed to reshaping the planetary-scale system. According to Le Quéré et al. (2018, in Hsiang & Kopp, 2018), each human contributes to approximately five tonnes of carbon dioxide emissions a year. Furthermore, Archer et al. (2009, in Hsiang & Kopp, 2018) also claim that almost a fourth of those emissions stay in the atmosphere for more than a thousand years. Experts claim that the concentration of CO_2 in the atmosphere should not rise above 450-550 ppm of CO_2, and ideally should also be maintained at about 385 ppm of CO_2 in the long term, or even less, to have a chance of staying below a 2°C of global warming, which is considered to be the tipping point above which irreversible damage cannot be avoided.

Many economists claim that climate change is a perfect example of market failure. The core of the problem is the so-called 'greenhouse-gas-externality', which refers to the fact that most economic activities involve the emission of GHGs without paying the price of doing so (Stern, 2007). For more than 200 years, industrial organizations were not compelled to bear the full cost of their production and have imposed significant impacts on our societies (Andrew, 2008). As these GHG emissions are external to the market, the emitters have no economic incentives to reduce their emissions (Stern, 2007).

Many argue that global climate change demonstrates the ’tragedy of commons’ on a global scale (Brown, Adger, and Cinner, 2018), which can lead to market failures. Individual economic agents receive the full benefit of fossil fuel consumption but bear only a fraction of its climatic cost (Boyce, 2018, p. 53). The tragedy occurs because people reason that their actions will have no detectible effects on global atmospheric quality. However, when people’s insignificant emissions are added up, they become consequential.

After almost three decades of climate change mitigation policies that failed to curb global GHG emissions, adopting successful policies is essential to reverse the dramatic effects of climate change. However, approaches on how to achieve this are highly contested and offer significantly different frameworks for solution. Some argue that climate change must be seen as a system failure – „*a collateral damage of rapid and unequal capitalist development*” (Storm, 2009, p. 1016). Proponents of this approach argue that there is an unresolvable conflict between capitalism’s drive for growth and ecological sustainability, which will eventually lead to the collapse of either of the two. Hence, climate change can only be effectively mitigated if natural resources are subject to effective decision making, where people willingly support a low-growth and high-equity model that results in improved overall welfare. Scientists argue it would be desirable because lower demand and economic growth result in less resource-intensive production, which in turn decreases overall CO_2 emissions and consumption. However, on the other side of the spectrum proponents claim that climate change can be stopped under our capitalist system by letting the market work for the environment. Economists argue for policy intervention to increase the price of activities that emit greenhouse gasses, thereby providing incentives to cut emissions as widely as possible. UNDP (2007) claims that carbon markets are a necessary condition for transitioning to a low-carbon economy, and states that *„emission targets and energy efficiency targets have an important role to play but it is the price system that has to make it easier to achieve our goals”* (UNDP, 2007, p. 7). Economists often argue that putting a price on carbon emissions is the most cost-effective regulatory approach in reducing those emissions (Stiglitz et al., 2017). Emission targets, cap-and-trade systems, and emission taxes are probably the three most supported market-based solutions for mitigating climate change (Aldy, Ley, and Parry, 2008). However, both emission targets and cap-and-trade systems have failed to deliver the desired results (Storm, 2009). They can contribute to the solution, but have a less certain and slower impact than carbon tax (Storm, 2009) as trading systems overall do not necessarily result in decreasing CO_2 emissions altogether, but encourage countries to outsource their emissions to so-called ’pollution-havens’, which further exacerbates the climate crisis. However, the overall effectiveness of carbon taxing has not been studied often yet.

1.1. Research aim and research question

The thesis aims to evaluate whether market-based solutions as such are capable to induce changes that are sufficient in mitigating climate change alone. Therefore, the central focus of this thesis is to assess to what extent carbon taxing has been successful in curbing global CO_2 emissions and thereby contributing to the existing body of literature on carbon taxing. The central research question of this thesis will be as follows:

RQ: „To what extent has carbon taxing been successful in reducing global CO_2 emissions?”

1.2. Sub-questions

To answer the research question, the following sub-questions are also needed to be assessed:

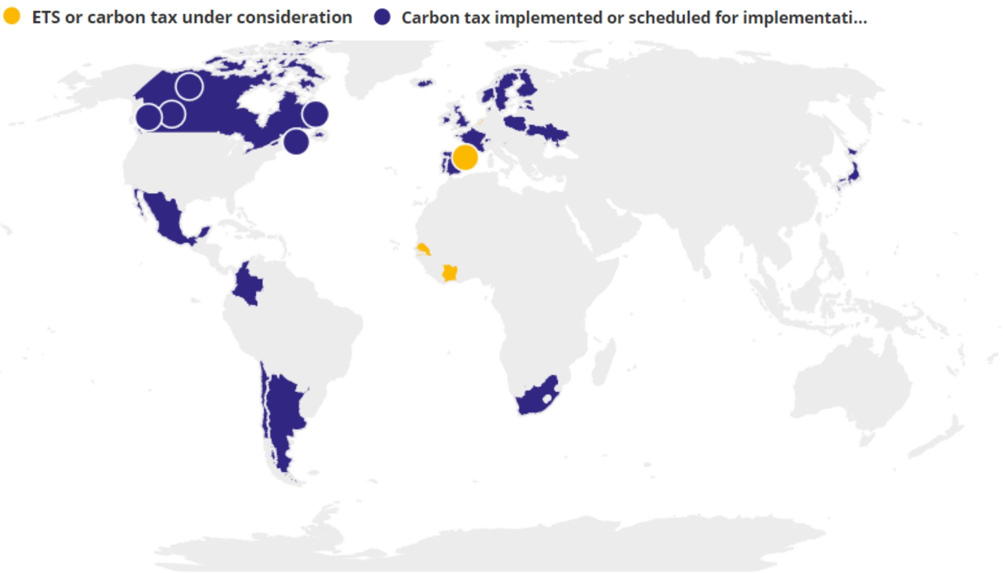
1. **What are possible approaches to reduce CO_2 emissions and how successful are they according to the literature?**
2. **How effective is carbon taxing in reducing CO_2 emissions according to the literature?**
3. **What are the outcomes of the analysis?**

1.3. Approach

To be able to answer its main research question, this thesis first aims to answer its three sub-questions separately. The research design of this study can be divided into two main parts. Firstly, the literature overview aims to provide answers to the first and second sub-questions of this analysis. Therefore, two different approaches to climate change are presented, namely the green growth and the degrowth movements. Afterwards, various market-based instruments are discussed so that carbon taxing can be put into context. Next, the findings of the previous body of literature are summarized on the effectiveness of carbon taxing. The evaluation of previous literature enables the selection of relevant control variables and also the development of hypotheses.

Regarding the second part of this analysis, a quantitative (non-experimental) design is applied to answer the third subqestion and the main research question. This research aims to evaluate the overall effectiveness of carbon taxing on CO_2 emissions. As demonstrated in Figure 1, numerous countries have implemented carbon taxing around the world up until 2019. Therefore, to account for cross-country differences over time, a pooled cross-country time-series research design (panel research) is applied. The analysis will cover a large sample of countries (N=54) over a period of 28 years (1990-2017). The operationalization of variables, the selection of countries included in the sample, further discussion of the empirical method, and the reliability and validity of this research is assessed in greater detail in Chapter 3.

Figure 1. Summary map of regional, national, and subnational carbon taxing initiatives



Source: Carbon Pricing Dashboard, World Bank (2019)

1.4. Relevance

1.4.1. Societal relevance

There is an increasing consensus that climate change is the most profound challenge that our society has ever had to face. The stakes are high and they hold serious risks in many areas of our lives such as employment, health, food security, and human rights. Without effective adaptation and mitigating measures, climate change is projected to further exacerbate vulnerabilities, place human health and security at risk, and block sustainable development (WHO, 2011).

According to the World Health Organization (2011), the impacts of climate change are expected to hit those the most that live in extreme poverty due to their dependency on natural resources (which are directly affected by climate change) and also because they have less capacity to protect themselves. Hence effective actions and policies must take place at both national and global levels to reverse the current trends of climate warming. Moreover, people are not only victims of this phenomenon, but drivers of climate change, thus measures depend on us to be successful. Hence, the central role of people in mitigating climate change should reshape the way policy-makers implement climate-change policies. However, according to the UN Emission Gap Report (Olhoff & Christensen, 2018), countries are far off course in meeting emission goals. According to Dryzek et. al. (2011, p. 1.) *„the social problem-solving mechanisms we currently possess were not designed, and have not evolved, to cope with anything like an interlinked set of problems of this severity, scale, and complexity. There are no precedents. So far, we have failed to address the challenge adequately."* Thus evaluating the effectiveness of carbon taxing helps us to determine whether the *„most important policy instrument providing a cost-effective mechanism for mitigating climate change"* (Sen & Vollebergh, 2018, p. 74) is indeed capable of addressing the adverse effects of climate change.

1.4.2. Scientific relevance

Most existing studies are based on simulating the possible effects of carbon taxing (see Dong et al., 2017; Boyce, 2018), and there are only a few studies that empirically analyzed the effectiveness of carbon tax. However, to my best knowledge, there are no quantitative empirical studies that estimate the overall effectiveness of carbon taxing initiatives around the world in reducing CO_2 per capita emissions. There are several studies (Bruvoll & Larsen, 2004; Andersen, 2004; Lin& Li, 2011; Frey, 2016) which focus on a particular country or region or that focus on specific sectors. However, estimates of the effectiveness of carbon taxation based on such studies have serious limitations. Studies that are focus on one sector are limited in offering explanations for economy-wide impacts of carbon taxing, while simply focusing on a certain country or region would significantly reduce the external validity of the findings. Therefore, this study fills in the gap and contributes to a better understanding of the mitigating effects of carbon taxing.

1.5. Outline

This thesis is structured as follows. Chapter 1 provides a general introduction to the topic, the aim of this research, and also the main question and the sub-questions of the study. Chapter 2 presents the literature review on two approaches to climate change, on market-based instruments, and also on the effectiveness of carbon taxing on CO_2 emissions. Furthermore, Chapter 2 establishes the theoretical assumptions of this study and also the control variables accounted for in this research. Chapter 3 adresses the research design in great detail, the choice of empirical models for the analysis, the operationalization of the variables, and the reliability and validity of this study. In Chapter 4 the assumptions of the Ordinary Least Squares (OLS) model are tested, the final model selection is justified and the results of the analysis are presented and discussed. Last but not least, Chapter 5 provides the interpretation of results, concludes the final answers to the research questions, and also discusses the limitations of this research.

Chapter 2.

2. Literature review

Scientific research shows that human activity, particularly the consumption levels in the developed world, is degrading the natural environment (Sandberg, Klockars and Wilén, 2019). Climate change has become one of the most serious threats to us and our environment in the 21st century. Scientists agree that to minimize irreversible damages in the long term, we need to limit the increase in temperature due to greenhouse gas emissions derived from human-related activities to 2°C, relative to pre-industrial levels, by 2100 (Rosen & Guenther, 2015). To ensure this, the concentration of greenhouse gases must not exceed 450 parts per million (ppm) of CO_2 (Lawn, 2016). Before the Industrial Revolution, there were only 280 ppm of CO_2 in the atmosphere, however, if unabated, many predict the concentration of CO_2 to increase to 560 ppm by 2050 (Sinn, 2008, p. 361). Moreover, the Stern Review suggests that this value of CO_2 concentration would even increase to 900 ppm by 2100 in a business-as-usual scenario (Sinn, 2008). Currently, a rapidly increasing trend is taking place globally in CO_2 emissions.

In 2018 the UN Intergovernmental Panel on Climate Change (IPCC) published a special report outlining what steps need to be taken to prevent global warming of more than 1.5°C over preindustrial levels (Hickel, 2019). According to the report, global emissions need to be halved by 2030 and reach net zero by 2050 (IPCC, 2018). However, currently, there are no agreed plans aimed at achieving this goal, as no absolute reductions to global emissions are included in the voluntary pledges made by those countries who signed the Paris Climate Agreement in 2015 (Hickel, 2019). As the years pass by, we have less time to act. Moreover, the cost of mitigating climate change tends to increase over time, while the budget decreases every year (Mundaca, Ürge-Vosatz, and Wilson, 2019). The available emission budgets defined by the 2°C were already challenging, but the goal to prevent global warming of more than 1.5°C over preindustrial levels, made it even harder to achieve.

To achieve the goals set in the Paris Agreement, profound social and technological change is required. Market-based instruments and in particular carbon taxing have emerged to provide solutions to these problems. Carbon tax is an incentive-based policy instrument that aims to internalize pollution costs into the production costs, thereby reducing CO_2 emissions (Dong et al., 2017; Andrew et al., 2010). However, before turning to the discussion on carbon taxing, it is important to take a look at the other possible approaches that have emerged and which aim to provide the solution to anthropogenic climate change. Furthermore, other market-based instruments (apart from carbon taxing) are also discussed that are at our disposal to act in order to avoid the worst-case consequences of global warming.

2.1. Approaches to solving climate change

As a result of the intensification of climate change, the relationship between environmental degradation and economic growth has been in the center of attention for the past decades. Before turning to the discussion on market-based instruments, this section aims to provide a brief overview of two significantly different approaches to solving climate change: green growth and de-growth. In particular, these approaches have different views on the role of economic growth in environmental degradation and thus climate change. Specifying these approaches are important because they propose vastly different solutions to achieve the goals set by the Paris Agreement and thus mitigating climate change.

2.1.1. Green growth

The most widely accepted approach in stopping the degradation of our environment is probably the so-called 'green growth' movement, which is highly endorsed for instance by the United Nations, Organization for Economic Cooperation and Development (OECD) and those neoclassical environmental economists, who see the ongoing environmental degradation as a result of market failures (Sandberg et al., 2019). According to the OECD (2011, in Wanner, 2014) green growth is a subset of development, not a replacement of it. Moreover, countries such as Japan, Germany, the Republic of Korea, and also China started to base their economy on green growth. The concept of green growth arose within environmental economics, but during the past few decades, it has moved to mainstream policy-making (Wanner, 2014).

The concept of green growth claims that economic growth can occur while environmental degradation is reduced. Thus, green growth does not only provide a normative ideal but also an economic one, as it claims that the relationship between environmental damage and economic growth is contingent and not necessary (Jacobs, 2012). Economists argue that currently externalized costs of environmental degradation need to be internalized into prices (Spash, 2013). Proponents of the green growth movement claim that economic growth and environmental preservation are compatible goals, resulting in a win-win situation. Hence, green growth aims to preserve the natural environment while advancing economic growth (Sandberg et al., 2019). As explained by Antal and Van Der Bergh (2014) this can be achieved through decoupling environmental pressures from the aggregate output at a sufficiently rapid rate. In fact, according to Wanner (2014), decoupled green growth does not endanger economic growth and has not only no environmental impacts, but it provides the potential to create jobs, alleviate poverty and enhance social equity.

However, a distinction needs to be made between relative and absolute decoupling. Relative decoupling refers to less environmental impact for every unit of GDP (UNEP, 2011), however, it is not sufficient for stopping the degradation of the environment. It is about 'doing more with less' as a result of increasing resource use efficiency (Jackson, 2009). Absolute decoupling, on the other hand, means that the growth rate of resource productivity exceeds the growth rate of the economy (UNEP, 2011), hence it refers to less overall environmental damage in the production and consumption process (Wanner, 2014). It is important to emphasize that the latter is necessary to reduce economic-growth led environmental degradation.

To achieve decoupling, green growth mainly relies on developing more advanced technologies that improve the resource efficiency of production (Sandberg et al., 2019, p. 137), such as the use of renewable resources, new materials, recycling of waste, sustainable harvesting practices and even changes to the structure of the economy (Jacobs, 2012). Electric cars or improved production processes that use less water or energy to produce the desired product are great examples of those technological advancements. Thus, green growth does not require substantial changes in consumption patterns and levels (Bina, 2013).

Effectiveness

Recent research shows that green growth is not likely to stop climate change and environmental degradation. McAfee (2016) argues that apparent environmental gains have only been possible as a result of the developed world outsourcing pollution to the so-called third-world 'pollution havens'. Three major empirical studies arrived at the same conclusion: on a global scale decoupling of GDP from resource use is not possible, even given the best conditions (Hickel, 2018). This is demonstrated by Jackson (2011, in McAfee, 2016), who claims that even though energy intensity has declined significantly, it did not result in lower levels of GHG emissions in the industrialized countries in the past 30 years. Thus, only relative decoupling took place. As Hickel (2018) argues, scientists begin to realize that there are physical limits to efficiently used resources. It might be possible to produce cars more efficiently and cheaply, but then more people can afford to buy them, which will eventually result in higher demand and greenhouse gas emissions. As Raftery et al. (2017 in Hickel, 2019) claim, the primary reason for this problem is that economic growth is likely to drive energy demand up to such a rate, where clean energy in itself can not supply sufficient level of energy. This can already be felt in the 21st century, as the increased energy capacity covers only 16% of the new demand (Hickel, 2019, p. 55). This is because the world produces 8 billion more megawatt-hours of clean energy each year since 2000, however over the same period, energy demand has grown by 48 billion megawatt-hours (Hickel, 2019, p. 55). Even though Jacobson and Delucchi (2011) claim that it would technically be possible to scale up energy output to cover total global energy demand, it remains highly questionable whether it can be done fast enough, while respecting the carbon budgets for 1.5°C and 2°C if the economy keeps growing at the same pace each year. As discussed above, economic growth leads to an increase in energy demand that in turn further increases emissions resulting from economic processes (Hickel & Kallis, 2019). Furthermore, critics of green growth emphasize that that concept only extends the economization of the relationship between nature and society, and thus refuses to bring a radical change and resolve the capitalist hegemony that drives limitless resource exploitation (Warren, 2014).

2.1.2. De-growth

As the effects of the climate crisis become more destructive, scientists have come to highlight economic growth as a matter of concern. Since the 1960s, a growing amount of criticism has come from some of the most respected economists of the 20th century, including Kuznets, Dagsputa, and Kahneman. As it is often argued, GDP growth is not necessarily a good indicator of social progress and welfare. As discussed by van den Bergh (2009), using GDP per capita as a measure of welfare suffers from several problems. To name but a few, GDP per capita does not capture all social costs. Moreover, basic needs, clean air, or direct access to nature are not captured by GDP either. Furthermore, it emphasizes average income and neglects income distribution. To top it up, according to happiness studies, somewhere in-between 1950 and 1970, the increase in mean happiness stagnated and to some extent even reversed into a negative trend, despite continuous GDP growth. Last, but not least, GDP per capita is also criticized for not counting for negative external effects, such as air or water pollution.

