Louvain School of Management

On the causal effect of climate policies on the reduction of carbon dioxide emissions

Empirical analysis applied to Nordic countries

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Année académique 2022-2023
Travail de fin d'études (TFE) en vue d'obtenir le titre de Master (60) en Sciences de Gestion
Horaire décalé

Abstract

Given the severe climate change that Earth is facing and the adoption of national and international climate policies to mitigate it, this master thesis aims to determine whether the domestic carbon taxes, the Kyoto Protocol and the European Union (EU) emissions trading system (ETS) have had an impact on the carbon dioxide emission reduction from their entry into force to the present day. To that end, an empirical analysis is carried out on three Nordic countries, namely Finland, Norway and Denmark, based on unconditional and conditional Granger causality tests in frequency domain. It demonstrates the effectiveness in the long run of the carbon tax for the three countries. The Kyoto Protocol is also proved to impact Norwegian and Danish carbon emissions whereas a long-term causal relationship of the EU ETS on those of Finland and Denmark is detected. This preliminary econometric investigation could assist policy-makers in defining future climate policies to reduce greenhouse gas emissions and therefore to reach the Paris Agreement objectives.

Résumé

Compte tenu de la gravité du changement climatique auquel la Terre est confrontée et de l'adoption de politiques climatiques nationales et internationales pour l'atténuer, ce mémoire vise à déterminer si les taxes carbone nationales, le Protocole de Kyoto et le système d'échange de quotas d'émission de l'Union européenne (UE) ont eu un impact sur la réduction des émissions de dioxyde de carbone depuis leur entrée en vigueur jusqu'à aujourd'hui. À cette fin, une analyse empirique est réalisée sur trois pays nordiques, à savoir la Finlande, la Norvège et le Danemark, sur la base de tests de Granger causalité inconditionnels et conditionnels dans le domaine des fréquences. Elle démontre l'efficacité à long terme de la taxe carbone pour les trois pays. Il est également prouvé que le protocole de Kyoto a un impact sur les émissions de carbone norvégiennes et danoises, tandis qu'une relation de causalité à long terme du système européen d'échange de quotas d'émission sur la Finlande et le Danemark est détectée. Cette étude économétrique préliminaire pourrait ainsi aider les décideurs politiques à définir les futures politiques climatiques visant la réduction des émissions de gaz à effet de serre et donc à atteindre les objectifs de l'Accord de Paris.

Acknowledgments

I would like to express my sincere gratitude to my supervisor, Pr. Jean-Baptiste Hasse, that accepted to supervise this master thesis despite the short time left to complete it. I really appreciated this topic that allowed me to discover a research field totally outside my comfort zone. Your availability, interest, motivation and positive attitude were the driving forces behind this thesis.

This thesis is also the endpoint of this master degree in management, that could not have been possible without the unfailing support of my wife, Marie. Combining it with our works, the DIY work of our new house, your pregnancy and finally the birth and first four months of our beloved Olivia required many sacrifices from you. I really wanted to acknowledge how you perfectly managed to handle everything almost alone and thank you for this and for always being there for me.

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1 Introduction

Climate change stands out as one of the major challenge of the current era. The Earth average temperature increased of approximately 1.1°C compared to the preindustrial period and records demonstrate that the last decade was the warmest one [Gillett et al., 2021]. Human activities have undoubtedly impacted and continue to alter the climate system, especially through the emissions of significant amount of greenhouse gases such as carbon dioxide and methane [IPCC, 2014]. The former mainly originates from, in order of importance, industries, transport and electricity production whereas the latter from the energy sector and the agriculture due to livestock, waste as well as rice paddies [Olczak and Piebalgs, 2019, Yusuf et al., 2012].

The effects of climate change are being felt all over the world and comprise, first and foremost, warming of the atmosphere and oceans, sea level rise, melting of glaciers and ice sheets but also extreme weather events, droughts, wildfires, decline of biodiversity and animal species migration as well as shifts of ocean current and wind patterns.