IPCC scientists argue that the only feasible way to meet the Paris Agreement targets is through actively scaling down the material throughput of the global economy (Hickel, 2019). Ecological economists call this approach the ’degrowth movement’, which is referred to as an alternative to the paradigm of economic growth. Degrowth is defined as an *„equitable downscaling of economic production and consumption”* which *„increases human well-being and enhances ecological conditions at the local and global level, in the short and long term”* (Schneider, Kallis, and Martinez-Alier, 2010, p. 511). Degrowth, however, moves even beyond the criticism of GDP, as it suggests a more radical transformation of society than green growth

(Muraca, 2013). As Kallis (2011) claims, a decline in GDP is not a goal in itself but a likely consequence of downscaling the material throughput of society. As stated by Daly (1996, in Kallis, 2011) a society's throughput refers to the energy and materials that a society extracts, processes, transports, distributes, consumes, and then returns to the environment as waste. It is claimed that eventually our planet will die, but the question is how fast that would happen. To limit the speed of environmental destruction, the degrowth movement proposes to access a steady-state of economy, whereby qualitative changes and innovations in the economic, social, and cultural aspects of life would still take place while restricting the number of materials used for that.

The degrowth movement challenges the arguments made by green growth, as it claims that material throughput can only be reduced if our economies are downscaled, i.e. through GDP degrowth. The basis for this argument is twofold. First, proponents of the degrowth movement argue that further economic growth is bound to exhaust non-renewable and renewable energy sources (Heinberg, 2010, in Kallis, 2011). Second, further economic growth also poses unrealistic expectations of technological improvement to respect the IPCC's CO_2 thresholds (Jackson, 2009). Degrowth's premise holds that efficiency and technological improvements alone are not sufficient in preventing climate change, but the scale of the economy needs to shrink too (van den Bergh & Kallis, 2012) by reducing sectors of economic activity that are ecologically destructive and offer little to no social benefit, such as advertising, fossil fuels, single-use products. This might seem unfavorable to human development, but the proponents of the degrowth movement claim that the society's standard of living can even improve while reducing economic throughput in high-income countries (Hickel, 2019, p. 54). Moreover, many studies pointed out that substantial levels of reductions in emissions require radical changes in consumption patterns, such us avoiding airplane travel, or shifting from meat consumption to other alternatives. Policy proposals focus on shortening the workweeks, redistributing existing income as well as expanding access to public goods (Hickel, 2019).

Effectiveness

Even though a growing number of scholars argue that degrowth is the only way to address climate change, it continues to be dismissed and criticized (Stuart, Gunderson, and Petersen, 2017). Firstly, it remains questionable whether degrowth strategies could obtain the necessary social and political support. Secondly, even if they do so, the question remains whether degrowth policies can actually contribute to a significant reduction of climate change, especially when considering the unintended rebound effects[1] (van den Bergh, 2011). Thirdly, if degrowth is indeed the solution to our century's greatest challenge, it would have to downscale the economy by a factor of 20 to 100 (van den Bergh & Kallis, 2012), which sets an enormous challenge. As Jackson (2009) argues, even to decarbonize the economy through technology, some level of degrowth is necessary. Furthermore, even though it is widely agreed that GDP growth is not a good indicator of social process, some argue that nor does GDP degrowth as such (van den Bergh, 2011). Moreover, one cannot exclude the possibility of 'dirty degrowth', whereby economic degrowth hardly reduces any destructive impact on the environment. As stated, degrowth as such does not provide any concrete strategies to effectively manage climate change or to transition to a sustainable economy (van den Bergh, 2011). The final criticism of the degrowth argument is that there is no single, consistent unit to measure the scale of the economy, hence the notion is not clear. It could mean the degrowth of many things, such as consumption, GDP per capita or even working hours (van den Bergh & Kallis, 2012). Proponents of the movement argue however, that this lack of precision is not a drawback, as degrowth mainly aims to offer a vision to build a better world, where people learn to live with less.

To conclude, green growth and degrowth movements offer significantly different solutions to mitigating climate change. Green growth claims that environmental preservation and economic growth are compatible goals and that the goals of the Paris Agreement can be achieved by internalizing externalized costs of environmental degradation into prices. Degrowth, on the other hand, argues that the economization of the relationship between nature and society further exacerbates the challenges set by climate change.

2. 2. Market-based instruments

To establish whether aiming for green growth can bring us closer to mitigate climate change, the following section provides an introduction of the history and economic theory behind carbon markets. Cap-and-trade systems and carbon taxing, the two most promising market-based instruments, are analyzed based on their rationale and their effectiveness.

Carbon markets and market-based instruments have been at the forefront of international climate politics for more than 20 years now and have been highly endorsed by the proponents of the green growth movement. They have been advocated as the miraculous, highly efficient

[1] Rebound effect refers to the phenomenon that improvements in resource efficiency result in lower prices and hence cause the demand to rise, thus losing some of the gains (Hickel, 2018).

and effective policy instrument to be able to mitigate climate change (Stern, 2009, in Lederer, 2012), but also been referred to as ’false solution’ and even ’poison’ (Lohman, 2009, in Lederer, 2012). Carbon markets or the so-called market-based instruments promise to protect society from the effects of climate change by way of the creation and commodification of emission rights (Carton, 2014). Carbon markets aim to assign prices to natural entities to reduce environmental degradation. This approach presupposes that environmental degradation and climate change - the so-called ’negative externalities’ - are results of uncompensated consumption of non-commodified resources (Stuart et al., 2017). Fairbrother (2016) argues that pollution and non-commodified resource use are not accounted for in the market price of the product or the product’s production costs. Hence, as it is argued by environmental economists, the solution is to internalize the negative externalities and hence making the market work for the environment through pricing mechanisms. Stuart et al. (2017, p. 92) claim that to do this *„one must think of the environment as a pool of commodified and not-yet-commodified resources… in order to assign price values to natural entities”*. Thus, market-based solutions connect environmental emissions with financial incentives (Zhang, 2012). This way market-based instruments provide flexible and cost-effective solutions, which spur actors of the global market to take action.

Market-based instruments (MBIs) involve various measures, such as emission trading systems -often also referred to as cap-and-trade systems-, and carbon taxing. This approach is highly endorsed by the IMF, UNDP, European Union, and even the World Bank, which acts as a carbon market facilitator and catalyst (Storm, 2009). To see if the market-based instruments are indeed successful instruments of mitigating climate change, as proposed by (among many) the proponents of the green growth movement, this thesis focuses on one of the most famous MBI, namely carbon taxing.

Carbon markets have mainly started to be used with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 (Lederer, 2012). The Kyoto Protocol set up compulsory targets for signatory countries to reduce GHG emissions. A total of 192 parties have signed and ratified the Kyoto Protocol and have set emission reduction targets for 2020 (Villora-Sáez, Tam, Merino, Arrebola, and Wang, 2016). The Kyoto Protocol established mechanisms, such as the international emission trading under Article 17 (discussed further in the next section), Joint Implementation (JI) under Article 6, and the Clean Development Mechanism (CDM) under Article 12 (Streck, 2004).

As argued by Newell, Pizer, and Raimi (2013), the Clean Development Mechanism serves as a vehicle, through which emission reduction endeavors in developing countries can be turned into credits. These credits in turn can be utilized to offset capped emissions[2] somewhere else. This means that the countries with sufficient credits can sell those credits to countries that have not put enough effort into emission reduction. Thereby the countries are financially incentivized to meet their emission reduction targets. Through CDM, industrialized countries with greenhouse gas reduction commitments are allowed to invest in projects that reduce emissions in developing countries instead of investing in more expensive emission reduction projects in their own countries (European Commission, n.a.). Joint Implementation is a related but smaller program that was created in the former Soviet Union and Eastern Europe, which is often included in the discussions of CDM. JI allows industrialized countries to partly satisfy their emission reduction targets by paying for projects that reduce emissions in other industrialized countries (European Commission, n.a.). In short, as argued by Lohmann (2005), the Kyoto Protocol attempted to set up a market in „carbon dumps" as a dominant global strategy for mitigating anthropogenic climate change.

2.2.1. Emission trading systems

Emission trading systems have emerged as the main strategy for mitigating climate change globally. The idea was born out by the desire of Northern countries to minimize their cost of complying with legally binding emissions reduction targets established by the United Nations Kyoto Protocol (Ervine, 2013). The idea behind emission trading systems, as described by Lohmann (2005), is to make fossil fuel sources economically scarce gradually through limits enforced by countries (Lohmann, 2005). This has no economic efficiency aspect but merely places a cap on pollution. The countries are given a number of emission rights that are equivalent to their 1990 levels of emission minus their reduction commitment (Bachram, 2004). These emission credits are to be measured in units of greenhouse gases, hence one ton of CO_2 equals one credit. The goal is to achieve the commitments set by the Kyoto Protocol, which set the goal to achieve the reduction by 5.2% below 1990 levels of greenhouse gases by 2012 in the EU (Bachram, 2004, p. 6). The credits are allocated on a nation-wide basis in such a way that the most polluting industries receive the biggest allocation of credits (Bachram, 2004). Hence, it is often argued that in this system it pays to pollute. However, it is also important to

[2] Capped emissions are emissions that have been limited by the government of a country to reduce pollution in the atmosphere.

mention that companies are heavily fined, if not all their emissions are covered by previously assigned allowances (Villoria-Sáez et al., 2016).

Moreover, the price of the units of CO_2 reflects the value it is worth for the society, as the system works through bargaining mechanisms, which provides the market efficiency aspect. Those emitters who manage to use CO_2 more efficiently can sell their unused permits, thus incentivizing participating countries to innovate and to be more efficient (Lohmann, 2005). Hence, the economic efficiency aspect arises by making those permits tradeable (Spash, 2010). This way, the market works as a facilitator for polluters for finding countries and operators with the lowest costs of CO_2, hence social gains occur. In short, these countries with high costs buy permits to continue polluting, while lower-cost ’operators’ of the market sell their unused permits for profit (Spash, 2010). The result of emission trading schemes is that prices of permits can be highly volatile, as information is provided to the market every once in a while (Andrew, Kiadonis, and Andrew, 2010). However, speculators can profit from the market by trading tradeable permits. Thus, the costs of emission are determined by market forces, which lies at the heart of the neoliberal argument in favor of cap-and-trade systems over carbon taxing (Andrew et al., 2010).

Various international, national, and regional emission trading schemes exist today. The first and most famous one is the Emission Trading Scheme established in 2005 by the European Union (EU-ETS) and signed by 25 member states. It covers around 50% of all CO_2 emissions in member states (Oestreich & Tsiakas, 2015). Countries such as New Zealand, Australia, Switzerland, Canada, and Japan have also launched similar trading systems on a national and regional level (Lederer, 2012). Moreover, numerous emerging economies, such as India, China, and Brazil are considering establishing their own emission trading schemes, although these mostly served as learning purposes rather than policy instruments until very recently (Sterk & Mersmann, 2011, in Lederer, 2012).

2.2.2. Carbon tax

Carbon taxing has many similarities to emission trading schemes. The internalization of pollution costs is included in both systems, hence both systems serve as a response to the market failure of climate change. Moreover, each system requires a certain level of government intervention as well. However, while emission trading systems expanded more rapidly, they convey more uncertainty and are rather complex, the infrastructure of carbon taxing is less complicated and provides more certainty (Andrew et al., 2010). As argued by Aldy, Ley, and Parry (2008), the tax changes the price of a product by a predictable amount. Moreover, carbon taxing is highly recommended by many economists and international organizations as well (Lin & Li, 2011). Furthermore, as argued by Hebbink et al. (2018), carbon taxation has a main advantage. It pushes the costs of products with high CO_2 emissions up related to lower-emission products, thereby incentivizing to produce more of the latter.

As demonstrated in this paragraph, a carbon tax is an incentive-based policy instrument for controlling carbon dioxide emissions, which has been in the focus of global attention since the 1990s (Dong et al., 2017). With a carbon tax, there is a specific price imposed on carbon emissions directly through the applied tax rate to the polluting entity (Andrew et al., 2010). Therefore, firms are forced to internalize the cost of pollution in the production costs that would otherwise be ignored (Andrew et al., 2010). Thus, social damages are reflected in the price of sold products and services. Moreover, the costs are not shared by the whole society or government but may be shifted to the individual consumer through the producer (Milne, 2003, in Andrew et al., 2010). However, carbon taxes require well-established government legislation, regulation, and also infrastructure (Andrew et al., 2010). Furthermore, a carbon tax can be set in two ways. First, it can be levied on the carbon content which, in turn, limits carbon emissions. Second, it can also be established at a uniform level, on the energy product that causes the emission of greenhouse gases. This thesis focuses on the first of the two options. It is also important to note that taxes provide a pool of resources to the governments in such a way that it is consistent with economic efficiency, hence it can even replace taxes that are not as efficient, such as labor taxes (Spash, 2010; Andrew et al., 2010). Moreover, Lin & Li (2011) describe the following impacts of implemented carbon taxing. On one hand, it promotes the substitution of products that have high levels of emissions, thereby promoting more efficient consumption habits. On the other hand, it also promotes investment in energy-efficient technologies.

Carbon prices are most commonly denominated in US dollars per metric ton of carbon dioxide ($/Mt CO_2). To achieve the established policy goals, prices must be high enough. As stated by World Bank (2019, p. 10), *„less than five percent of global emissions covered under carbon pricing initiatives are priced at a level consistent with achieving the goals of the Paris Agreement"*. Carbon prices in 2019 ranged from less than $1/Mt to $127/Mt, while 51% of the emissions covered are priced less than $10/Mt (World Bank, 2019). Before turning to see actual carbon prices implemented by carbon taxing initiatives, it is important to mention why carbon prices are well below the recommended levels by climate policy analysts. One plausible explanation for this, according to Boyce (2018), is that groups who have vested interest in the continued use of fossil fuels have political power. A second explanation can be the public backlash from consumers, who are reluctant to pay for rising fuel costs. According to the Global Carbon Account (2018), the average price of carbon dioxide implemented by carbon taxing initiatives around the world is \$12.09/tCO_2, and prices range from \$0.02 in Ukraine to \$140 per metric tons of CO_2 in Sweden. However, as Table 1 also demonstrates, it is not only the price that varies from country to country but also the share of jurisdiction's emission covered (%). As shown, this indicator ranges from 3% in Estonia to 71% in Ukraine.

Table 1. National and subnational carbon taxing initiatives implemented until 2018

	Jurisdiction	**Year launched**	**Price 2018 US\$/tCO_2**	**Share of jurisdiction's emissions covered (%)**
1.	Finland	1990	76	36
2.	Poland	1990	1	4
3.	Norway	1991	57	60
4.	Sweden	1991	139	40
5.	Denmark	1992	29	40
6.	Slovenia	1996	21	24
7.	Estonia	2000	2	3
8.	Latvia	2004	5	15
9.	British Columbia	2008	27	70
10.	Liechtenstein	2008	102	26
11.	Switzerland	2008	102	33
12.	Ireland	2010	29	49
13.	Iceland	2010	18	55
14.	Ukraine	2011	0.02	71
15.	Japan	2012	3	68
16.	United Kingdom	2013	25	23
17.	France	2014	55	35
18.	Mexico	2014	2	46
19.	Portugal	2015	10	29
20.	Alberta	2017	23	45

21.	Chile	2017	5	42
22.	Colombia	2017	5	24

Source: Global Carbon Account (2018); Frey (2016)

2.2.3. Effectiveness of MBI's

To see whether the argumentation of the green growth or the degrowth movement holds true, this thesis focuses on evaluating the effectiveness of market-based instruments, particularly of carbon taxing. If, based on empirical evidence, carbon taxing proves to be effective in curbing anthropogenic CO_2 emissions, aiming for green growth is indeed the right goal for governments and policy-makers. However, if it does not prove to be successful in cutting CO_2 emissions, claims made by the proponents of the degrowth movement need to be taken seriously.

As mentioned earlier, various forms of market-based policy instruments exist today, such as the Kyoto Protocol's Clean Development Mechanism or the European Union's Emission Trading Scheme. However, existing research established not so favorable results and critics often see MBI's as 'false solutions'. As Storm (2009, p. 1019) claims *„putting a price on emissions does not encourage meaningful investments in emissions-reducing technologies and even often slows the changes needed to cope with global warming, sacrificing the benefits of long-term environmental progress to the imperative of short-term cost-effectiveness and short-term profitability"*. Furthermore, Stuart et al. (2017) argue that carbon markets increase commodification and further embed society in market relations while deepening fundamental contradictions. As stated, *„carbon markets perpetuate the structural causes of climate change by recommending the expansion of carbon commodification rather than its reduction"* (Stuart et al., 2017, p. 93). The following section aims to provide a brief discussion on the existing literature on the effectiveness of cap-and-trade systems and carbon taxing on reducing CO_2 emissions.

2.2.3.1. Emission trading systems' effectiveness

Regarding the cap-and-trade systems, most research has focused on evaluating the effectiveness of the EU Emission Trading System (EU-ETS). Most papers report 2.4-4.7% reductions in total emissions in Phase I, which entered into force in 2005 and lasted until 2007 (Stuart et al., 2017). For Phase II, EU-wide emission reductions are estimated at 6.3% between 2008 and 2009 against baseline emissions (Hu, Crijn-Graus, Lam, and Gilbert, 2015). The EU-ETS's performance is characterized by an oversupply of allowances[3] since 2008 (Burtraw, Löfgren, and Zetterberg, 2014), which affects the performance of EU-ETS even in Phase III, which entered into force in 2013. The oversupply of allowances is argued to undermine the EU-ETS's role in supporting low carbon investment (EC, 2014 in Hu et al., 2015). Carbon Trade Watch (2011) states that the EU-ETS has failed to reduce emissions, partly because companies have received generous allocations of permits to pollute, which means that they lack the obligation to cut their CO_2 emissions. As they argue, emission reductions that occurred are results of the economic recession of 2008-2009 and the growing significance of renewable energy production, but not of the implementation of EU-ETS. While some claim that the EU is the only region which is well on track to meet the Kyoto Protocol targets (Villoria-Sáez et al, 2016), it is also often argued that the failure of EU-ETS is well demonstrated by the sharp decline of the trading prices that fell from €30 to 10 euro cents in three years (Andrew et al., 2010). In comparison, according to the European Commission's (2011, in Burtraw et al., 2014, p. 1) estimation, emission reduction levels consistent with the 2-degree target require a carbon price of at least €32 by 2030. The failure of meeting the targets is well demonstrated by the argument that claims that 16 member states out of the 28 will not reach their targets for 2020 without significant efforts (European Union Commission, 2012, in Villoria-Sáez et al., 2016). Thus, drawing on the findings on the largest cap-and-trade system (EU ETS), it can be established that the effectiveness of emission trading schemes is highly questionable.

2.2.3.2. Carbon tax effectiveness

As this thesis aims to evaluate to what extent carbon taxing has affected CO_2 emissions per capita, it is important to discuss the findings of previous studies on this topic. This review of previous bodies of literature only focuses on ex-post evaluations, as the paper aims to draw conclusions on already existing results to establish what has actually been the effect of carbon taxing so far.

Before turning to discuss studies made on evaluating the effect of carbon taxing on CO_2 emissions, it is useful to provide a brief overview of the carbon taxing literature in general. Timilsinas (2018, p. 6), who analyzed the literature of carbon taxing for the previous 30 years, found that carbon tax literature can be classified into the eight following groups: literature investigating the 1) economic impacts of the carbon tax in general; 2) distributional effects of

[3] Since 2008 a buildup of emission allowances has taken place as a result of several factors, such as the economic recession between 2008-2009, the auctioning of Phase III allowances too soon and also an unexpected inflow of certified emissions reductions credits under CDM (European Commission, 2012 in Burtraw et al., 2014, p. 1).

the carbon tax; 3) various schemes to recycle carbon tax revenues to the economy; 4) competitiveness and emission leakage of unilateral carbon taxes; 5) difference and similarities of carbon taxing with other policies; 6) qualitative issues related to carbon tax policies; 7) impacts of carbon tax on a particular sector; and finally 8) specific issues related to carbon tax. As this paper aims to focus on the effectiveness of carbon taxing policies on emission reductions, the scope of this study is not necessarily covered by any of the aforementioned groups. The following section summarizes the existing body of literature on the effectiveness of carbon taxing on CO_2 emissions in chronological order.

Bruvoll & Larsen (2004) used an applied general equilibrium simulation to evaluate the effects of carbon taxes for the period of 1990-1999 in Norway. They found that even though total emissions have increased, a significant reduction took place in emissions per unit of GDP due to reduced energy intensity, reduced process emissions, and changes in the energy mix. However, the authors emphasize that even though CO_2 emissions were reduced by 14%, carbon taxes only contributed to 2% reductions. They concluded that the relatively small effects are due to extensive tax exemptions and inelastic demand in the sectors where carbon taxes are implemented.

Andersen (2004) showed that among the Nordic countries Denmark's scheme is the most successful in reducing CO_2 emissions by conducting an ex-post evaluation analysis, whereby the author summarized the findings of ten years of research on the effectiveness of carbon taxing in the Nordic countries. Andersen (2004) claims this result is also due to the structure of the Danish energy sector, as it is characterized by higher carbon content. However, this study did not consider the rate of carbon tax or the share of the emissions covered by the carbon tax.

Lin & Li (2011) using a method of difference-in-difference (DID)[4] estimated the mitigation effects of carbon taxes in five north European countries: Denmark, Finland, Sweden, Netherlands[5], and Norway. Lin & Li (2011) included GDP per capita, industry structure,

[4] The DID method is a statistical technique often used in quantitative research. It aims to assess the effect of the independent variable(s) on the dependent variable(s) by grouping the countries (cases) in the study according to whether they have been influenced by the independent variable or not. Those countries that are influenced by the independent variable(s) are part of the treatment group, while those who are not, are part of the control group. The effect of the independent variable(s) on the dependent variable(s) is calculated for both groups. Then, by comparing the average change for both groups, the effect of the independent variable can be established.

[5] It is important to mention that even though the Netherlands does not have an explicit carbon tax, it is included in the treatment group of this study, probably because it did introduce a carbon tax in 1990, however that was later transformed into energy tax (Lin & Li, 2011).

urbanization level, and energy price as main independent variables affecting the difference between the control and treatment group, which were chosen after summarizing the results of previous studies that evaluated the factors affecting CO_2 emissions. Even though renewable energy consumption and energy intensity are shown to affect CO_2 emissions, Lin & Li (2011) excluded them from their model, as those can be easily influenced by carbon taxing. GDP per capita of each county was included based on purchasing power parity to achieve full comparability among the countries (Lin & Li, 2011). Industry structure represented the share of the service industry in the countries, while energy price was represented by the Landed Cost of American imported crude oil. Furthermore, gross domestic expenditure on Research and Development (R&D) was added to the model as a technological factor. As argued, CO_2 emissions tend to decrease as a result of technological progress (Brannlund, Ghalwash, and Nordström, 2007). Lin & Li (2011) found that carbon tax resulted in a significant decline in per capita CO_2 growth. The greatest mitigation effects of the carbon tax were shown in the case of Finland, as the carbon tax imposed a negative and significant impact on CO_2 emissions according to the authors. However, for Denmark, Sweden, and Netherlands, they found negative but non-significant effects. Notwithstanding, carbon tax has not realized mitigation effects in Norway (CO_2 emissions increased) which can be attributed to the fact that Norway is a major oil and natural gas exporter around the world (Lin & Li, 2011). Therefore, Norway's economy relies heavily on energy-intensive industries. The authors concluded that there is a positive correlation between GDP per capita growth and per capita CO_2 emissions. Moreover, it is important to mention that the level of urbanization showed no significant effect on CO_2 emissions in their study. Furthermore, services' share of GDP, expenditure on R&D, and energy prices were shown to have a significant and negative effect on per capita CO_2 emissions.

Frey (2016) applied a computable general equilibrium (CGE) model for evaluating the impact of different carbon tax levels on the economy and environment in Ukraine. It is important to note that currently, Ukraine has one of the highest levels of CO_2 emissions per GDP in the World (World Bank, 2020; Frey, 2016) and that they have the lowest rate of carbon tax implemented ($0.02/$tCO_2$) (see Table 1). Frey (2017) finds that the current tax rate has negligible effects on CO_2 reduction. Furthermore, he concludes that to achieve a reduction of 10% of CO_2 emission compared to 2010 levels, a carbon tax rate of approximately $3.46/$tCO_2$ would be necessary.

Aydin & Esen (2018) used a dynamic panel threshold regression model to evaluate the effects of environmental taxes on CO_2 emissions in 15 EU member countries between 1995 and

2013. They relied on the research conducted by Lin & Li (2011) when selecting the control variables, hence they put GDP per capita[6], the share of services, urbanization level, and energy price in their model. The independent variables were operationalized in the following ways: 1) GDP per capita was calculated as GDP at market prices in constant 2010 US dollars, 2) industry structure was calculated by the share of service sector's added value to the GDP (%), 3) urbanization was calculated by the share of the urban population of the total population, 4) and the energy price was calculated as a log of energy prices measured as the US Landed Cost of Crude Oil in dollars per barrel. They found that there is a robust and significant nonlinear relationship between environmental taxes and CO_2 emissions. Furthermore, their findings show that GDP per capita and urbanization have a significant and positive effect, while energy prices and industrial structure have a mitigating effect on CO_2 emissions. Finally, their findings indicate a negative but non-significant effect of R&D expenditures on CO_2 per capita emissions. They concluded that their results indicate a threshold effect in environmental taxes on CO_2 emissions, which means that these taxes are only beneficial to our environment beyond a certain threshold of the level of the carbon tax. Below that threshold the effects of environmental taxes are limited.

Haites (2018) summarized the main findings of five studies (Andersen, 2010; Andersson, 2017; Bruvoll & Larsen, 2004; Lin & Li, 2011; Mideksa & Kallbekken, undated) that estimated the emission reductions induced by carbon taxes in one or more European countries. These studies all include Denmark, Finland, Norway, and Sweden, while some include Austria, Germany, Italy, Netherlands, Slovenia, and the United Kingdom. Haites (2018) finds that carbon taxes have achieved only small reductions (up to 6.5% over several years) from business-as-usual emissions. Moreover, Haites (2018) states that even though compared to business-as-usual scenarios emissions were reduced, actual GHG emissions continued to rise. Furthermore, he also compared non-ETS emissions for countries with and without a tax[7]. Haites (2018, p. 961) found that non-ETS emissions declined more rapidly in countries without a carbon tax (-2.59%/year) than in countries with a carbon tax (-2.08%/year). He suggests that this means that other policies have contributed more to reduce non-ETS emissions than the carbon tax. Haites (2018) concludes that since 2008, actual emissions subject to carbon taxes

[6] Even though Aydin & Esen (2018) relied on the research done by Lin & Li (2011) when choosing the relevant control variables, they measured GDP per capita in constant 2010 US dollars, while Lin & Li (2011) measured it constant 2010 US dollars based on PPP.
[7] Carbon taxes are applied almost exclusively to non-ETS emissions in the EU (Haites, 2018).

have declined in European countries, but much of those reductions are likely to be caused by non-tax policies.

Turning to non-European countries, the number of studies that focus on ex-post evaluation and not forecasting the effect of carbon taxing is mostly lacking. In fact, no study was found that met the previously mentioned conditions. The main reason for the lack of ex-post studies on assessing the impact of carbon taxing on CO_2 emissions might be that most non-European countries have only implemented carbon taxing in very recent years.

To conclude, as this literature overview shows, the literature on the effectiveness of carbon tax on CO_2 emissions is rather limited. Appendix A provides an overview of the analyzed studies. Most studies only focus on a specific country or region (such as the northern European countries) and only focus on a shorter period. Moreover, as summarized in Appendix A, there are some inconsistencies in the findings of available studies. While in some cases, a significant effect has been attributed to carbon taxing in CO_2 emission reductions (Lin & Li, 2011; Aydin & Esen, 2018;), in other cases only a relatively small or negligible effect has been shown (Bruvoll & Larsen, 2004; Lin & Li, 2011; Frey, 2016; Haites, 2018). Furthermore, to my best knowledge, there has not been any study so far that evaluated the overall effectiveness of carbon taxing on CO_2 per capita emissions for all the countries that implemented carbon taxing up until 2017. Thus, this thesis aims to fill this gap by answering its main research question: „To what extent has carbon taxing been successful in reducing global CO_2 emissions?”.

2.3. Conceptual model

This part of the paper formulates a hypothetical answer to the central research question based on the findings of the previous body of literature. This section also aims to present additional variables that can also account for changing patterns of CO_2 emission per capita. Besides, a conceptual model is established to demonstrate the relationship between the dependent, independent, and control variables.

2.3.1. Hypotheses

The central research question of this paper is as follows:

„To what extent has carbon taxing been successful in reducing global CO_2 emissions?"

As discussed in the previous section, different studies came to different conclusions on the effectiveness of carbon taxing on CO_2 emissions. To evaluate, what overall trends show, the following hypothesis has been formulated

H1: A carbon tax reduces CO_2 emissions.

In addition, to see if the rate of carbon tax and the share of jurisdiction's coverage has a significant effect on CO_2 emission, the following two hypotheses have also been added:

H2: The higher the rate of carbon tax, the lower the levels of CO_2 emissions of a country.

H3: The higher the share of jurisdiction's emissions covered by carbon tax, the lower the levels of CO_2 emissions of a country.

2.3.2. Control variables

Changing patterns of CO_2 emissions can be caused by various factors, not just the implementation of carbon pricing instruments. To account for changes in the dependent variable, other variables are also accounted for in the model. To establish the real relationship between carbon taxing and CO_2 per capita emissions, the following control variables are included in this research: economic development, industry structure, urbanization, and energy price. The selection of these control variables is based on previous quantitative studies that evaluated the factors affecting CO_2 emissions (Lin & Li, 2011; Aydin & Esen, 2018). The two studies concluded the same results on the effects of control variables on CO_2 emissions for three variables: GDP per capita (significant and positive effect), industry structure (measured as the share of services to GDP), and energy price (significant and negative effect). Regarding the level of urbanization, Lin & Li (2011) concluded that it had no significant effect, while Aydin

& Esen (2018) concluded that it had a significant and positive effect on CO_2 emissions. Moreover, while both studies found a negative effect of the technological factor on CO_2 emissions, Aydin & Esen (2018) established that those effects are not significant. However, this study does not include the technological factor as a control variable due to a lack of data[8]. Therefore, this paper aims to control for the effects of four variables.

2.3.2.1. Economic development

Several studies had established a significant and positive relationship between the economic development of a country and CO_2 (per capita) emissions (Azomahou, Laisney, and Nguyen Van, 2006; Acaravci & Ozturk, 2010; Al-Mulali, 2012; Dong, Long, Chen, Li and Yang, 2013; Wang & Feng, 2017). Moreover, both quantitative studies which focused on the effectiveness of carbon taxing on CO_2 emissions (see Appendix A) used some form of economic development as a control variable in their model (Lin & Li, 2011; Aydin & Esen, 2018). Therefore, to account for the level of economic development as a contributing factor of CO_2 emission, it is included in the regression model of this study too.

2.3.2.2. Industry structure

Different sectors of industry contribute to CO_2 emissions at different levels. This thesis differentiates between three main sectors of industry. The primary sector encompasses agriculture, forestry, animal husbandry, fishery, and water conservancy. The secondary sector consists of industry and construction, while the third sector, which is referred to as tertiary industry or service sector, includes transport, storage and post, wholesale, retail trade, hotels and restaurants (Wang & Feng, 2017). The service sector is known for its relatively lower energy consumption and CO_2 emissions (except the transporting sector) than the secondary sector, which is responsible for high levels of CO_2 emissions (Wang & Feng, 2017). On the other hand, numerous studies claim that the industry's share of GDP is significantly related to per capita CO_2 emissions (Jobert, Karanfil, and Tykhonenko, 2010; Lin & Li, 2011; Xiaoqing & Jianlan, 2011; Zhang, Liu, Zhang, and Tan, 2014; Wang & Feng, 2017). Therefore, to account for the share of the most CO_2 intensive sector of the economy, the share of industry (secondary sector) to GDP is included in this study as the second control variable.

[8] As it is established in Chapter 3, out of the 54 countries in the sample, the data on technological factor is only available for 35 countries.

2.3.2.3. Urbanization

According to Lin (2009, in Lin & Li, 2011), a rapid rise in urbanization levels results in higher CO_2 per capita emissions. Both quantitative studies, which assessed the effectiveness of carbon tax on CO_2 emissions (Lin & Li, 2011; Aydin & Esen, 2018) included the level of urbanization as a control variable in their model, however, only Aydin & Esen (2018) found a significant (and positive) effect of the level of urbanization on CO_2 emissions. Therefore, to establish if the level of urbanization indeed has a significant effect on CO_2 emissions, and to control for the possible contributing effect of urbanization to CO_2 emissions, this study includes the level of urbanization of a country as the third control variable.

2.3.2.4. Energy price

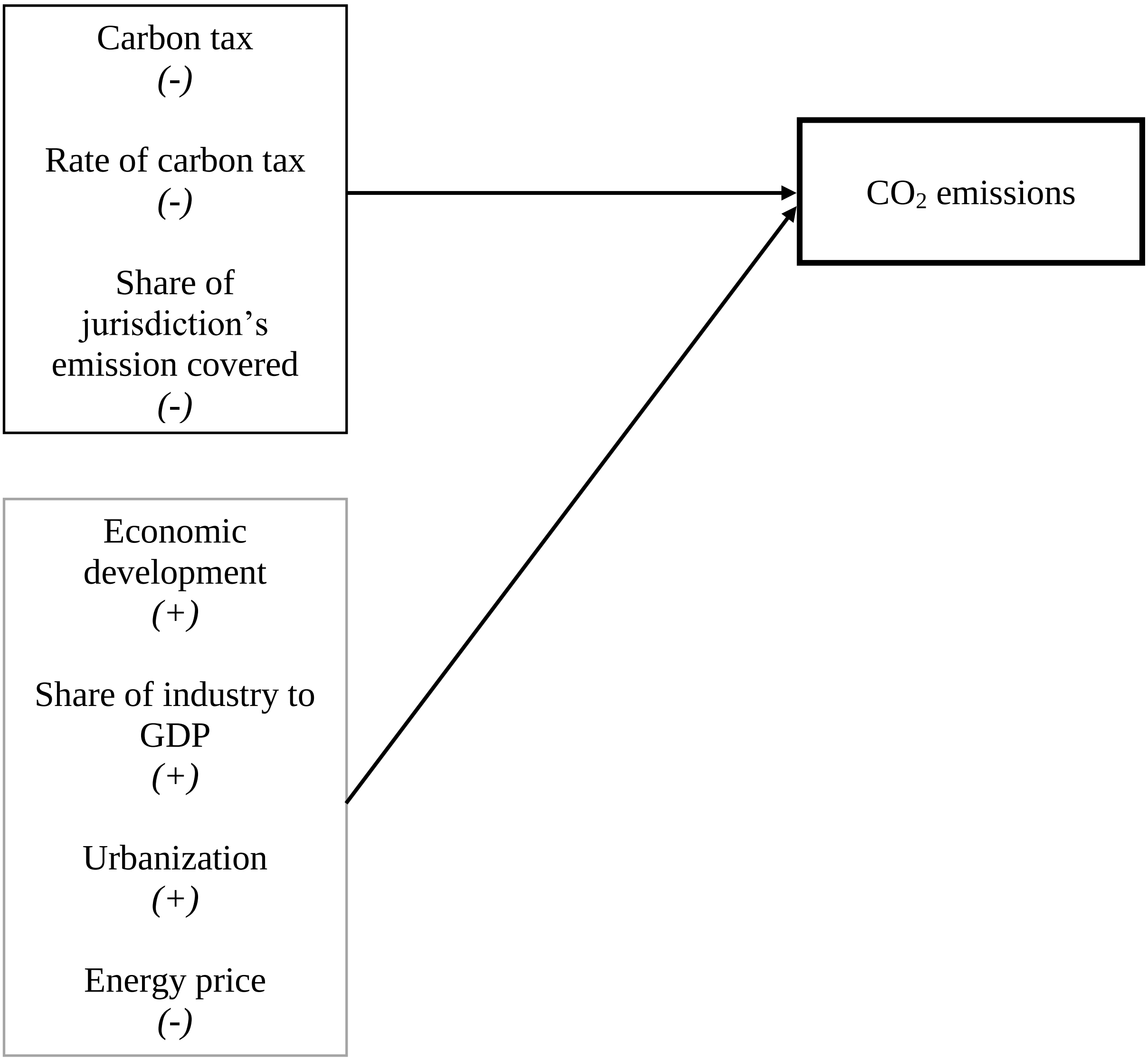
Alshehry and Belloumi (2015) found that energy price is an important factor in explaining CO_2 emissions. After analyzing the relationship between energy price and energy consumption, Bjorner and Jensen (2002, in Lin & Li, 2011) concluded that energy tax led to a 10% decrease in total energy use in Sweden between 1993 and 1997[9]. Furthermore, both quantitative studies that focused on the effectiveness of carbon taxing on CO_2 emissions (Lin & Li, 2011; Aydin & Esen, 2018) incorporated energy price as a control variable in their model, and they both found a significant and negative effect of energy price on CO_2 emissions. Therefore the energy price is the fourth control variable of this study.