According to the scientific community, human still have the opportunity and capacity to shape the trajectory of the climate so as to secure a liveable future provided that strong measures are taken [IPCC, 2023]. This requires collective and concerted actions of governments worldwide. In that regard, the last thirty years have seen the adoption of several policies to mitigate climate change and its negative effects by acting on anthropogenic greenhouse gas emissions.

Among theses climate policies, carbon taxes are commonly recognised for their effectiveness in decreasing emissions [Bruvoll and Larsen, 2004, Metcalf, Spri, Andersson, 2019, Khastar et al., 2020]. They consist in establishing a price that carbon dioxide emitters are obligated to pay for each ton of gas they release, thereby transferring the burden of the damage to them and enabling them to alleviate their negative externalities on climate. This mechanism aims to give an incentive for polluters to decrease their emissions so as to avoid the additional taxation. The expected outcomes also comprise promotion and investments in low-carbon and clean technologies as well as energy savings [Elkins and Baker, 2001]. The public acceptance of these taxes significantly depends on the allocation of their revenues, e.g. for deficit reduction, cutting other taxes, investing in sustainable technological improvements for industries or supporting further actions against climate change [Marron and Morris, 2016, Steenkamp, 2021].

Nordic countries pioneered the adoption of this mechanism. More precisely, Finland was the first to implement a carbon tax, in 1990, quickly followed by Norway and Sweden in 1991 and finally Denmark in 1992. Other countries then adopted this carbon pricing method in the next decades, including e.g. Switzerland and British Columbia (Canada) in 2008, Ireland and Iceland in 2010, Japan and Mexico in 2012 and France in 2014. The coverage of these carbon taxes highly varies according to the country and has evolved, as the tax rate, since their enactment but generally encompasses all or part of fossil fuel (natural gas, coal as well as oil and its by-products) consumption for transportation, enery production, industries and/or heating. Numerous sectoral exemptions and tax rate differentiations are however introduced for the sake of competitiveness, tempering the effectiveness of carbon taxes [Ekins and Speck, 1999, Lin and Li, 2011].

The Kyoto Protocol was adopted in 1997 with the aim to reduce the emissions of the six main greenhouse gases through legally-bindings restrictions. The signature of at least 55 parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, together accounting for at least 55% of the carbon dioxide emissions of industrialised countries, was required for its entry into force, delaying the latter to 2005 when Russia ratified it.

For the first commitment period, from 2008 to 2012, the signatories committed to decrease their emissions compared to the 1990 levels based on individual targets for each countries and the European Union, leading to an average reduction of approximately 5.2% [United Nations, 1998]. No emission targets were set for developing countries under the principle of common but differentiated responsibility and respective capabilities. The EU member states distributed their total 8% joint reduction target among themselves, certain countries being subject to a maximal emission increase, e.g. 4% for Sweden, while the remaining ones to a diminution, such as Belgium and Denmark with respectively 7.5% and 21%. An emission trading system has been set up between countries, as a part of the Kyoto flexible mechanisms. The Doha Amendment was adopted in late 2012 to prolong Kyoto Protocol for a second commitment period, from 2013 to 2020. The purpose was mainly to increase the reduction targets, to reach at least 18% with respect to 1990 levels. However, it came into force in late 2020 as a result of the late achievement of the required ratification threshold.

The fifteen member states of the EU at the time of the ratification reached their joint emission reduction goal, achieving a 11.7% decrease on average for the first period [IPCC, 2014]. Although not all countries have met their targets, several empirical studies further concluded that the commitments made under the Kyoto Protocol have had a tangible impact in reducing carbon dioxide emissions [Aichele and Felbermayr, 2013, Iwata and Okada, 2014, Grunewald and Martinez-Zarzoso, 2016, Maamoun, 2019]. Despite that, the treaty is generally acknowledged as a failure [Napoli, 2012]. Indeed, due to the absence of numerous significant emitters, such as the United States of America, its coverage is limited to approximately 18% of global emissions. In addition, the limited time frame of the commitment period led the signatories to take short-sighted actions to reach the targets instead introducing policies and investing for long run reductions [Keeler and Thompson, 2008, Rosen, 2015]. An empirical analysis also demonstrated that the Kyoto Protocol conducted to carbon leakage due to increasing import of embodied carbon from noncommitted countries [Aichele and Felbermayr, 2015].

The European Union introduced the Emissions Trading System (ETS) in 2005 to cope with the climate change by promoting investment in low carbon technology and reducing greenhouse gas emission in a cost-effective manner, thus allowing to meet the targets set by the Kyoto Protocol.

The system operates based on a cap-and-trade scheme. Specifically, the amount of greenhouse gas emissions is limited by caps on the total number of allowances. These caps are progressively reduced each year, at an annual rate of 1.74% until 2020 and 2.2% from 2021 onwards, guaranteeing a decrease in overall emissions. The allowances are either freely allocated, notably to maintain competitiveness and thereby prevent the so-called carbon leakage in traded sectors [Naegele and Zaklan, 2019], purchased at auction [Hepburn et al., 2006] or acquired on the trade market by companies to offset each ton of gas they emit. In this way, companies diminishing their emissions are rewarded by accumulating allowances that can be sold to other that exceed their limit. Significant penalties are provided for companies failing to compensate for their emissions.

The EU ETS is currently the largest of its kind in operation in the world, including over 11 000 power plants and factories, which collectively account for approximately 45 percent of the EU total greenhouse gas emissions, located in the twenty-seven EU member states alongside with Iceland, Liechtenstein, and Norway, that joined the system in 2008. The concept of emission trading system is expanding to several countries such as Canada, China, Korea, Switzerland and the United States.

The Paris Agreement was enacted in late 2015 at the 21st Conference of Parties (COP). This legally-binding treaty establishes long-term objectives to limit climate change and adapt to its adverse effects, the primary one being to maintain the average temperature rise well below 2°C above pre-industrial levels and, preferably, to restrict the increase to 1.5°C so as to prevent critical climate change impacts. To that end, each country has to establish every five years more ambitious climate action plans and goals to reduce its own greenhouse gas emissions. Unlike the Kyoto Protocol, this agreement therefore relies on voluntary determined instead of legally-imposed targets, which was a condition for the ratification by the United States of America and China [Lawrence and Wong, 2017]. In addition, developed, developing and emerging countries are all involved, while acknowledging a graduated approach efforts based on responsibilities and capacities.

In this context, this master thesis aims to empirically investigate the causal impact of three climate policies, namely the national carbon taxes, the Kyoto Protocol and the EU emissions trading system, on the reduction of domestic carbon dioxide emissions, pursuing the research work initiated in [Candelon and Hasse, 2023]. In this way, the effectiveness of these three types of climate policies can be assessed, thus providing political decision-makers with a preliminary econometric analysis to assist them define their future policies, for instance to achieve the Paris Agreement objectives. The present study focuses on Nordic countries, specifically Norway, Finland and Denmark, given that they are less prone to carbon leakage. Indeed, they introduced their respective carbon tax in a row and, regarding transport sector leakage, they share few populated borders with other countries [Andersson, 2019]. As far as the climate policies are concerned, their selection is motivated by the sufficient hindsight since their adoption, thus offering enough sample data to capture long-term effects and to carry out relevant statistical causality tests both in time and frequency domains.

2 Literature Review

This section first surveys the studies analysing the impact of climate policies on greenhouse gas emission reduction, with a focus on the implemented methodological approaches. On this basis, the literature that concerns the concept of Granger causality and the underlying statistical tests, both in time and frequency domains, is then reviewed.