2.3.3. Conceptual model

To visualize the relationship between the dependent, independent, and control variables, the following conceptual model has been constructed (Figure 2).

[9] This study has not been included in the literature review, as it looked at company level CO_2 emissions.

Figure 2. Conceptual Model



Chapter 3.

3. Research methodology

This chapter provides an overview of the chosen methodology that aims to answer the main research question of this study. First, the chosen research methodology is discussed. Second, detailed information about the country selection and classification is provided. Third, the operationalization of variables is explained. Fourth, the reliability and validity of the study are discussed.

3.1. Research design selection: panel-data regression

The research design of this thesis is a panel-data regression, as briefly discussed in the first chapter. It is a non-experimental design, which solely relies on observations. In experimental research designs, the researcher arbitrarily creates a treatment and control group. Carrying out an experiment is not feasible in this research, as the units of analysis are countries, hence we are not able to influence the implementation of carbon taxing and to control the application of the independent variables. Observational, or non-experimental study is chosen, when researchers aim to take reality as it is and observe it, attempting to sort out connections without the benefit of randomly assigning participants to treatment groups (Kellstedt and Whitten, 2013, p. 82). As this thesis aims to identify the effect of carbon taxes on CO_2 emissions, an observational research design is suitable for the analysis. It is important to mention that observational designs have the disadvantage of not always being strong enough to make causal inferences (Johnson & Reynolds, 2012, p. 147), as casual inference requires the accurate estimation of missing non-exposure outcomes for those who were exposed and vice versa (McGue, Osler, and Kristensen, 2010, p. 547). However, as countries either have carbon taxing implemented or not, it is not possible to estimate the effects of non-exposure once they have carbon taxing implemented and vice versa. Therefore, to increase the validity of the findings of an observational study, a large number of cases need to be included.

The two main approaches to observational design are quantitative and qualitative analysis. In qualitative research, a single-case or comparative studies are studied in depth. As this research aims to establish the overall effectiveness of carbon taxing all around the world and not only in one country, a large number of cases (large N design) will be included in the sample. Hence, this thesis relies on a quantitative research design to answer its research question and subquestions. Within quantitative designs, cross-sectional and time-series studies are distinguished (Kellstedts & Whitten, 2007). A cross-sectional design focuses on the variation between spatial units (countries) for a single time unit (one year), while a time-series design is used to examine the variation within one spatial unit over multiple time units (Kellstedt and Whitten, 2013, p. 87). Moreover, it is also possible to conduct a pooled cross-sectional time-series research design, if the dependent variables vary significantly over the chosen period.

As this study analyzes multi-dimensional datasets, a pooled cross-sectional time-series research will be conducted, which is a mixture of cross-sectional and time-series designs. This research design – which is also often called panel-data regression -, enables to identify patterns of association, as it analyzes variation among variables and cases, which in turn enables the establishment of causality between the dependent and independent variables. Hence in the ideal scenario, a large sample of cases (large N) are included in the research, which increases the generalizability and external validity of this research (Bryman & Bell, 2011). As this study aims to analyze the variation of effects of carbon taxing on CO_2 per capita emissions in a total of 54 countries, as discussed further in detail in III.3., a panel-data regression is the ideal method applied in this research. Moreover, this research method also enables the inclusion of various control variables as well as dummy variables. This is important, as CO_2 per capita emissions are likely to be affected by many other variables other than carbon taxing. Hence the incorporation of the aforementioned control variables enables to check for different confounding factors, which contributes to a higher level of internal validity of the study. Furthermore, the inclusion of a dummy variable on carbon taxing enables to evaluate whether the presence of a carbon tax leads to reduced per capita CO_2 emissions independent from the amount of the tax and the share of the jurisdictions' emissions coverage. Last, but not least, other relevant quantitative studies (Li & Li, 2011; Aydin & Esen, 2018) that evaluated the effectiveness of carbon taxing on CO_2 per capita emissions also applied panel-data regression to analyze the relationship between the dependent, independent and control variables. Thus, it can be established that it is the ideal research methodology employed for this research, which is also in line with the aims of the study.

3.2. Empirical Method

3.2.1. Linear Panel Regression Model

various statistical models examine the relationship between the dependent (Y) and independent variables (X), which also account for confounding factors. A commonly used model is a linear regression model, which requires that the model is linear in regression parameters (Yan, Su, and World Scientific, 2009). Regression analysis is a method that aims to discover the relationship between one or more variables and the predictors (Yan et al., 2009). Two types of regressions exist. First is the simple linear regression, which models the linear relationship between two variables, of which one is a dependent variable, while the other is an independent variable (Yan et al., 2009). Second is the multiple linear regression, which adds more independent variables and also control variables to the model. This model is especially useful when dealing with three-dimensional data (multiple units, multiple variables, and multiple measurements in time), which is often referred to as panel data. The general model of the multiple linear regression model is as follows:

$$y_{it} = \beta_0 + \beta_1 x_{it,1} + \beta_2 x_{it,2} + \ldots + \beta_k x_{it,k} + \varepsilon_{it},$$

where y is the dependent variable, x_1, $x_2, \ldots,$ x_n are independent variables, β_0, $\beta_1, \ldots,$ β_k are regression coefficients in the model. *i* stands for the unit of observation, *t* for the period of time, *k* for the kth explanatory variable, and ε_{it} for the error term. In a classical regression setting, the error term ε usually follows a normal distribution (Yan et al., 2009)

$$E(\varepsilon)=0.$$

As this thesis analyses three-dimensional (panel) data, multiple regression analyses will be carried out. The variables included in the models of the analysis are represented by the following abbreviations:

CO2	CO_2 emissions
TAX	Carbon tax (dummy variable)
RAT	Rate of carbon tax[10]
SHA	Share of jurisdiction’s emissions covered
ECD	Economic development
IND	Industry structure
URB	Urbanization
PRI	Energy price.

[10] ’Rate’ refers to the amount of the tax, as it is the usual way of referring to it by the literature.

To establish the relationship between carbon taxing and CO_2 emissions, this thesis has constructed four models: one model with two independent variables (RAT and SHA), and three models with only one independent variable (TAX; RAT; SHA). Therefore, the following four models are established after adding the dependent, independent and control variables to all the models:

1. $CO2_{it} = \beta_0 + \beta_1 RAT_{it} + \beta_2 SHA_{it} + \beta_3 ECD_{it} + \beta_4 IND_{it} + \beta_5 URB_{it} + \beta_6 PRI_{it} + \varepsilon_{it}$,
2. $CO2_{it} = \beta_0 + \beta_1 RAT_{it} + \beta_2 ECD_{it} + \beta_3 IND_{it} + \beta_4 URB_{it} + \beta_5 PRI_{it} + \varepsilon_{it}$,
3. $CO2_{it} = \beta_0 + \beta_1 SHA_{it} + \beta_2 ECD_{it} + \beta_3 IND_{it} + \beta_4 URB_{it} + \beta_5 PRI_{it} + \varepsilon_{it}$,
4. $CO2_{it} = \beta_0 + \beta_1 TAX_{it} + \beta_2 ECD_{it} + \beta_3 IND_{it} + \beta_4 URB_{it} + \beta_5 PRI_{it} + \varepsilon_{it}$,

where i denotes a country (i=[1…54]), t denotes a given year (t=[1…28]). β_0 is the intercept, β_k is the regression coefficient, k is the k^{th} explanatory variable (k=[1…6)], and ε_{it} is the error term.

3.2.2. Assumptions of Ordinary Least Squares

OLS is a generalized modeling technique that models linear relationships (Hutcheson, 1999). However, several requirements need to be fulfilled when applying this regression method. First, all the variables and the error term need to be normally distributed. Second, all the dependent, independent, and control variables used in the analysis have to be measured on a ratio or interval scale. In case any of the variables are measured on a nominal or ordinal scale, it needs to be converted into a dummy variable in the model. Third, there should be a linear relationship between the dependent and independent variables. Fourth, a large number of cases should be included in the model (large N). As stated by Graddy and Wang (2008, p. 484), the number of observations should be higher than the number of independent variables in the model. Fifth, the independent variables can not have a perfect linear relationship with each other, because if they do, multicollinearity occurs. Sixth, as argued by Graddy and Wang (2008, p. 468), the error term for a given observation should not be systematically correlated with any other observation's error term. If this requirement is not fulfilled, autocorrelation occurs. And last but not least, the error term needs to have a constant variance for all observations, which means that homoscedasticity needs to occur (Graddy & Wang, 2008, p. 467). Whether these requirements are met is analyzed in greater detail in Chapter 4 (IV.2.).

The Ordinary Least Square method is often used together with linear panel regression. This particular method is often referred to as 'Pooled OLS'. The aforementioned requirements need to be fulfilled also in the case when considering applying this regression model.

3.2.3. Fixed effects, Random effects

When OLS assumptions are not met it is generally a sign of model misspecification, which, in the case of panel data can often be remedied by the use of statistical models that are designed to deal with such data structures. The most commonly used examples of panel regression methods are Fixed effects and Random effects models, which can control for unobserved differences between individuals between cross-sections and if necessary, also over time, thereby controlling for the possible correlation between the independent variable(s) and the error term (Raffalovich & Chung, 2014, p. 212). Under the fixed effects model, the parameters are fixed or non-random variables, and it is assumed that differences in observed effects are a result of sampling error (Borenstein, Hedgesb, Higgincs and Rohstein, 2010, p. 97). In comparison, under the random effect model, the parameters are random variables (Borenstein et al., 2010).

To establish which model fits the best, the following tests can be performed. While an F-test enables us to choose between Pooled OLS and the Fixed Effects model, an LM test enables to choose between the Pooled OLS and the Random Effects model, and a Hausman test enables to choose between the Fixed effects and the Random Effects model. As discussed later in Chapter 4, the assumptions of the Pooled OLS model are not met, therefore this thesis chooses to perform a Hausman test to establish which model is more suitable. These tests will be executed in STATA MP 16.0. These results of the test are to be evaluated in Chapter 4.

3.3. Population and Sample

As demonstrated in Table 1, carbon taxing has been implemented in 22 countries around the world as of 2017. When looking at the economic status of these countries an interesting trend emerges. All countries around the world are divided into main categories based on their GNI per capita levels. Those with lower levels of GNI per capita of $1,025 (calculated with World Bank Atlas Method) are considered low-income countries. Middle-income economies (lower-middle-income and upper-middle-income) are those with a GNI per capita between $1,026 and $12,375 (World Bank, 2018). Countries are considered high-income economies above $12,376 GNI per capita levels. According to the World Bank's Country Classification (2018), out of the

21 countries that have carbon tax implemented up until 2017, 18 countries[11] are high-income countries. The countries that are not part of the group of high-income countries are Mexico, Colombia, and Ukraine with implemented carbon taxing. Two of these countries – Mexico and Colombia - had a GNI per capita level of $9,180 and $6,180 in 2018, respectively (World Bank, 2018). Thus, both of them are part of the upper-middle-income country group. In comparison, Ukraine only had a GNI per capita level of $2,660 in 2018, thus it is a part of a lower middle-income country group (World Bank, 2018).

As of 2018, there are 81 high income, 60 upper middle income, and 47 lower-middle-income countries around the world (World Bank, 2018). Regarding the data for the dependent variable (CO_2 per capita emissions), it is available for 58 high-income countries, 58 upper-middle-income countries, and 44 lower-middle-income countries. In total, this adds up to 160 countries in the sample. However, the total number of countries that have carbon tax implemented only amounts to a total of 21 countries[12] in 2017 (see Table 1), which is relatively low compared to the number of middle-income and high-income countries. To achieve a balanced dataset, where the number of countries without carbon tax is not excessively higher than those with carbon tax, middle-income countries are excluded from the model. Even though it is often claimed that the greater the size of the sample, the better the results (Bryman & Bell, 2011, p. 188), in the case of this study, it is not desirable to have a very big sample, as the number of countries who implemented carbon tax is relatively small. Thus, having a too big sample could distort the results and undermine the effects of carbon taxing in the results.

The final sample includes a total of 54 countries because out of the 81 countries, no data was available on 1) 2 high-income countries on the World Bank's Database 2) the dependent variable in 21 countries, and 3) on the variable industry structure for 3 countries. Furthermore, Canada is excluded from the sample of this study, as it has two provinces (British Columbia and Alberta), which have carbon taxing implemented. As the units of the sample are countries in this study, and no sufficient data is available on Alberta's and British Columbia's CO_2 emissions or any other independent or control variable, it would be difficult to evaluate the effectiveness of carbon taxes in those provinces. Furthermore, even though Lin & Li (2011) included the Netherlands in the treatment group of their study (see II.2.3.2.), as the Netherlands does not have an explicit carbon tax, and as it is also not included among the countries with an

[11] British Columbia and Alberta are provinces of Canada, therefore they represent the same country.
[12] Again, British Columbia and Alberta are provinces of Canada, therefore they represent only one country.

implemented carbon tax in the Global Carbon Account (2018), this study does not include the Netherlands in the treatment group.

A list of countries included in this study can be found in Appendix C. Furthermore, as the first country to implement carbon taxing was Finland in 1990, the analysis of this research will focus on the years between 1990 and 2017. 2017 was chosen as the final year of the analysis because it is the most recent year for which data on the dependent and independent variables are both available. However, as some countries in the sample have gained their independence later than 1990, there are some missing observations in this study, for which information is provided under Appendix D. To conclude, this research focuses on 54 countries over 28 years. However, 14 values are missing for countries that gained their independence later than 1990. Therefore the research should contain 1,498 (54 times 28 minus 14) observations.

3.4. Operationalization of variables

The following section provides an overview of how the different dependent, independent, and control variables are operationalized. The operationalization of these variables enables the statistical exploration of the relationship between them.

3.4.1. Dependent variable

3.4.1.1 CO_2 emissions per capita

The dependent variable of this research is CO_2 emissions. To account for different population sizes across the countries of the sample, CO_2 emission is measured in per capita terms. CO_2 emissions are mostly measured in per capita terms, however, it is also possible to operationalize CO_2 emissions per unit of GDP terms. This research has opted to measure CO_2 emissions in per capita terms, as the thesis aims to establish whether carbon taxing has a significant effect on per capita CO_2 emissions in general, and not in terms of economic development. Furthermore, both quantitative studies that evaluated the effectiveness of carbon taxing on CO_2 emissions (Lin & Li, 2011; Aydin & Esen, 2018) measured CO_2 emissions in per capita terms.

The data is provided by Our World in Data[13] (2019). Even though the World Bank also has a dataset on per capita CO_2 emissions, it is only available up to the year of 2014. As this study focuses on the years between 1990 and 2017, it is more desirable to use the dataset

[13] which derived per capita CO_2 emissions based on four datasets: Carbon Dioxide Information Analysis Centre (CDIAC), Global Carbon Project, UN Population estimates, and the HYDE Database.

provided by Our World in Data. CO_2 emissions per capita are measured in tonnes per year for a given country. The variable is measured on a ratio scale.

3.4.2. Independent variables

3.4.2.1. Carbon tax

The first independent variable is operationalized by the information whether up until 2017[14] a country has carbon taxing implemented or not. Thus, this is a dummy variable, which takes the form of 0 if the particular country does not have carbon taxing, and is labeled as 1 if the particular country has carbon taxing. The variable of carbon tax is a categorical one. Furthermore, the data is retrieved from the Global Carbon Account (2018).

3.4.2.2. Rate of carbon tax

The rate of carbon tax is the second independent variable of this study. The rate of carbon taxes implemented in all the countries ranges from less than $1/t$CO_2$ in Poland to $140/t$CO_2$ in Sweden (see Table 1). The dataset is retrieved from the Global Carbon Account (2018). It is important to mention that even though the rate of carbon tax may have changed many times throughout the analyzed period (1990-2017), as no sufficient data is available on the evaluation of those rates, this study uses the same rate for a given country for all the years of the research. The rate of carbon tax is measured on a ratio scale.

3.4.2.3. Share of jurisdiction's emissions covered

The third independent variable of this research is the share of jurisdiction's emission covered. As demonstrated in Table 1, this indicator ranges from 3% in Estonia to 68% in Japan among the analyzed countries. The data on the share of jurisdiction's emission covered is retrieved from Global Carbon Account (2018). Similar to the rate of carbon tax, this variable has also shown some changes throughout the analyzed period for the countries with an implemented carbon tax. However, due to the lack of information on these exact changes, this variable was measured using the same data for a given country for all the years of the research. The share of jurisdiction's emissions covered are measured on a ratio scale.

[14] It is important to emphasize that the scope of analysis is until 2017, as Argentina has implemented carbon taxing in 2018. However, its dummy variable will take the form of 0 because the study analyzes the countries in the sample until 2017.

3.4.3. Control variables

3.4.3.1. Economic development

GDP measures the total value produced by producers in a given year in a given country. Economic development is operationalized in GDP per capita terms. This indicator has been chosen, as GDP per capita demonstrates the level of development of a country and therefore enables the comparison of different countries. It is expected that the higher the levels of GDP per capita, the higher the levels of CO_2 emissions of a country. The data for this control variable comes from the World Development Indicators Database of the World Bank. This control variable is measured in constant 2010 dollars (World Bank, 2020a). Even though Lin & Li (2011) operationalized GDP per capita based on the PPP index, GDP per capita has been measured in current US dollars in Aydin and Esen (2018). By using GDP measured in constant dollars, the effects of inflation are controlled for, and thus real GDP is included in the model. Furthermore, some values were missing for some countries. The missing values have been filled in by an extrapolation using the average change of the observed values. Appendix D summarizes all the values that have been filled in by this method.

3.4.3.2. Industry structure

Industry structure is measured as the share of industry (value-added) of GDP. As mentioned previously, numerous studies found that the industry's share of GDP is related to per capita CO_2 emissions (Lin & Li, 2011). As the industry is known to be responsible of high levels for CO_2 emissions compared to other sectors, it can be assumed that the higher the share of industry of GDP, the more CO_2 is likely to be emitted. The data is retrieved from the World Bank database, and it encompasses value added in mining, manufacturing, construction, electricity, water, and gas (World Bank, 2020b). This variable is also measured in ratio scale. Furthermore, some values were missing for some countries. The missing values have been filled in by an extrapolation using the avetrage change of the observed values. Appendix D summarizes all the values that have been filled in by this method.