2.1 Methods for Climate Policy Evaluation

Studies investigating the effect of climate policies, particularly carbon taxation, have gained in interest over the last fifteen years, owing to the increasing availability of data, on the one hand, and the need to adopt new policies and therefore to take advantage of the acquired experience, on the other hand [Koppl and Schratzenstaller, 2022]. Table 1 provides a non-comprehensive list of references to recent publications along with the method employed to obtain the results as well as the climate policy and the country under analysis. The effectiveness of carbon taxation is commonly recognised and corroborated by the corresponding studies. The impact of the Kyoto protocol and the European Union emissions trading sytem (EU ETS) on the carbon emission reduction appears to be more contrasted, see e.g. [Aichele and Felbermayr, 2013, Candelon and Hasse, 2023] and [Klemetsen et al., 2020, Wagner et al., 2014] respectively.

The methodological approaches implemented in the vast majority of these empirical studies are regression analysis, synthetic control method, difference-in-differences as well as panel data regression. However, the commonly used methods can not dissociate the short and long-term causal effects. In this context, an innovative approach based on frequency domain Granger causality tests has been recently proposed and applied to climate policies in Sweden [Candelon and Hasse, 2023].

2.2 Granger Causality

The notion of causality is difficult to formalise and therefore to apply to econometric problems. Granger introduced, in accordance with the work of Wiener defining to the causal relations that may link variables [Wiener, 1956], the notion of Granger-causality for autoregressive models of stochastic processes [Granger, 1969]. It is based on the principle that there exists a causal relationship from a variable x to a variable y provided that the latter can be better forecasted when adding the past history of the variable x in the prediction model. Numerous improvements have been made since early developments [Shojaie and Fox, 2022]. However, this causality test achieved in the time domain solely reports on the average spectral impact of the cause variable throughout the studied time series, thereby being unable to provide a frequency representation of causal influence.

Causality tests have thus been extended to the frequency domain, relying on R^2 measures for time series in a first instance [Pierce, 1979]. The Granger causality measure from a time series to another was further investigated thanks to a frequency decomposition, allowing to dissociate long-run and short-run impacts that correspond respectively to low and high frequencies [Geweke, 1982, Geweke, 1984]. Association, reciprocity and, above all, one-way effect causal measures were later defined based on this frequency approach [Hosoya, 1991]. A Wald-type test allowing to test the causal relationships in cointegrated systems according to the frequency was then developed [Yao and Hosoya, 2000]. The framework of the previous causality measures was later on adopted to propose a simple test procedure leaning on a bivariate vector autoregressive (VAR) model and linear restrictions on the underlying parameters for the null hypothesis [Breitung and Candelon, 2006]. The relevance of this test for extreme frequencies was proved for specific VAR models [Yamada and Yanfeng, 2014] and it was subsequently shown, based on a more generic one, that the power at each frequency depends on the model roots [Wei et al., 2021]. The null hypothesis was also generalised to enable the causality analysis for unspecified frequencies within a predefined band [Breitung and Schreiber, 2018]. A novel bootstrap approach for unconditional and conditional Granger causality was recently introduced and consists in testing with a F-test the null hypothesis of zero causality at each frequency and compares it to the distribution of the median causality across frequencies, thereby allowing to disambiguate the most prominent causalities among significant ones [Farne and Montanari, 2022].

Policies whose impact on a dependant variable is to be determined are usually represented by binary variables, equal to one when applied and zero otherwise. The applicability of traditional Granger causality tests in time domain to mixed VAR models, i.e. comprising both continuous and discrete variables, was validated in [Candelon et al., 2013]. The procedure formulated in [Breitung and Candelon, 2006] for testing Granger causality in frequency domain was lately demonstrated through Monte Carlo simulations to be valid for a set of binary and continuous dependent variables [Candelon and Hasse, 2023]. This study further concludes that the frequency domain has more power than its time domain counterpart to disclose abrupt and smooth structural breaks, which is of interest for the study of the impact of climate policies.