3.4.3.3. Urbanization

The control variable for urbanization aims to measure the share of the urban population of the total population (World Bank, 2020c). According to the World Bank (2020c), urban population refers to people living in urban areas. Urban areas most commonly refer to towns, cities, or suburbs, where high population density occurs. It is expected that the higher the levels of urbanization, the higher the levels of CO_2 emissions per capita. The data is retrieved from the World Bank database. This variable is also measured in ratio scale.

3.4.3.4. Energy price

Energy price is the fourth control variable of this research. Both previous studies (Lin & Li, 2011; Aaydin & Esen, 2018) that measured the effectiveness of carbon tax on CO_2 emissions measured energy prices as the U.S. Landed Costs of Crude Oil, in dollars per barrel. Therefore this research will also rely on this measure. The data is retrieved from the Electric Industries Association's (EIA) database and is measured on a ratio scale. However, it is important to mention that no information is provided on how the energy prices were calculated at the website, from where the data is retrieved (EIA). Furthermore, it is also not specified further by Lin & Li (2011) and Aydin & Esen (2018), who used the same source for the variable for energy price.

3.4.4. Operationalization Table

Appendix B provides an overview of the operationalization of the dependent, independent, and control variables of this research.

3.5. Reliability and validity

Ensuring high reliability and validity of research is of the highest importance because it demonstrates that the findings of the study are accurate. This part of the thesis summarizes how high levels of validity and reliability are achieved in this research.

3.5.1. Reliability

The reliability of a study demonstrates the quality, representativeness, and coherence of a study (Brymann & Bell, 2011, pp 41). The measurements are considered reliable when the "*measuring procedure yields the same results on repeated trials*" (Johnson & Reynolds, 2012, p. 94). In other words, reliability focuses on the repeatability of the research. Ensuring reliability is of the highest importance when conducting a quantitative or qualitative study. To achieve high levels of reliability, the stability of variables must be ensured (Bryman & Bell, 2011). In this research, reliability is provided by the avoidance of errors during data collection and by assessing data provided by reliable sources, which have also been chosen by previous studies focusing on the relationship between carbon taxing and CO_2 emissions (World Bank, Our World in Data, Global Carbon Account, EIA). The database used in this research consistently covers a total of 54 countries over a 28 year-long period. Therefore it can be stated that this study meets the requirements of reliability, as all of its variables are consistent and stable over time. Furthermore, as the datasets used in this research are available to anyone, it can be established that this research overall has a high level of reliability.

3.5.2. Validity

The validity of research is closely related to reliability. As stated by Kellstedt & Whitten (2013), measurement validity refers to what extent the theoretical concepts are measured with indicators that accurately reflect those concepts in the focus of measure. Therefore, if a measure is considered unreliable, the measured concept can not be valid either (Bryman & Bell, 2011, p. 42). In the case of this research, all measures are considered to be valid. Most of the indicators used in this research are direct measures of certain concepts (such as CO_2 emissions, rate of carbon tax or the share of jurisdiction's emissions covered), while for the other indicators (such as the industry structure or the urbanization), the most commonly used measures have been applied. However, it is also important to mention that for some indicators (rate of carbon tax and share of jurisdiction's emissions covered) the same values have been used for the whole analyzed period for a given country, as no sufficient data is available on those indicators' evolution. Therefore, the results of this research need to be evaluated with caution.

3.5.2.1. Internal validity

For the results of this research to be valid, the internal and external validity needs to be ensured. Internal validity focuses on whether a trustworthy cause-and-effect relationship can be established, and whether variations in the dependent variable can be attributed to the independent variable (Bryman & Bell, 2011, p. 42). Thus, internal validity is established if all the other factors that can affect the outcome of the study, apart from the independent variables, are accounted for. To rule out alternative explanations for the findings of this research, 4 control variables have also been included (economic development, industry structure, urbanization, energy price). The fact that these control variables are based on previous body of literature also positively contributes to the internal validity of the study. Moreover, internal validity is also focused on causality, which aims to demonstrate whether the independent variable affects the dependent variable. Even though the most desirable research method for establishing causality is experimental design, cross-sectional time-series studies also have the advantage of analyzing the variables over several years.

3.5.2.2. External validity

External validity refers to the extent to which the results of the research can be generalized to similar cases, or not (Bryman, 2012). Compared to qualitative research designs, quantitative research designs have a higher level of external validity as a result of including large N cases in the study. To provide a high level of external validity and thus generalizability, a large sample of 54 countries are analyzed in this research. As a result, it can be expected that the obtained results can be generalized for those high-income countries as well that could not be included in the sample of this study due to the lack of sufficient data (see Appendix C).

Chapter 4.

4. Analysis

The fourth chapter aims to answer the third sub-question of this research before proceeding to the main research question of the study. To do that, the descriptive statistics of all dependent, independent, and control variables are demonstrated. Then, the seven assumptions of the OLS model are tested separately. Next, based on whether the assumptions are met, the most suitable model is chosen for the regression analysis. Finally, the results of the regression analysis are discussed.

4.1. Descriptive Statistics

It is common to assess the descriptive statistics of numeric variables before performing the linear regression analysis. Descriptive statistics aim to provide some general information on the applied variables, such as the number of observations, mean, standard deviation, or minimum and maximum values of a given variable. Furthermore, any occurrence of an outlier variable is also easier to detect. Therefore, a summary of the descriptive statistics of all variables of this study is demonstrated in Table 2.

Table 2. Descriptive Statistics

Variable	***Obs***	***Mean***	***Standard Deviation***	***Min***	***Median***	***Max***
CO_2 emissions per capita **(CO2)**	1,498	9.539	5.969	1.073	8.090	36.001
Carbon tax **(TAX)**	1,498	0.157	0.363	0	0	1
Rate of carbon tax **(RAT)**	1,498	7.052	23.935	0	0	139
Share of jurisdiction's emissions covered **(SHA)**	1,498	0.051	0.139	0	0	0.68
Economic Development **(ECD)**	1,498	29,597.31	19,408.62	4,061.59	25,548.8	111,968.30
Industry's share to GDP **(IND)**	1,498	0.270	0.114	0.067	0.253	0.741
Urbanization **(URB)**	1,498	0.741	0.163	0.247	0.769	1
Energy price **(PRI)**	1,498	44.412	29.842	11.84	36.07	102.92

The mean represents the average value of a certain variable. Standard deviation (SD) stands for a measure of dispersion. Low levels of SD represents a concentrated distribution, while high levels of SD represent a divergent distribution of the values of the variables. Min represents the minimum value of a variable. For instance, in the case of urbanization, no other country has a lower share of urban population to total population than 24.7%. The median resembles the middle value of a variable. For instance, 31,88 dollars per barrel is the middle value for energy price. Max corresponds to the maximum value of a variable. For example, no country has a higher share of industry to GDP than 74.1%.

However, as can be seen in Table 2, not all variables of the analysis have a normal distribution. When evaluating which variables have a normal distribution, the mean and median variables together play an important role. If the median and mean values of a variable are equal, it can be established that the particular variable is symmetrically distributed. However, if the two values are not the same, the particular variable has a skewed distribution, which can be skewed towards either the right or left side (Mo, 2008, p. 381). After looking at Table 2, it can be established that in this research the variables for the share of jurisdiction's emissions covered, industry structure and urbanization come closest to have a perfect normal distribution. The distribution of the other variables is evaluated further in the next section of this study.

4.2. Testing the Assumptions of Ordinary Least Squares

As discussed in Chapter 3 (III.2.2.1.), several assumptions need to be met when applying OLS regression. The following section elaborates on whether the data used in this research meets those assumptions.

4.2.1. Measurement level

As discussed earlier, the variables used in the analysis need to be measured on a ratio or interval scale if OLS regression is applied. However, in this research, as Appendix B shows, one variable (TAX) is a categorical one, as it aims to show if a country has carbon taxing implemented (labeled as 1) or not (labeled as 0). It is also stated, however, that independent variables can also be measured on a categorical level, if they are labeled by only two categories. In this research all values are labeled as 0 and 1 for the categorical variable, therefore this assumption is met.

4.2.2. Sample size

The second assumption states that a large number of cases (large N) need to be included in the research when applying OLS regression. As mentioned in the previous section, this study includes 1,498 observations for each variable, which is considered as a large sample. Therefore, the assumption regarding the size of the sample is also met.

4.2.3. Normal distribution

According to the next assumption, the variables of the research should be normally distributed in case of OLS regression. There are various ways to establish whether this assumption is met, such as visualizing the distribution of variables, looking at the values of skewness and kurtosis, or also to perform statistical tests, such as the Jarque-Bera test (Graddy & Wang, 2008). This research has opted for the graphical visualization of the distribution of variables by using two methods: first looking at the histograms of the variables, then using a technique called Q-Q Plots. The results are summarized in Appendix E and F, respectively. Q-Q Plots is a graphical method that enables comparing two probability distributions by plotting their quantiles against each other (Wilk & Gnanadesikan, 1968). For Q-Q Plots, if the values fall along a roughly straight line at the 45-degree angle, then the variable is normally distributed. However, it is important to note that the dummy variable of this research (TAX) and those variables that often take the value 0 (RAT, SHA) have not been included in the Appendix E and F because they evidently do not have a normal distribution.

After looking at the first column of Appendix E and F, it can be established that the variables of this research do not have a normal distribution. However, it is possible to transform the variables to achieve a distribution of their values closer to normal. Transformation refers to the procedure where the values of a given variable are faced with the same mathematical equation. There are several ways to transform a variable, such as taking the reciprocal, square root, or logarithmic form of a variable. This research has opted for taking the natural logarithmic forms of three the variables (CO_2, ECD, IND), while one variable (URB) has been raised to the power of 2. Regarding the variable on energy price (PRI), as no transformation would significantly improve it, therefore it is left as it is. The second column in Appendix E and F demonstrates the results transforming the variables. It can be established that the transformations were successful, as the transformed variables show a distribution closer to normal on Appendix E, while the values of the transformed variables fall along closer to the straight line on the 45-degree angle on Appendix F. Furthermore, from now on the transformed values are used for the analysis for the variables CO2, ECD, IND and URB (lnCO2, lnECD, lnIND, URB2).

4.2.4. Linearity

The next assumption holds that there should be a linear relationship between the dependent and independent variables, and also between the dependent and control variables. The most common way of checking for linearity is by applying scatter plots. Therefore, each independent and control variables have been plotted against the dependent variable. The results are shown in Appendix G. According to the scatter plots, it can be established that apart from the variables that often take the value 0 (TAX, RAT, SHA), the assumption of linearity is roughly met.

4.2.5. No Multicollinearity

According to the next assumption, the explanatory variables of the study should not be in a perfect linear relationship with each other, because if they do, multicollinearity occurs. Multicollinearity can be assessed by evaluating the correlations between the independent and control variables. Correlation between two variables can range from 0 (no correlation) to 1 (full correlation). If the degree of correlation between two variables reaches 0.8, it can be established that multicorrelation occurs (Frost, n.a.). The results of the correlation analysis are demonstrated in Table 3.

Table 3. Correlation Analysis

	TAX	**RAT**	**SHA**	**lnECD**	**lnIND**	**URB2**	**PRI**
TAX	1.000						
RAT	0.683	1.000					
SHA	0.846	0.749	1.000				
lnECD	0.202	0.315	0.367	1.000			
lnIND	0.044	0.029	0.044	-0.059	1.000		
URB2	-0.013	0.095	0.091	0.394	-0.051	1.000	
PRI	0.118	0.054	0.100	0.165	-0.121	0.059	1.000

Based on Table 3, it can be established that some variables correlate more strongly than others, and there are some cases where negative correlation occurs. The highest level of correlation is shown between the variables SHA and RAT (0.846), however, as these two variables are not included in the same model, it is not required to omit one of them from the analysis. Fortunately, no other two variables show a correlation higher than 0.8. Therefore, it can be stated that the assumption of no multicorrelation is also met, thus no variable needs to be omitted from the analysis.

4.2.6. No Autocorrelation

According to the sixth assumption, the error term for a given observation should not be systematically correlated with any other observation's error term, thus autocorrelation should not occur. This study tested for autocorrelation by applying a statistical test called Wooldridge test. According to Drukker (2003), the Wooldridge test was specially developed for panel datasets and is attractive due to its high level of robustness. According to the result of the Wooldridge test (P = 0.0000), the null hypothesis of no autocorrelation is strongly rejected, therefore the sixth assumption is not met.

4.2.7. Homoscedasticity

And finally, the seventh assumption holds that the error term needs to have a constant variance for all observations, so homoscedasticity needs to occur for pooled OLS. It is possible to test homoscedasticity by several statistical tests, such as the Breusch and Pagan test or the White test. As both tests show the same result (P = 0.0000), the null hypothesis of homoscedasticity can be strongly rejected. These two tests provide strong evidence that heteroscedasticity occurs, therefore the seventh assumption is not met. Appendix H provides an overview of all the statistical tests of this study.

4.3. Model selection

The previous section discussed whether different assumptions of the pooled OLS are met. As two assumptions (no autocorrelation and homoscedasticity) out of the seven are not met, it can be concluded that the pooled OLS is not the best linear unbiased estimate. Therefore, this research now focuses on whether the Fixed effects or Random Effects model is more appropriate. To establish that, a Hausman test is conducted, which has widely been used to differentiate the Fixed effects and Random effects models in applied economics. According to the null hypothesis of the Hausman test, the difference in coefficients is not systematic. When the null hypothesis is rejected, the Fixed effects model is applied, otherwise, the Random effects model is chosen for the research (Baltagi, Bresson & Pirotte, 2003). The Hausman test results in a *p-value* of 0.1338, therefore the null hypothesis is not rejected and hence the Random effects model is chosen.

To verify whether the Random effects model is more appropriate than the Pooled OLS model, an LM test is also performed. As the LM test shows highly significant results (P = 0.0000), the null hypothesis is strongly rejected, and therefore it can be established again that the Random effects model is more appropriate than the Pooled OLS model. However, it is important to mention that autocorrelation and heteroscedasticity still occurs. Fortunately, as argued by Wooldridge (2013, p. 511), clustering provides a simple solution to satisfy Assumptions 6 and 7, which is a general approach that aims to obtain fully robust standard errors and test statistics. Furthermore, clustering is easily justified when N is substantially larger than T, but not when the opposite is true. In the case of the Random effects model, the clustering gets applied to the „*quasi-time-demeaned equation*" (Wooldridge, 2013, p. 511). As this research includes 54 countries (N) over 28 years (T), clustering appears to be the ideal solution for meeting the assumptions of no autocorrelation and homoscedasticity.

4.4. Results

This section presents the results of panel data regression analysis. The coefficients of the variables, the corresponding significance levels, the robust standard errors, and the R-square values are discussed. However, it is important to emphasize that many of the variables have been transformed, therefore their interpretations need to take into consideration those transformations.

The results of the panel data regression analyses based on the clustered Random effects method are demonstrated in Table 4. To establish the relationship between carbon taxing and CO_2 emissions, this thesis has constructed four models, as elaborated in Chapter 3 (III.2): one model with two independent variables (RAT and SHA) - (1), and three separate models with only one independent variable (TAX), (RAT), (SHA) - (2), (3), (4). The coefficients in regression analysis provide information on the level and direction of correlation between the explanatory and dependent variables. Furthermore, the significance level provides information on what level the coefficient is significant. Finally, the value of R-square, which is also often called the coefficient of determination, assesses to what extent the variation in the dependent variable can be explained by the model (Wiess, 2008). The values of R-square can range from 0 (variability in the dependent variable can not be predicted by the model) to 1 (variability in the dependent variable can completely be predicted by the model).

Table 4 demonstrates the findings of the regression analysis. Regarding the overall results, it can be established that the four models show similar results. Looking at the independent variables first, all variables show a negative effect on CO_2 per capita emissions, which is in line with hypotheses 1, 2, and 3. However, under model (1), when the variables RAT and SHA are both included in the same model, it can be seen that only the rate of the carbon tax has a significant effect (P=0.001) on per capita CO_2 emissions. Regarding the variable for the rate of carbon tax, the estimated coefficient equals -0.0020, which indicates that a one-dollar increase in the carbon tax leads to a 0.2% decrease in per capita CO_2 emissions[15]. When only the variable RAT is included (in model (2)), the coefficient is -0.0026 and it is highly significant again (P=0.000), therefore it means that one dollar increase in the carbon tax likely leads to a 0.26% decrease in the dependent variable. In model (3), when the only independent variable included is the share of jurisdiction's emissions covered, this time the regression analysis shows significant results (P=0.047) for the variable SHA. It is important to mention that even though the coefficient equals -0.2715, it needs to be interpreted slightly differently because SHA is a ratio measured on a 0 to 1 scale. Thus, one percentage point increase in the variable SHA is expected to lead to a 0.272% decrease in per capita CO_2 emissions. Turning to model (4), the coefficient for the dummy variable TAX is -0.1448 and is highly significant (P=0.001). Therefore, it indicates that the presence of carbon tax may decrease per capita CO_2 emissions by 14.5%.

Looking at the control variables, the four models indicate very similar results (regarding coefficients, signs of coefficients, standard errors, and significances). Economic development and the industry's share to GDP are both positively and significantly (P<0.01) correlated with the dependent variable in all models. A one percent increase in the economic development of a country (measured as GDP per capita) may lead to an approximately 0.25%, 0.246%, 0.25% and 0.271% increase in per capita emissions according to models (1), (2), (3) and (4), respectively. Regarding the next control variable, a one percent increase of industry's share to GDP leads to an approximately 0.44% increase in per capita CO_2 emissions, according to models (1), (2), (3) and (4). However, the level of urbanization and the energy price do not seem to have a significant effect on the dependent variable, as shown in Table 4.

15 The interpretation of the variables is different for the transformed variables than for the non-transformed ones. For non-transformed variables, when the explanatory variable increases by one unit, the dependent variable changes by the amount of units that equal to the coefficient (if all the other variables remain constant) (Graddy & Wang, 2008, p. 460). If the dependent variable is transformed to its logarithmic form, while the explanatory variable(s) is not transformed, then one unit change in the independent variable leads to a 100*ß percent change (ß equals the coefficient) in the dependent variable. However, if both the dependent and explanatory variables are transformed to their logarithmic forms, the interpretatiton is as follows: one percent change in the independent variable leads to ß percent change in the dependent variable (KDnuggets, 2017).