Table 1: Literature review – Non-comprehensive list of publications on climate policy evaluation

Method	Policy	Country	Reference
Panel data regression	EU ETS	EU countries	[Anderson and Di Maria, 2011]
Difference-in-differences	Carbon tax	Denmark, Finland, Norway, Sweden	[Lin and Li, 2011]
Synthetic control method	Carbon tax	Norway	[Mideksa and Kallbeken, 2012]
Regression analysis	Kyoto Protocol	133 countries	[Aichele and Felbermayr, 2013]
Difference-in-differences	Kyoto Protocol	170 countries	[Grunewald and Martinez-Zarzoso, 2016]
Difference-in-differences	EU ETS	France	[Wagner et al., 2014]
Regression analysis	Carbon tax	Sweden	[Brannlund et al., 2014]
Difference-in-differences	EU ETS	Lithuania	[Jaraite and Di Maria, 2016]
Regression analysis	Carbon tax	British Columbia (Canada)	[Lawley and Thivierge, 2018]
Panel data regression, synthetic control method	Carbon tax	British Columbia (Canada)	[Xiang and Lawley, 2019]
Synthetic control method	Carbon tax	Denmark, Finland, Norway, Sweden	[Fernando, 2019]
Synthetic control method	Carbon tax	Sweden	[Andersson, 2019]
Difference-in-differences	EU ETS	Norway	[Klemetsen et al., 2020]
Synthetic control method, difference-in-differences	Carbon tax	Sweden	[Runst and Thonipara, 2020]
Regression analysis	Carbon tax	France	[Dussaux, 2020]
Synthetic control method	Carbon tax	Finland	[Mideksa, 2021]
Synthetic control method, difference-in-differences	Carbon tax	British Columbia (Canada)	[Pretis, 2022]
Granger causality	Carbon tax, Kyoto Protocol, EU ETS	Sweden	[Candelon and Hasse, 2023]

Note: this table is partially based on Table 1 from [Candelon and Hasse, 2023].

3 Methodology

This section presents the methodology followed to retrieve the empirical results and is structured as follows. Section 3.1 formulates the problem statement that this master thesis aims to address as well as the underlying hypotheses to be tested. The dataset is then introduced in Section 3.2. Finally, Section 3.3 describes the tools, namely vector autoregressive (VAR) models and Granger causality tests, based on which the statistical tests are carried out.

3.1 Hypotheses

The purpose of this work is to determine whether climate policies, including carbon taxes, the Kyoto Protocol and the EU Emission Trading System, are efficient to cope with climate change and more precisely to act on carbon emissions. Specifically, it aims to extend the case study carried out for Sweden in [Candelon and Hasse, 2023] to three other Nordic countries, namely Finland, Norway and Denmark. To that end, the three following hypotheses are formulated:

1. Carbon taxes do lead to a reduction in domestic carbon emissions in the long run.
2. The Kyoto protocol did result in a reduction in domestic carbon emission.
3. The EU ETS does conduct to a reduction in domestic carbon emission.

3.2 Dataset

The dataset consists of six variables, encompassing the domestic carbon intensity, dummies related to the climate policies as well as economic indicators, as detailed hereinafter. The corresponding time series are sampled on an annual basis for a period ranging from 1964 to 2021, thus providing 58 observations per variable per country.

3.2.1 Carbon Intensity

Carbon intensity (CI), defined as the ratio between carbon dioxide emissions and the gross domestic product (GDP) per capita, is considered as the best single measure of trends for decarbonisation [Nordhaus, 2019]. The present work therefore uses this indicator to assess the impact of climate policies on emission reduction. The time series of the GDP per capita, in constant local currency unit (LCU) to prevent the influence of fluctuations in exchange rates, are collected from the database

Table 2: Dataset – Carbon intensity

Variable	Description
CO_2 emissions	Annual emissions of carbon dioxide in tons
GDP per capita	Annual gross domestic product per capita in constant LCU
Carbon intensity	Ratio between carbon dioxide emissions and GDP per capita

of the World Bank whereas the annual emissions of carbon dioxide are reported in the Global Carbon Budget disclosed by the Integrated Carbon Observation System (ICOS). Fig. 1 depicts the evolution of the carbon intensity from 1964 to 2021 for the three countries under study, highlighting a global trend towards decarbonisation since around the early 1970s.

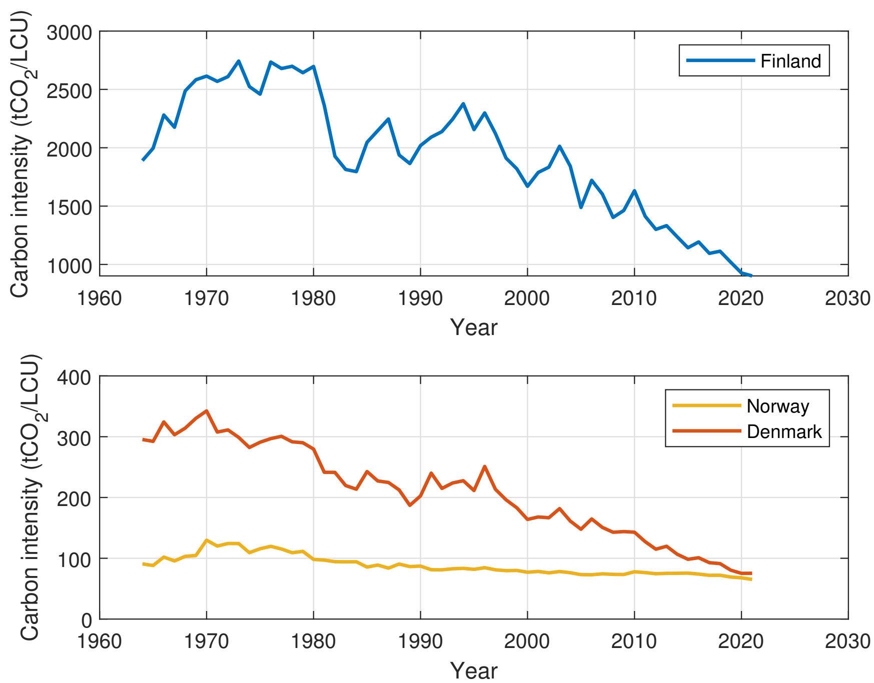

Figure 1: Evolution of the carbon intensity from 1964 to 2021 for Finland, Norway and Denmark.

It should be pointed out that the autoregressive models related to the carbon intensity (CI) are estimated based on its growth rate, denoted CIR, so as to improve the properties of the residuals:

$$\text{CIR}_t = \frac{\text{CI}_t - \text{CI}_{t-1}}{\text{CI}_{t-1}}. \tag{1}$$

3.2.2 Climate Policy Variables

Table 3 lists the variables related to the three climate policies whose causal effect on carbon intensity is empirically analysed. The latter are each represented by a dummy variable, i.e. a binary time series worth 1 when the policy is in application and to 0 otherwise. The year of entry into force of the carbon tax depends on the country, being 1990 for Finland, 1991 for Norway, and 1992 for Denmark. The Kyoto Protocol is considered effective from its adoption, in 1997. The EU emissions trading system was launched in 2005 and is still in operation. It should be noted that, as is, the starting points of the different policies are fairly well split up, thereby facilitating the dissociation of their respective impact. However, as far as the Kyoto Protocol is concerned, the beginning year could also be fixed to 2002, the ratification year by Nordic countries, 2005, corresponding to the treaty entry into force, or 2008, the start of the first commitment period. These different starting years could be used to assess the robustness of the present empirical analysis.

The Granger causality of each of these variables on carbon intensity is examined through both unconditional and conditional tests, the other policies serving as control variables in the latter case.

Table 3: Dataset − Climate policy variables

Variable	Description
Carbon tax	Dummy variable equal to 1 from 1990, 1991 and 1992 for Finland, Norway and Denmark respectively and 0 otherwise
Kyoto Protocol	Dummy variable equal to 1 between 1997 and 2021 and 0 otherwise
EU ETS	Dummy variable equal to 1 between 2005 and 2021 and 0 otherwise

3.2.3 Economic Variables

Following the approach adopted in [Andersson, 2019] and later in [Candelon and Hasse, 2023], economic indicators are included in the conditional Granger causality tests as control variables.