Table 4. Regeression Results

Dependent variable: CO_2 emissions per capita **(lnCO2)**

Variable	**(1)**	**(2)**	**(3)**	**(4)**
Carbon Tax **(TAX)**				**-0.1448*****
				(0.0453)
Rate of carbon tax **(RAT)**	**-0.0020*****	**-0.0026*****		
	(0.0006)	(0.0007)		
Share of jurisdiction's emissions covered **(SHA)**	-0.1199		**-0.2715****	
	(0.1379)		(0.1369)	
Economic Development **(lnECD)**	**0.2497*****	**0.2461*****	**0.2503*****	**0.2708*****
	(0.0924)	(0.0925)	(0.0921)	(0.0947)
Industry's share to GDP **(lnIND)**	**0.4398*****	**0.4401*****	**0.4406*****	**0.4356*****
	(0.0861)	(0.0867)	(0.0863)	(0.0848)
Urbanization **(URB2)**	0.4633	0.4267	0.5016	0.4594
	(0.3441)	(0.3335)	(0.3431)	(0.3407)
Energy price **(PRI)**	-0.0001	-0.0001	-0.0001	-0.0001
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
_cons	-0.0634	-0.0076	-0.0943	-0.2759
	(0.8556)	(0.8526)	(0.8537)	(0.8809)
N	1,498	1,498	1,498	1,498
R^2	0.3898	0.3935	0.3703	0.3656

Notes: (i) clustered standard errors in parenthesis. (ii) *P-values*: * p<0.1; ** p<0.05; *** p<0.01

Finally, in this research, the R-square values of models (1), (2), (3) and (4) equal approximately 0.3898, 0.3935, 0.3703, and 0.3656, respectively, as demonstrated on Table 4. This means that the explanatory variables of this research explain approximately 39%, 39.4%, 37%, and 36.6% of variation in the dependent variable under models (1), (2), (3), and (4), respectively.

Chapter 5.

5. Conclusion

This final chapter of the thesis first answers the research question and sub-questions based on the findings of the literature review and the regression analysis. Next, the main limitations of the research are reviewed. In addition, research implications are discussed. And finally, policy recommendations are presented.

5.1. Interpretation of the results

To conclude, the central aim of this thesis is to establish whether carbon taxing proves to be effective in reducing global CO_2 emissions. Therefore, the following research question has been formulated in Chapter 1:

„To what extent has carbon taxing been successful in reducing global CO_2 emissions?"

To thoroughly answer this research question, three sub-questions have been formulated. These sub-questions have been addressed in different chapters of this study. The first subquestion, which is addressed in Chapter 2, focused on identifying and evaluating two approaches - green growth and de-growth -, that aim to provide solutions to climate change and hence curbing CO_2 emissions. While the proponents of the green growth movement (who also highly endorse market-based instruments) claim that economic growth can occur while environmental degradation is reduced, proponents of the de-growth movement argue that meeting the targets set by the Paris Agreement and thus stopping climate change requires to scale down the material throughput of the global economy (Hickel, 2019). To assess whether the MBIs are successful in reducing CO_2 emissions, the two most common MBIs – carbon taxing and emission trading systems – have been presented. As mentioned, these instruments are highly endorsed by the proponents of green growth. Many previous studies have established that emission trading schemes have failed to reduce GHG emissions, as they only managed to reduce total emissions by 2.4-6.3% (Andrew et al., 2010; Villoria-Sáez et al., 2016; Stuart et al., 2017). Therefore, this study focused on evaluating whether the other market-based approach, namely carbon taxing, shows better results.

The second sub-question is tightly connected to this point, as it focused on determining how successful is carbon taxing in reducing CO_2 emission according to the literature. This sub-question is also addressed in Chapter 2. To answer this research question, the results of six papers have been discussed that together cover a time-frame of 28 years (1987-2015). While in some cases, a significant effect has been attributed to carbon taxing in CO_2 emission reductions (Lin & Li, 2011; Aydin & Esen, 2018;), in other cases only a relatively small or negligible effect has been shown (Bruvoll & Larsen, 2004; Lin & Li, 2011; Frey, 2016; Haites, 2018). Therefore it can be stated that the analyzed studies show different results on the effectiveness of carbon taxing on reducing CO_2 emissions.

Finally, the third sub-question, which concerns the outcomes of the analysis, is addressed in Chapter 4. According to the results of the regression analysis, it can be established that overall carbon taxing seems to be succesful in curbing CO_2 emissions. As mentioned, the presence of a carbon tax in a country is expected to decrease per capita CO_2 emissions by 14.5%. Furthermore, both the rate of the carbon tax and the share of jurisdiction's emissions covered are negatively correlated with the dependent variable of this study. Therefore, it can be stated that all three hypotheses of this thesis are supported by the results of the panel regression. However, their effects are relatively limited, as one dollar increase in the rate of carbon tax leads to approximately 0.2% decrease, while one percentage point increase in the share of jurisdiction's emissions covered is expected to lead to an approximately 0.27% decrease in per capita CO_2 emissions (per ton).

5.2. Research Implications

The following implications can be established as a result of the study. This main empirical finding of this thesis is that the presence of carbon tax in a country is expected to decrease per capita CO_2 emissions by approximately 14.5%. Therefore, according to the results of this study, carbon taxing can be an important and effective instrument in contributing to reduce the causes of climate change. This finding is partly in line with the findings of previous studies, as Lin & Li (2011) and Aydin & Esen (2018) have also attributed significant effects to carbon taxing in reducing per capita CO_2 emissions. However, some other studies have claimed that carbon taxing only has a relatively negligible effect on CO_2 emissions (Bruvoll & Larsen, 2004; Lin & Li, 2011; Frey, 2016; Haites, 2018).

Additionally, this research not only found a negative impact of carbon taxing on the dependent variable but also established that the rate of carbon tax and the share of jurisdiction's emissions covered are also negatively and significantly correlated with per capita CO_2 emissions. Aydin & Esen (2018) claims that the relationship between environmental taxes and

CO_2 emissions is not linear, therefore the carbon tax is only able to affect CO_2 emissions once a certain level of carbon tax is established. Furthermore, as mentioned earlier, less than 5% of global emissions covered under carbon pricing initiatives are priced at a level that is consistent with achieving the goals set by the Paris Agreement (World Bank, 2019, p. 10). Therefore, further research is required to establish the exact relationship between these variables and the optimal rate of the carbon tax in mitigating climate change. In addition, as this research has only included high-income countries in its sample, further empirical analysis on the effects of carbon taxing in middle-, and low-income countries are needed.

5.3. Limitations

It is important to mention that there are six main limitations of this research. Firstly, starting with the sample, even though this research tried to include as many countries in the sample as possible, 27 high-income countries still needed to be excluded from the sample (see Appendix C), as no sufficient data were available for many of the variables of this study. Secondly, not all countries that have carbon taxing implemented have been included in the treatment group of this study, as the inclusion of those countries would have required including the middle-, and low-income countries in the sample as well. However, as argued earlier, having included a too big sample relative to the number of countries with implemented carbon tax could have and undermined the effects of carbon taxing and distorted the results. Therefore, this study only focused on high-income countries.

Thirdly, turning to the variables of this study, due to the lack of available data on the evolution of the rate of carbon tax and the share of jurisdiction's emissions covered in the countries whereby carbon taxing has been implemented, this study has decided to use the same rate and share for a given country for all the years of the research. This is probably the greatest limitation of this research. However, if this shortcoming of the research is taken into consideration, the results of the analysis can still provide insightful information regarding the effectiveness of carbon taxing. Furthermore, to balance out the limitation discussed in this paragraph, this research has also opted to include a third independent variable (TAX) as well, which is independent of the limitations of the other two independent ones (RAT, SHA). However, it is important to emphasize, that three variables of this research (TAX, RAT, SHA) do not have normal distribution. Therefore, the results implied in the regression analysis require special caution. Next, this study has not examined the possible threshold effect of the carbon tax. And last but least, as Appendix D demonstrates, several values have been missing for the variables ECD and IND. To be able to work with those variables, the missing values have been filled in by an extrapolation using the average change of the observed values. This method helped to overcome the lack of sufficient data, but might have distorted the actual values of those variables. In general, due to the six limitations discussed in this section, the results of this study need to be interpreted cautiously.

5.4. Policy Recommendations

The results of this analysis hold important implications for policy-makers. The results imply that carbon taxing has a significant and negative effect on per capita CO_2 emissions (in high-income countries). Therefore, these results indicate that market-based instruments may provide a way out of one of the most profound challenges of the 21st century. As discussed in the literature review, two particular movements – green growth and de-growth - can be distinguished which have widely different approaches to solve climate change. As discussed earlier, these approaches have a different view on the relationship between environmental degradation (and thus climate change) and economic growth. Based on the results of this thesis, it can be concluded that the green growth movement's premise seems to hold true: environmental preservation and economic goals can indeed be compatible goals, thereby contributing to a win-win situation. This is an important implication, as it means that green growth can be part of an ideal approach to overcome the challenges posed by global warming and climate change.

According to the results of the regression analysis, the presence of carbon tax in a country is expected to decrease per capita CO_2 emissions by 14.5%. In contrast, the EU ETS is shown to be able to reduce total emissions by approximately 2.4-6.3% (Stuart et al.; see II.2.3.1). If the results regarding the effectiveness of EU ETS in curbing CO_2 emissions are valid, it can be established that carbon taxing seems to be 2 to 4 times more effective in reducing atmospheric CO_2 emissions than the emission trading systems.

However, it is also important to mention that reducing per capita emissions by approximately 14.5% is not sufficient to reverse climate change, and thus other serious measures also need to be taken. Furthermore, the fact that market-based instruments have a somewhat negative effect on per capita CO_2 emissions does not mean that the arguments made by the de-growth movement are false. To conclude, market-based instruments can serve as important instruments in stopping and even reversing climate change. However, policy-makers should not only strive to promote the many advantages of market-based instruments but also to incentivize consumers and governments to make significant changes in their consumption patterns as well.

Reference list

Acaravci, A. & Ozturk, I. (2010). On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. *Energy*, 35(12), 5412-5420. Doi: 10.1016/j.energy.2010.07.009

Aldy, J. E., Ley, E. & Parry, I. (2008). A Tax-Based Approach to Slowing Global Climate Change. *National Tax Journal*, 61(3), 493-517. Retrieved Apr 3, 2020. Retrieved from: https://www.jstor.org/stable/41790459?seq=1#

Al-mulali, U. (2012). Factors affecting CO_2 emission in the Middle East: A panel data analysis. *Energy*, 44(1), 564-569. Doi: 10.1016/j.energy.2012.05045

Alshehry, A. S., & Belloumi, M. (2015). Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. *Renewable and Sustainable Energy Reviews*, 41, 237-247. Doi: 10.1016/j.energy.2012.05.045

Andersen. M. S. (2004). Vikings and virtues: a decade of CO_2 taxation. *Climate Policy*, 4(1), 13-24. Doi: 10.1080/14693062.2004.9685507

Andrew, B. (2008). Market failure, government failure and externalities in climate change mitigation: The case for a carbon tax. *Public Administration and Development: The International Journal of Management Research and Practice*, 28(5), 393-401. Doi: 10.1002/pad

Andrew, J., Kaidonis, M. A., & Andrew, B. (2010). Carbon tax: Challenging neoliberal solutions to climate change. *Critical Perspectives on Accounting*, 21(7), 611-618. Doi: 10.1016/j.cpa.2010.03.009

Aydin, C., & Esen, Ö. (2018). Reducing CO_2 emissiont in the EU member states: Do environmental taxes work? *Journal of Environmental Planning and Management*, 61(13), 2396-2420. Doi: 10.1080/09640568.2017.1395731

Azomahou, T., Laisney, F., & Nguyen Van, P. (2006). Economic development and CO_2 emissions: A nonparametric panel approach. *Journal of Public Economics*, 90(6-7), 1347-1363. Doi: 10.1016/j.jpubeco.2005.09.005

Bachram, H. (2004). Climate fraud and carbon colonialism: the new trade in greenhouse gases. *Capitalism Nature Socialism*, 15(4), 5-20. Doi: 10.1080/1045575042000287299

Baltagi, B. H., Bresson, G., & Pirotte, A. (2003). Fixed effects, random effects of Hausman-Taylor?: A pretest estimator. *Economic letters*, 79(3), 361-369. Doi: 10.1016/S0165-1765(03)00007-7

Bina, O. (2013). The green economy and sustainable development: an uneasy balance?. *Environment and Planning C: Government and Policy*, 31(6), 1023-1047. Doi: 10.1068/c1310j

Borenstein, M., Hedegs, L.V., Higgins, P.T., & Rothstein, H.R. (2010). A basic introduction to fixed-effect and random-effects models for meta-analysis. *Research Synthesis Methods*, 1, 97-111. Doi: 10.1002/jrsm.12

Boyce, J. K. (2018). Carbon Pricing: Effectiveness and Equity. *Ecological Economics*, 150, 52-61. Doi: 10.1016/j.ecolecon.2018.03.030

Brannlund, R., Ghalwash, T., Nordström, J., (2007). Increased energy efficiency and the rebound effects on consumption and emissions. *Energy Economics*, 29, 1–17.

Brown, K., Adger, W. N., & Cinner, J. E. (2018). Moving climate change beyond the tragedy of the commons. *Global Environmental Change*, 54, 61-63. Doi: 10.1016/j.gloenvcha.2018.11.009

Bruvoll, A., & Larsen, B. M. (2004). Greenhouse gas emissions in Norway: do carbon taxes work? *Energy Policy*, 32(4), 493-505. Doi: 10.1016/S0301-4215(03)00151-4

Bryman, A. & Bell, E. (2011). *Business Research Methods (3rd ed.)*. Oxford: Oxford University Press.

Burtraw, D., Löfgren, A., & Zetterberg, L. (2014). A Price floor solution to the allowance surplus in the EU Emission Trading System. Resources for the Future, 14(2). Retrieved from: http://www.ourenergypolicy.org/wp-content/uploads/2014/01/rff-price-floor.pdf

Carbon Trade Watch (2011). *EU Emission Trading System: failing at the third attempt*. Retrieved March 20, 2020. Retrieved from: http://www.carbontradewatch.org/downloads/publications/ETS_briefing_april2011.pdf

Chavda, K. (2008). *Introduction to Data Analysis*. In K. Yang & G.J. Miller (Eds.), Handbook of Research Methods in Public Administration, 343-360. Boca Raton, London, New York: CRC Press.

Dong, F., Long, R., Chen, H., Li, X., & Yang, Q. (2013). Factors affecting regional per-capita carbon emissions in China based on an LMDI factor decomposition model. *PLoS One*, *8*(12), e80888 . Doi: 10.1371/journal.pone.0080888

Dong, H., Dai, H., Geng, Y., Fujita, T., Liu, Z., Xie, Y., ... & Tang, L. (2017). Exploring impact of carbon tax on China's CO_2 reductions and provincial disparities. *Renewable and Sustainable Energy Reviews*, 77, 596-603. Doi: 10.1016/j.rser.2017.04.044

Drukker, D. M. (2003). Testing for serial correlation in linear panel-data models. *The stata journal*, 3(2), 168-177. Doi: 10.1177/1536867X0300300206

Dryzek, J. S., Norgaard, R. B., & Schlosberg, D. (Eds.). (2011). *The Oxford handbook of climate change and society*. Oxford University Press.

Ervine, K. (2013). Carbon markets, debt and uneven development. *Third World Quarterly*, 34(4), 653-670. Doi: 10.1080/01436597.2013.786288

European Comission (n.a.). *Use of international credits*. Retrieved May 7, 2020. Retrieved from: https://ec.europa.eu/clima/policies/ets/credits_en

European Union Commission (2012). *Making it Happen: the European Semester, Annual Europe 2020 Policy Coordination Exercise*. Brussels, Belgium.

Frey, M. (2017). Assessing the impact of a carbon tax in Ukraine. *Climate Policy*, 17(3), 378-396. Doi: 10.1080/14693062.2015.1096230

Frost, J. (n.a.). *Multicollinearity in Regression Analysis: Problems, Detection, and Solutions*. Retrieved from: https://statisticsbyjim.com/regression/multicollinearity-in-regression-analysis/

Gnanadesikan, R., & Wilk, M. B. (1968). Probability plotting methods for the analysis of data. *Biometrika*, *55*(1), 1-17. Doi: 10.1093/biomet/55.1.1

Graddy, E.A. & Wang, L. (2008). *Multivariate Regression Analysis*. In K. Yang & G.J. Miller (Eds.), Handbook of Research Methods in Public Administration (457-488). Boca Raton, London, New York: CRC Press.

Haites, E. (2018). Carbon taxes and greenhouse gas emissions trading systems: what have we learned?. *Climate Policy*, 18(8), 955-966. Doi: 10.1080/14693062.2018.1492897

Hájek, M., Zimmermannová, J., Helman, K., & Rozenský, L. (2019). Analysis of carbon tax efficiency in energy industries of selected EU countries. *Energy Policy*, 134, 110955. Doi: 10.1016/j.enpol.2019.110955

Hebbink, G., Berkvens, L., Bun, M., van Kerkhoff, H., Koistinen, J., Schotten, G., & Stokman, A. (2018). *The price of transition. An analysis of the economic implications of carbon taxing*. De Nederlandsche Bank n.v.

Hickel, J. (2018). *Why growth can't be green?*. Retrieved from: https://foreignpolicy.com/2018/09/12/why-growth-cant-be-green/

Hickel, J. (2019). Degrowth: a theory of radical abundance. *Real-world economics review*, *87*, 54-68. Retrieved from: https://static1.squarespace.com/static/59bc0e610abd04bd1e067ccc/t/5cb6db356e9a7f14e5322a62/1555487546989/Hickel+-+Degrowth%2C+A+Theory+of+Radical+Abundance.pdf

Hickel, J., & Kallis, G. (2019). Is green growth possible?. *New political economy*, 1-18. Doi: 10.1080/13563467.2019.1598964

High-Level Commission on Carbon Prices (2017). *Report of the high-level commission on carbon prices*. Washington, DC: World Bank. Retrieved from: https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices/

Hsiang, S., & Kopp, R. E. (2018). An economist's guide to climate change science. *Journal of Economic Perspectives*, 32(4), 3-32. Doi: 10.1257/jep.32.4.3

Hu, J., Crijns-Graus, W., Lam, L., & Gilbert, A. (2015). Ex-ante evaluation of EU ETS during 2013–2030: EU-internal abatement. *Energy Policy*, 77, 152-163. Doi: 10.1016/j.enpol.2014.11.023

Hutcheson, G. D. (1999). Ordinary least-squares regression. *The SAGE dictionary of quantitative management research*, 224-228.

IPCC, C. C. (2007). *The physical science basis*.

IPCC. (2018). *Global Warming of 1.5°C – Summary for Policymakers*. Switzerland: IPCC.

Jackson, T., & Senker, P. (2011). Prosperity without growth: Economics for a finite planet. *Energy & Environment*, 22(7), 1013-1016. Retrieved from: https://journals.sagepub.com/doi/pdf/10.1260/0958-305X.22.7.1013?casa_token=XT4j3E3JM_EAAAAA:-qGcv2Wtxlvas67CPKI2xUTAOk3IFoilUwBnDPf3I4uSH5b6T1eScyswJrXN9-aDp098iMrJu0ztqA

Jacobs, M. (2012). *Green growth: economic theory and political discourse* (No. 92). Grantham Research Institute on Climate Change and the Environment.

Jobert, T., Karanfil, F., & Tykhonenko, A. (2010). Convergence of per capita carbon dioxide emissions in the EU: legend or reality?. *Energy Economics*, 32(6), 1364-1373. Doi: 10.1016/ j.eneco.2010.03.005.

Johnson, J. B., & Reynolds, H.T. (2012). *Formulating Hypotheses*. Political Science Research Methods, 109-126. Washington: SAGE Publications Inc.

Kallis, G. (2011). In defence of degrowth. *Ecological economics*, 70(5), 873-880. Doi: 10.1016/j.ecolecon.2010.12.007

KDNuggets. (2017). *Learn Generalized Linear Models (GLM) Using R*. Retrieved May 16, 2020. Retrieved from: https://www.kdnuggets.com/2017/10/learn-generalized-linear-models-glm-r.html/2

Kellstedt, P. M., & Whitten, G. D. (2007). *The fundamentals of political science research*. Cambridge: Cambridge University Press.

Kellstedt, P. M., & Whitten, G. D. (2013). Research Design. *The fundamentals of political science research*. Cambridge: Cambridge University Press.

Lederer, M. (2012). The practice of carbon markets. *Environmental Politics*, 21(4), 640-656. Doi: 10.1080/09644016.2012.688358

Lin, B., & Li, X. (2011). The effect of carbon tax on per capita CO_2 emissions. *Energy policy*, 39(9), 5137-5146. Doi: 10.1016/j.enpol.2011.05.050

Lohmann, L. (2005). Marketing and making carbon dumps: commodification, calculation and counterfactuals in climate change mitigation. *Science as culture*, 14(3), 203-235. Doi: 10.1080/09505430500216783

McAfee, K. (2016). Green economy and carbon markets for conservation and development: a critical view. *International Environmental Agreements: Politics, Law and Economics*, 16(3), 333-353. Doi: 10.1007/s10784-015-9295-4

McGue, M., Osler, M., & Christensen, K. (2010). Causal inference and observational research: The utility of twins. *Perspectives on Psychological Science*, 5(5), 546-556. Doi: 10.1177/1745691610383511

Métivier, C., Bultheel, C., & Postic, S. (2018). *Global Carbon Account*. Institute for Climate Economics. Retrieved March 29, 2020. Retrieved from: https://www.i4ce.org/wp-core/wp-content/uploads/2018/04/Global-Carbon-Account-2018_5p.pdf

Mo, C. (2008). *Univariate Analysis*. In K. Yang & G.J. Miller (Eds.), Handbook of Research Methods in Public Administration (pp. 375-383). Boca Raton, London, New York: CRC Press.

Mundaca, L., Ürge-Vorsatz, D., & Wilson, C. (2019). Demand-side approaches for limiting global warming to 1.5 C. *Energy Efficiency* 12**,** 343–362. Doi: 10.1007/s12053-018-9722-9

Newell, R. G., Pizer, W. A., & Raimi, D. (2013). Carbon markets 15 years after Kyoto: Lessons learned, new challenges. *Journal of Economic Perspectives*, 27(1), 123-46. Doi: 10.1257/jep.27.1.123

Oestreich, A. M., & Tsiakas, I. (2015). Carbon emissions and stock returns: Evidence from the EU Emissions Trading Scheme. *Journal of Banking & Finance*, 58, 294-308. Doi: 10.1016/j.jbankfin.2015.05.005

Olhoff, A. (Ed.), & Christensen, J. M. (2018). *Emissions Gap Report 2018*. UNEP DTU Partnership

Our World in Data (2019). *Where in the world do people emit the most* CO_2*?*. Retrieved from: https://ourworldindata.org/per-capita-co2

Raffalovich, L. E., & Chung, R. (2014). Models for pooled time-series cross-section data. *International Journal of Conflict and Violence (IJCV)*, 8(2), 209-221. Retrieved from: https://www.researchgate.net/publication/282988391_Models_for_Pooled_Time-Series_Cross-Section_Data

Rosen, R. A., & Guenther, E. (2015). The economics of mitigating climate change: What can we know?. *Technological Forecasting and Social Change,* 91, 93-106. Doi: 10.1016/j.techfore.2014.01.013

Sandberg, M., Klockars, K., & Wilén, K. (2019). Green growth or degrowth? Assessing the normative justifications for environmental sustainability and economic growth through critical social theory. *Journal of cleaner production*, 206, 133-141. Doi: 10.1016/j.jclepro.2018.09.175

Sen, S., & Vollebergh, H. (2018). The effectiveness of taxing the carbon content of energy consumption. *Journal of Environmental Economics and Management*, 92, 74-99. Doi: 10.1016/j.jeem.2018.08.017

Sinn, H. W. (2008). Public policies against global warming: a supply side approach. *International Tax and Public Finance*, 15(4), 360-394. Doi: 10.1007/s10797-008-9082-z

Spash, C. L. (2010). The brave new world of carbon trading. *New Political Economy*, 15(2), 169-195. Doi: 10.1080/13563460903556049

Spash, C. L. (2013). The shallow or the deep ecological economics movement?. *Ecological Economics*, 93, 351-362. Doi: 10.1016/j.ecolecon.2013.05.016

Stern, N., & Stern, N. H. (2007). *The economics of climate change: the Stern review*. Cambridge: Cambridge University press.

Stiglitz, J. E., Stern, N., Duan, M., Edenhofer, O., Giraud, G., Heal, G., & Winkler, H. (2017). *Report of the High-Level Commission on Carbon Prices*. Carbon Pricing Leadership Coalition.

Storm, S. (2009). Capitalism and climate change: Can the invisible hand adjust the natural thermostat?. *Development and Change*, 40(6), 1011-1038. Doi: 10.1111/j.1467-7660.2009.01610.x

Streck, C. (2004). New partnerships in global environmental policy: The Clean Development Mechanism. *The Journal of Environment & Development*, 13(3), 295-322. Doi: 10.1177/1070496504268696

Timilsina, G. R. (2018). *Where is the carbon tax after thirty years of research?*. The World Bank.

UNEP, U. (2011). *Towards a green economy: Pathways to sustainable development and poverty eradication*. Nairobi, Kenya: UNEP.

UNDP. (2007). *Human Development Report 2007/8*. New York: Palgrave Macmillan.

Van den Bergh, J. C. (2009). The GDP paradox. *Journal of Economic Psychology*, 30(2), 117-135. Doi: 10.1016/j.joep.2008.12.001

Van den Bergh, J. C. (2011). Environment versus growth—A criticism of "degrowth" and a plea for "a-growth". *Ecological economics*, 70(5), 881-890. Doi: 10.1016/j.ecolecon.2010.09.035

Van den Bergh, J. C., & Kallis, G. (2012). Growth, a-growth or degrowth to stay within planetary boundaries?. *Journal of Economic Issues*, 46(4), 909-920. Doi: 10.2753/JEI0021-3624460404

Villoria-Sáez, P., Tam, V. W., del Río Merino, M., Arrebola, C. V., & Wang, X. (2016). Effectiveness of greenhouse-gas Emission Trading Schemes implementation: a review on legislations. *Journal of cleaner production*, 127, 49-58. Doi: 10.1016/j.jclepro.2016.03.148

Wang, M., & Feng, C. (2017). Decomposition of energy-related CO_2 emissions in China: an empirical analysis based on provincial panel data of three sectors. *Applied energy*, 190, 772-787. Doi: 10.1016/j.apenergy.2017.01.007

Wanner, T. (2015). The new 'passive revolution'of the green economy and growth discourse: Maintaining the 'sustainable development'of neoliberal capitalism. *New Political Economy*, 20(1), 21-41. Doi: 10.1080/13563467.2013.866081

Weiss, N. A. (2008). *Elementary Statistics (7th ed.)*. Boston: Pearson Education.

Wooldridge, J. M. (2013). *Introductory econometrics: A modern approach (5th Eds.)*. Nelson Education.

World Bank. (2018). *World Bank Country and Lending Groups.* Retrieved Apr 27, 2020. Retrieved from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519

World Bank. (2019). *State and trends of carbon pricing 2014*. World Bank Publications.

World Bank. (2020a). *GDP per capita (constant 2010$US)(NY.GDP.PCAP.KD).* Retrieved May 2, 2020. Retrieved from: https://data.worldbank.org/indicator/NY.GDP.PCAP.KD

World Bank. (2020c). *Urban population (of total population) (SP.URB.TOTL.IN.ZS)*. Retrieved May 6, 2020. Retrieved from: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

World Bank. (2020b). *Industry (including construction, calue added (% of GDP) (NV.IND.TOTL.ZS)*. Retrieved May 4, 2020. Retrieved from: https://data.worldbank.org/indicator/NV.IND.TOTL.ZS

Worldwatch Institute. (2009). *Into a Warming World*. State of the World Report 2009. New York: W.W. Norton & Co.

Xiaoqing, Z., & Jianlan, R. (2011). The relationship between carbon dioxide emissions and industrial structure adjustment for Shandong province. *Energy Procedia*, 5, 1121-1125. Doi: 10.1016/j.egypro.2011.03.197

Yan, X., & Su, X. (2009). *Linear regression analysis: theory and computing*. World Scientific.

Appendix A. Summary of previous ex-post studies (in chronological order)

Author(s)	Dependent variables(s) [DV]	Indepen-dent variable(s) [IV]	Countries covered	Method of analysis	Period of time covered	Main findings
Andersen (2004)	CO_2 emissions	carbon tax	Denmark, Finland, Sweden, Norway, Iceland	ex-post qualitative analysis	1987-2000	Danish model is the most successful in emission reductions
Bruvoll and Larsen (2004)	CO_2 emissions, energy intensity	carbon tax	Norway	general equilibrium simulation	1990-1999	relatively small effect of IV on DV
Lin and Li (2011)	CO_2 per capita growth	carbon tax	Denmark, Finland, Netherlands, Sweden, Norway	difference-in-difference (DID), panel regression	1981-2008	carbon tax has only had positive and significant effect in Finland, it had a positive but not significant effect in Denmark, Sweden, Netherlands, and it had a negative and non-significant effect in Norway on CO_2 emissions
Frey (2016)	CO_2 emissions, GDP, welfare	carbon tax	Ukraine	computable general equilibrium model	2007-2010	current tax rate has negligible effect on DV
Aydin and Esen (2018)	CO_2 emission	environmental tax	15 EU member countries	panel regression	1995-2003	significant and non-linear relationship between IV and DV
Haites (2018)	GHG and CO_2 emissions	carbon tax	Denmark, Sweden, Fiinland, Norway, Asutria, Germany, Italy, Netherlands, Slovenia and United Kingdom	summary of ex-post studies	2005-2015	GHG emissions continued to rise, but at a slower rate compared to busines-as-usual scenario (however due to other factors)

Appendix B. Operationalization of variables

Dependent variable	Indicator	Level of measurement	Time span	Source
CO_2 emissions	CO_2 emissions per capita	Ratio	1990-2017	Our World in Data
Independent variables	**Indicator**	**Level of measurement**	**Time span**	**Source**
Carbon Tax	Whether a country implemented carbon tax or not	Categorical	1990-2017	Global Carbon Account
Rate of carbon tax	Rate of carbon tax	Ratio	1990-2017	Global Carbon Account
Share of jurisdiction's emissions covered	Share of jurisdiction's emissions covered	Ratio	1990-2017	Global Carbon Account
Control variables	**Indicator**	**Level of measurement**	**Time span**	**Source**
Economic development	GDP per capita in constant 2010 dollars	Ratio	1990-2017	World Development Indicators database (World Bank)
Industry structure	industry's share to GDP	Ratio	1990-2017	World Development Indicators database (World Bank)
Urbanization	share of urban population of total population	Ratio	1990-2017	World Development Indicators database (World Bank)
Energy price	U.S. landed cost crude oil measured in dollars per barrel	Ratio	1990-2017	Electric Industries Asssociation (EIA)

Appendix C. High–income countries

Andorra

Antigua and Barbuda

Argentina

Aruba

Australia

Austria

Bahamas

Bahrain

Barbados

Belgium

Bermuda

British Virgin Islands

Brunei Darussalam

Canada

Cayman Islands

Channel Islands

Chile

Croatia

Curacao

Cyprus

Czech Republic

Denmark

Estonia

Faroe Islands

Finland

France

French Polynesia

Germany

Gibraltar

Greece

Greenland

Guam

Hong Kong

Hungary

Isle of Man

Iceland

Ireland

Israel

Italy

Japan

Korea, Rep.

Kuwait

Latvia

Liechtenstein

Lithuania

Luxembourg

Macao

Malta

Monaco

Netherlands

New Caledonia

New Zealand

Nothern Mariana Islands

Norway

Oman

Palau

Panama

Poland

Portugal

Puerto Rico

Qatar

San Marino

Saudi Arabia

Seychelles

Singapore

Sint Marteen (Dutch part)

Slovakia

Slovenia

Spain

St. Kitts and Nevis

St. Martin (French part)

Sweden

Switzerland

Taiwan

Trinidad and Tobago

Turks and Caicos Islands

United Arab Emirates

United Kingdom

Unated States

Uruguay

Virgin Islands

Glossary:

Example Country – part of the sample, but carbon taxing is not implemented

Example Country – part of the sample and carbon taxing is implemented

Example Country – not part of the sample because no data is available on the dependent variable

Example Country – not part of the sample because the World Bank's Database has no data regarding this country

Example Country – not part of the sample because data on the industry structure is not available

Example Country – not part of the sample because the country has specific provinces with implemented carbon tax, which is not the scope of this study

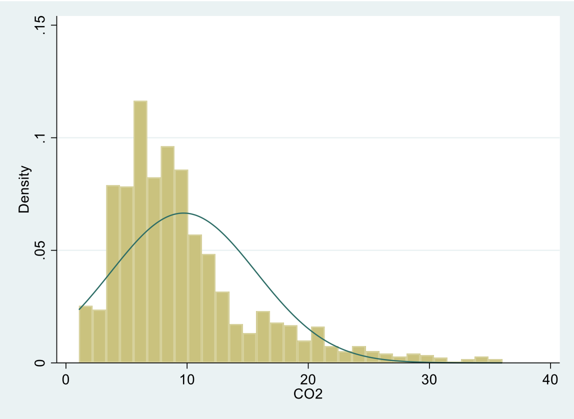
Appendix D. Missing values

	Industry sturcutre	**GDP per capita**
Andorra	1990-1999	-
Bahrain	1996-2005	-
Barbados	2011-2017	-
Belgium	1990-1994	-
Croatia*[16]	1991-1994	1991-1994
Canada	1990-1996 2016-2017	-
Estonia*	1991-1994	1991-1992
Greece	1990-1994	-
Hong Kong	1990-1999	-
Hungary	1990-1994	1990
Iceland	1990-1996 2017	-
Ireland	1990-1994	-
Israel	1990-1994	-
Japan	1990-1993	-
Latvia*	1991-1994	1991-1993
Lithuania	1990-1994	1990-1994
Luxembourg	1990-1994	-
New Zealand	2017	-
Palau*	1994-1999	1994-1999
Poland	1990-1994	-
Portugal	1990-1994	-
Slovakia*	1993-1994	-
Slovenia*	1991-1994	-
Spain	1990-1994	-
USA	1990-1996	-

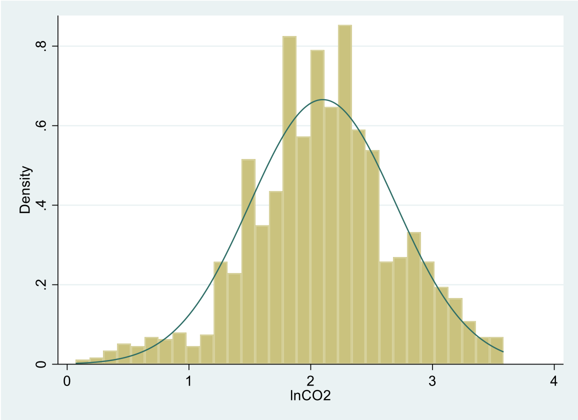
[16] * denotes countries which gained their independence after 1990, therefore their analysis only starts after that year. Furthermore, Czech Republic is missing from this table, because it has no missing values after the year (1993) it gained its independence.