They comprise the unemployment rate as a percentage of active population, retrieved from the Statistical Data Warehouse of the European Central Bank for EU countries and from the World Bank database for Norway, as well as a recession indicator, i.e. a dummy variable proposed by the Organisation for Economic Co-operation and Development (OECD) and retrieved from the Federal Reserve Economic Data website.

Table 4: Dataset − Economic control variables

Variable	Description
Unemployment rate	Unemployment rate as a percentage of total labor force
Recession indicator	Dummy variable equal to 1 for a recession period and 0 otherwise

3.3 Statistical Tools

The vector autoregression modelling tool, employed to model the time series of the different variables under study, is first described. The concept of Granger causality, based on which the causal relationship between climate policies and carbon dioxide emission reduction is investigated, and the underlying statistical tests both in time and frequency domains, are then explained. The corresponding R packages and functions are also provided.

3.3.1 Vector Autoregressive (VAR) Model

An autoregressive (AR) model of order p allows to describe the evolution of a time series y by predicting its value at time t through a linear combination of its p former ones:

$$y_t = a_1 y_{t-1} + \cdots + a_p y_{t-p} + r_t + \epsilon_t, \tag{2}$$

where $a_1, \ldots, a_p$ are the parameters of the model, ϵ_t is a stochastic normally distributed error term and r_t is a deterministic regressor that takes the following form:

$$r_t = c + st, \tag{3}$$

with c and s adding respectively a constant and a trend term. The $p + 2$ time-invariant parameters characterising the model can, for instance, be calculated by minimising the sum of the square of the residuals (OLS method), and, depending on the variable that is modelled, be null.

Vector autogression (VAR) is the generalisation of autoregressive models to multivariate time series. In this way, assuming N endogenous variables, the value $y_{t,i}$ of the i-th at time t is obtained as the linear combination of its lagged values as well as those of the other variables of the vector. This can be written in a matrix form as follows:

$$\mathbf{y_t} = \mathbf{a_1 y_{t-1}} + \cdots + \mathbf{a_{t-p} y_{t-p}} + \mathbf{r_t} + \boldsymbol{\epsilon_t}, \tag{4}$$

where $\mathbf{y_t}$, $\mathbf{r_t}$ and $\boldsymbol{\epsilon_t}$ are $N \times 1$ vectors, each row of which refers to a specific variable, and $\mathbf{a_i}$ are $N \times N$ matrices, including time-invariant parameters linking these variables.

The order p of the model is selected based either on an extensive analysis of the residuals, that should ideally follow a normal distribution with zero mean and no drift, or on information criteria (IC), such as Akaike (AIC), Hannan-Quinn (HQ), Schwartz (SC) or final prediction error (FPE). These latter allows to evaluate the quality of the model while overcoming drawbacks of the classical R^2 criterion and therefore enable the comparison between different fits.

R code VAR models can be established based on the function `VAR` of the package `vars` and their characteristics are then obtained with the function `summary`. The function `VARselect` provides information criteria for several lag numbers, thereby allowing to properly select the latter. The residuals can finally be analysed with `resid`.

3.3.2 Granger causality

Granger causality basically measures whether the evolution of a variable y can be better explained and therefore forecasted by taking into account both its own history and events occurring in another variable x [Granger, 1969]. In other words, this is a statistical test that allows to determine if a time series y_t can be predicted by the past values of a time series x_t, in addition to its own lagged values. These definitions highlight that the causal events should precede the effects, on the one hand, and that the former provide statistically significant information regarding the latter, on the other hand.