Appendix E. Histogramms

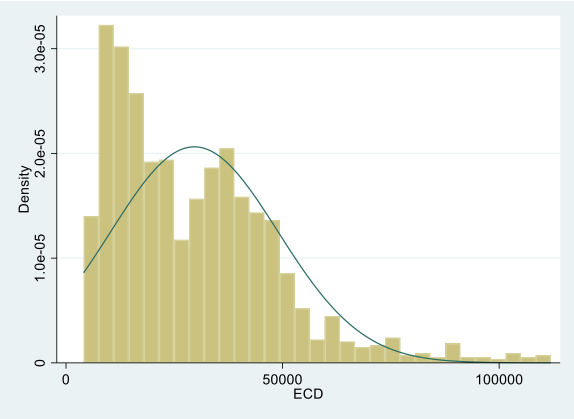
CO2



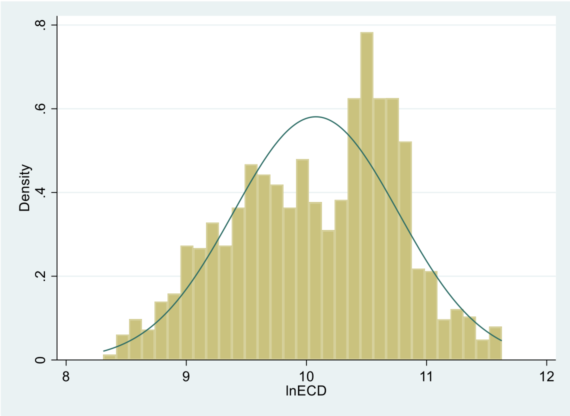
lnCO2



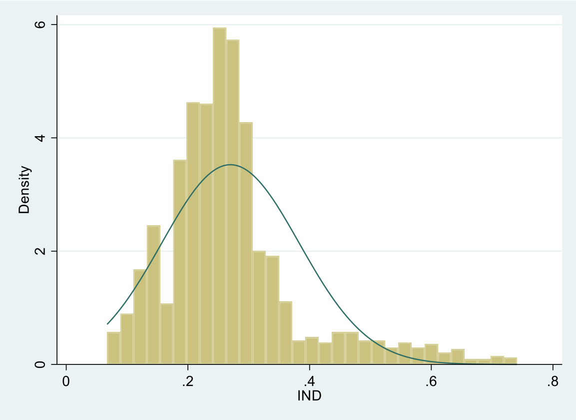
ECD



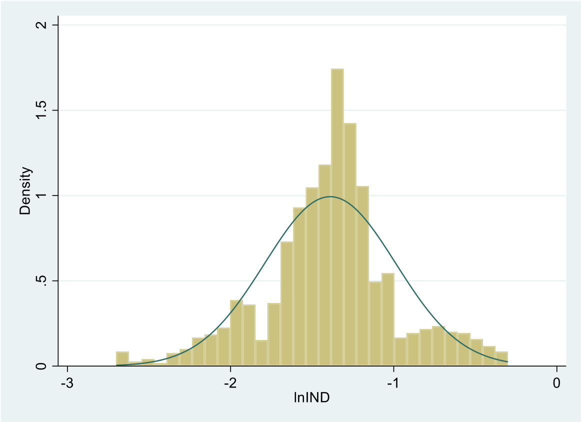
lnECD



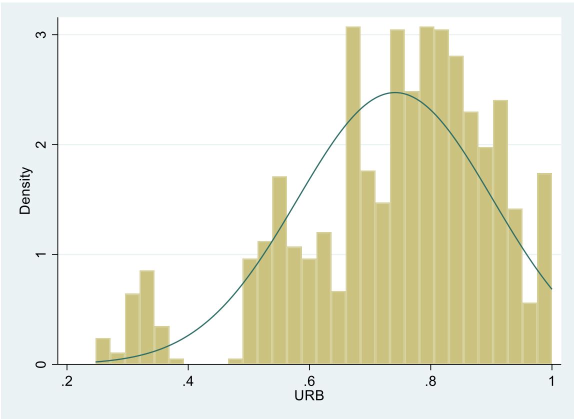
IND



lnIND

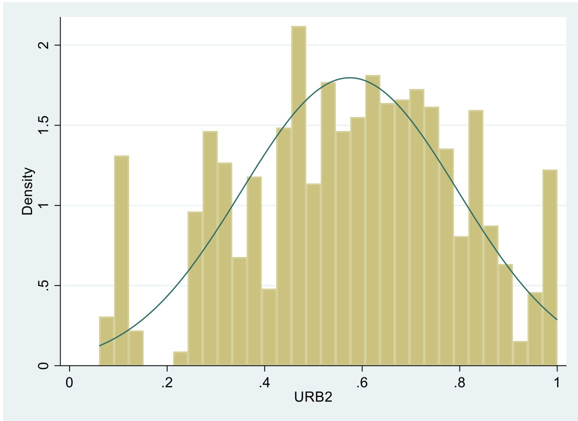


URB



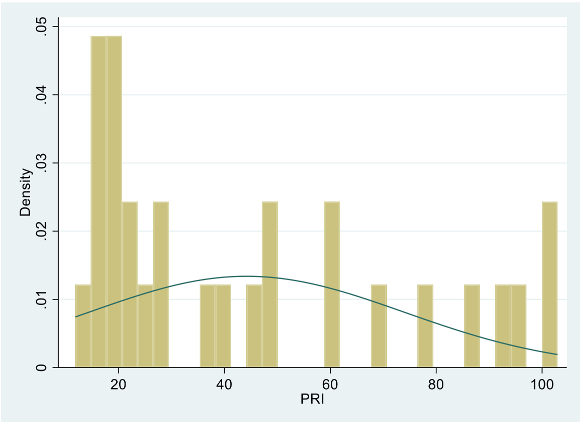
Density
0
1
2
3
.2
.4
.6
.8
1
URB

URB2



Density
0
.5
1
1.5
2
0
.2
.4
.6
.8
1
URB2

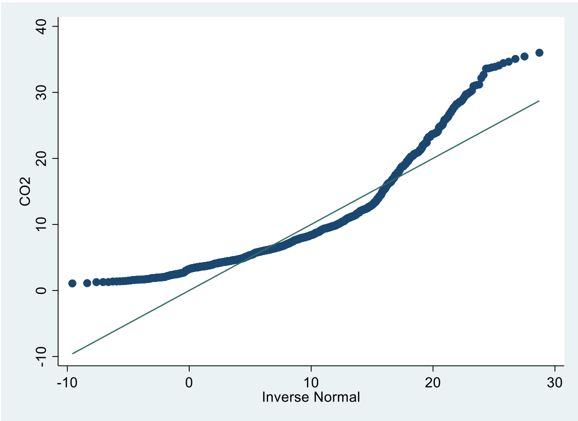
PRI



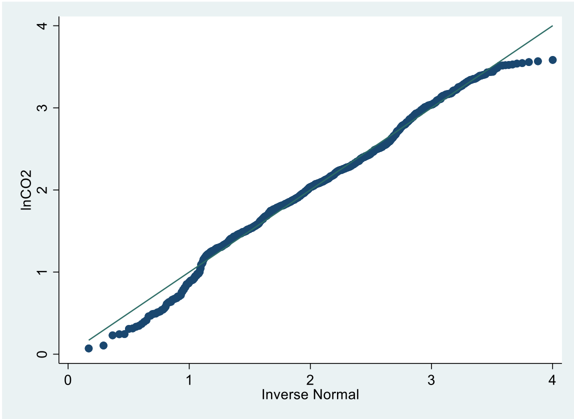
Density
0
.01
.02
.03
.04
.05
20
40
60
80
100
PRI

Appendix F. Q-Q Plots

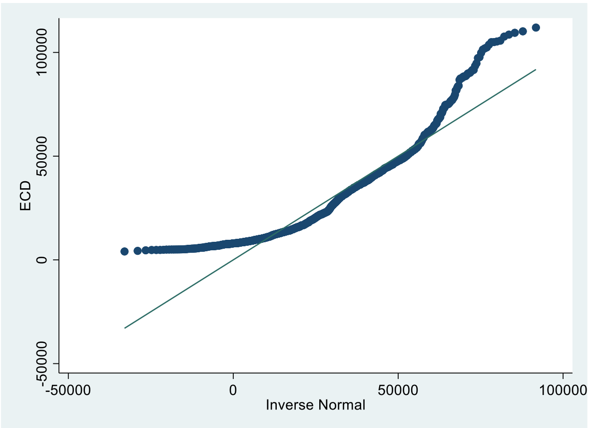
CO2



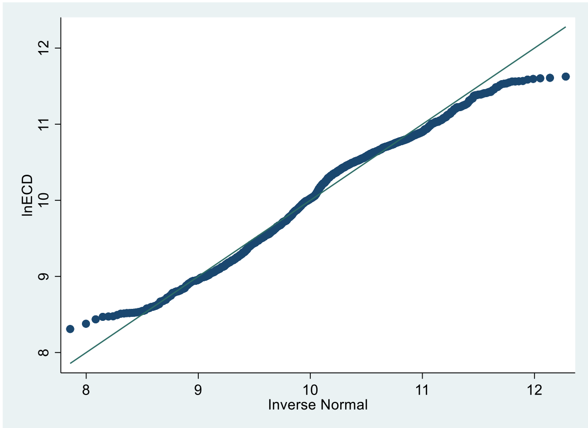
lnCO2



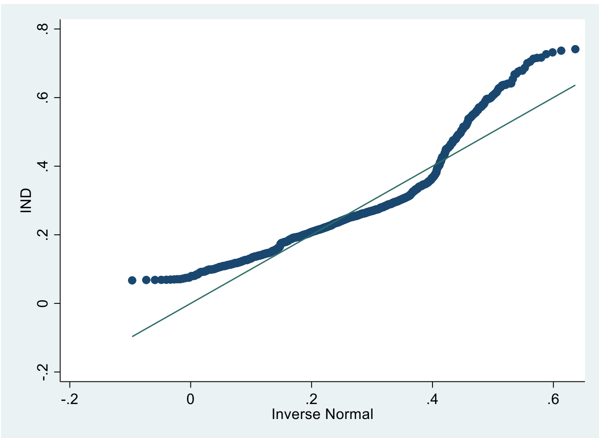
ECD



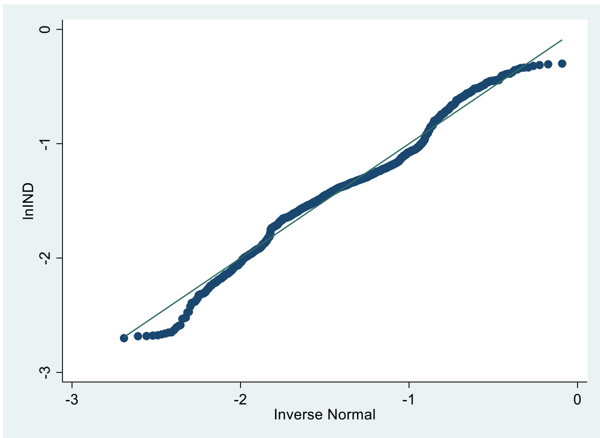
lnECD



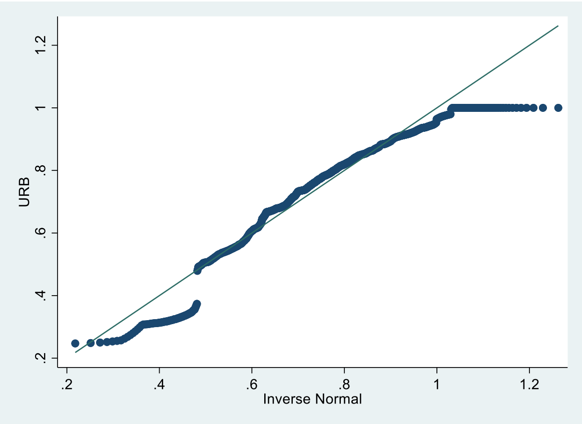
IND



lnIND

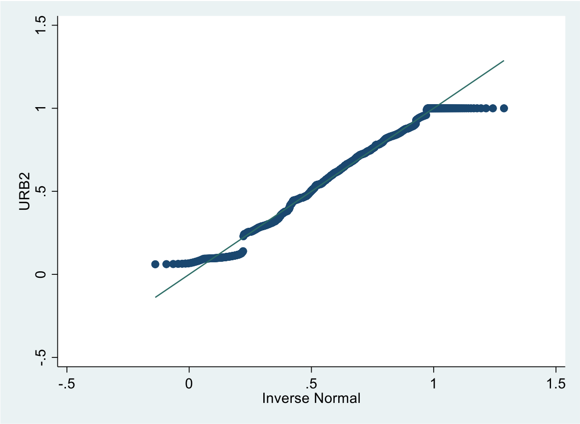


URB



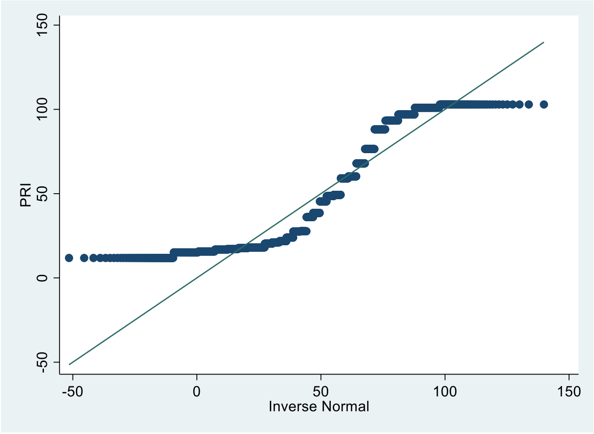
URB
.2
.4
.6
.8
1
1.2
Inverse Normal

URB2



URB2
-.5
0
.5
1
1.5
Inverse Normal

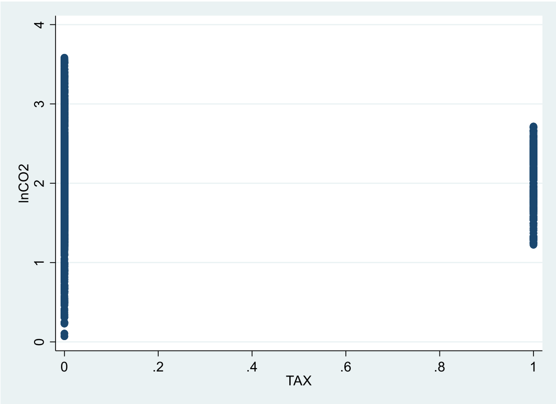
PRI



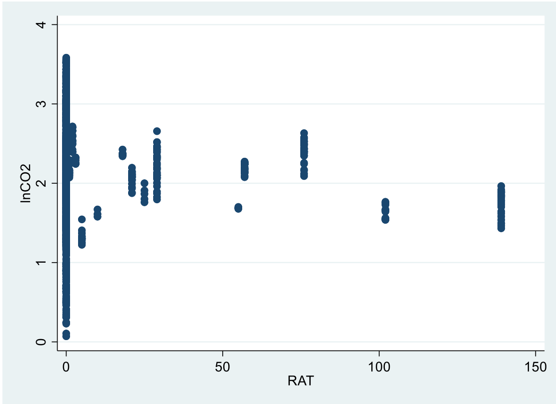
PRI
-50
0
50
100
150
Inverse Normal

Appendix G. Scatter Plots

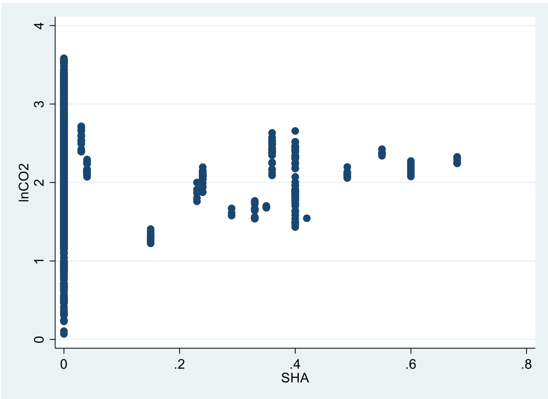
lnCO2 – TAX



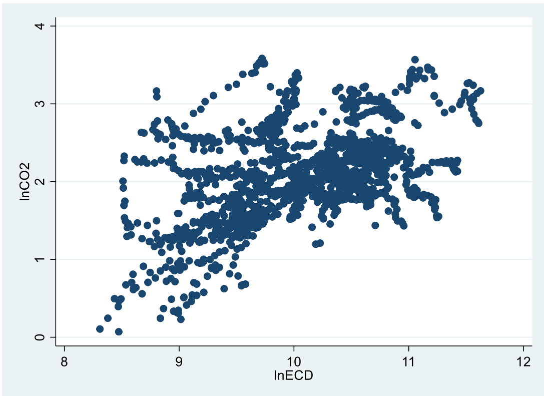
lnCO2 - RAT



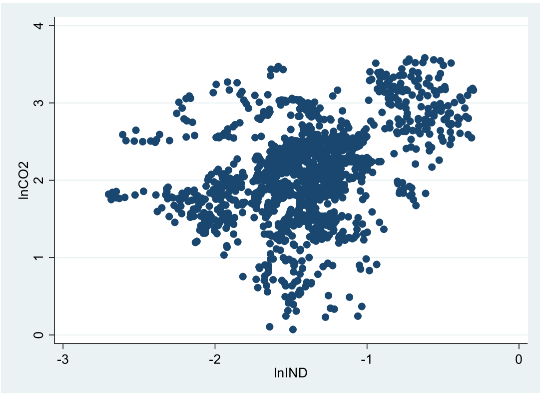
lnCO2 – SHA



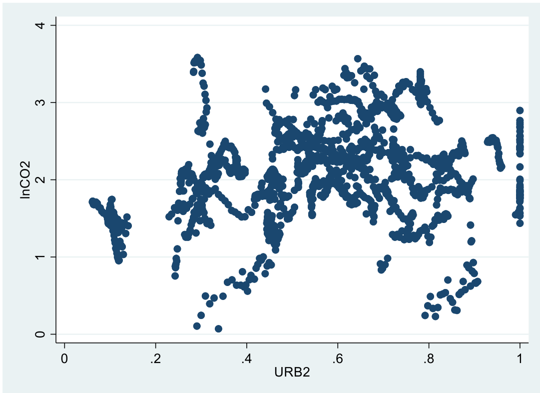
lnCO2 – lnECD



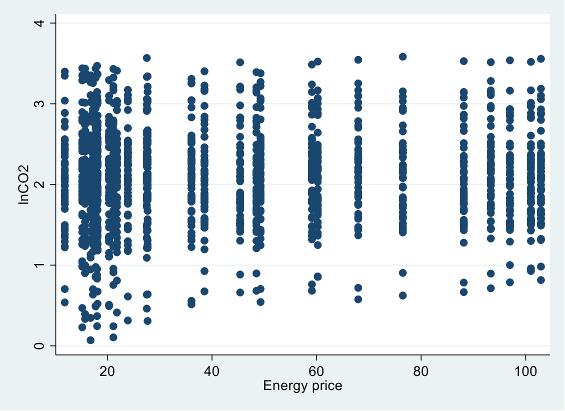
lnCO2 – lnIND



lnCO2 – URB2



lnCO2 – PRI



Appendix H. Test results

Test name	Econometric Assumption	Null Hypothesis (Ho)	Model	Associated statistics	Prob>Associated statistic	Ho at 95% confidence?	Consequence
Wooldridge test	Serial correlation	No first order autocorrelation among the regression errors	1.	F(1,53)=164.008	P-value=0.000	Rejected	Correction for autocorrelation is required for all four models
			2.	F(1,53)=163.995	P-value=0.000	Rejected	
			3.	F(1,53)=163.599	P-value=0.000	Rejected	
			4.	F(1,53)=164.046	P-value=0.000	Rejected	
Breusch-Pagan test	Homoscedas-ticity	Variance of the regression errors are constant	1.	Chi-sq(1)=112.91	P-value=0.000	Rejected	Robust standard errors need to be included in the models
			2.	Chi-sq(1)=96.90	P-value=0.000	Rejected	
			3.	Chi-sq(1)=107.11	P-value=0.000	Rejected	
			4.	Chi-sq(1)=106.81	P-value=0.000	Rejected	
White test	Homoscedas-ticity	Variance of the regression errors are constant	1.	Chi-sq(27)=395.15	P-value=0.000	Rejected	Robust standard errors need to be included in the models
			2.	Chi-sq(19)=391.79	P-value=0.000	Rejected	
			3.	Chi-sq(20)=383.98	P-value=0.000	Rejected	
			4.	Chi-sq(20)=380.42	P-value=0.000	Rejected	
Hausman test	Country-specific unobservable effects are correlated with explanatory variables	Differences in coefficients are not systematic	-	Chi-sq(7)=11.11	P-value=0.1338	Not rejected	Random-effects model is chosen