Relying on the autoregression formalism, the stationary time series y_t can be expressed as:

$$y_t = a_1 y_{t-1} + \cdots + a_p y_{t-p} + \epsilon_t. \tag{5}$$

This model can then be expanded by taking into account q lagged values of the time series x_t constituting the potential cause variable:

$$y_t = a_1 y_{t-1} + \cdots + a_p y_{t-p} + b_1 x_{t-1} + \cdots + b_q x_{t-q} + \epsilon_t, \tag{6}$$

Intuitively, it can be can inferred that x does impact y provided that the prediction error of this extended model is reduced compared to that of the initial one, implying that at least one of the q additional parameters $b_1, \ldots, b_q$ of the autoregressive model is different from zero. From a statistical point of view, this can be translated into the following null hypothesis [Gelper and Croux, 2007]:

$$H_0 : b_1 = \cdots = b_q = 0. \tag{7}$$

This significance test can, for instance, be based on a simple F-test [Farne and Montanari, 2022] or a Wald-type test [Breitung and Candelon, 2006]. The rejection of the null hypothesis implies that one rejects that x_t does not Granger-cause y_t. For the sake of clarity, this double negation is abandoned in the remainder of this document.

Control variables z can also be considered in Granger causality tests to verify the causal relation from x to y when taking into account the mediating effect of z. The conditioning variable set can potentially have a significant influence on the test results and should consequently be properly selected to include all variables that could be responsible for the observed effects.

Granger causality tests are traditionally achieved in time domain but recent research extended them to the frequency domain. In the former case, the tests assess the average spectral impact of the cause variable throughout the period under study and thus exclude the potential variation in causality across frequencies. In contrast, in the latter case, the tests are carried out as a function of the frequency, thereby enabling to distinguish short-run from long-run impacts. The period T corresponding to each frequency ω can be easily calculated as:

$$T = \frac{2\pi}{\omega}. \tag{8}$$

Furthermore, the frequency domain test has been proved to exhibit better power to detect abrupt and smooth structural breaks than its time domain counterpart, which is of interest when investigating the impact of climate policies on emission reduction [Candelon and Hasse, 2023].

R code Granger causality tests in time domain are carried out via the function `causality` of the package `vars`. The frequency domain statistical tests are based on the package `grangers`, and more precisely the functions `bc_test_uncond` and `bc_test_cond` for the unconditional and conditional tests, developed by [Farne and Montanari, 2022] on the basis of the test procedure proposed in [Breitung and Candelon, 2006] but with a F-test.

4 Empirical Analysis

This section presents the results of the empirical analysis carried out to determine the respective impact of the national carbon taxes, the Kyoto Protocol and the European Union emissions trading system on the carbon intensity reduction for Finland, Norway and Denmark.

The climate policies causal effect is investigated through unconditional and conditional Granger tests performed in time and frequency domains. For robustness assessment, the results of the underlying F-tests are provided for lag number p varying from three to six, these latter leading to the best residuals and information criteria for the VAR models. The labels *, ** and *** indicate significance at 90, 95 and 99% respectively. The control variables include first the non-targeted climate policies and then the combination of the latter with the economic indicators.

4.1 Finland

4.1.1 Unconditional Tests

Focusing first on the time domain, Table 5 presents the causality test statistics for the carbon tax, the Kyoto Protocol and the European Union emission trading system. It reveals that no Granger causal relationship of these policies on the carbon intensity is detected for the period under study given that no confidence level is reached regardless of the lag order p.

Table 5: Empirical analysis – Finland: time domain unconditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity for different lag orders p.

	Carbon tax	Kyoto Protocol	EU ETS
$p = 3$	0.51	0.39	1.73
$p = 4$	0.48	0.55	1.58
$p = 5$	0.67	0.62	1.68
$p = 6$	0.76	0.86	1.69

Concerning the Granger causality tests in frequency domain, Fig. 2 illustrates the spectral evolution of the F-test results performed for the Finnish carbon tax while Table 6 reports the underlying data for a selected set of frequencies, highlighting that this climate policy does impact the domestic carbon emissions in the long run, namely for very low frequencies, close to $\omega = 0.05$ (rad/s).

Similarly, as reported in Table 7, the EU ETS appears to Granger cause the carbon intensity reduction at low frequencies, around $\omega = 0.25$ (rad/s), corresponding to a period of 25 years. In contrast, the Kyoto Protocol is shown to have had no influence on domestic emissions in Finland. It should be noted that the results are fairly independent from the lag order p selected for the vector autoregressive models, confirming the robustness of the observations.

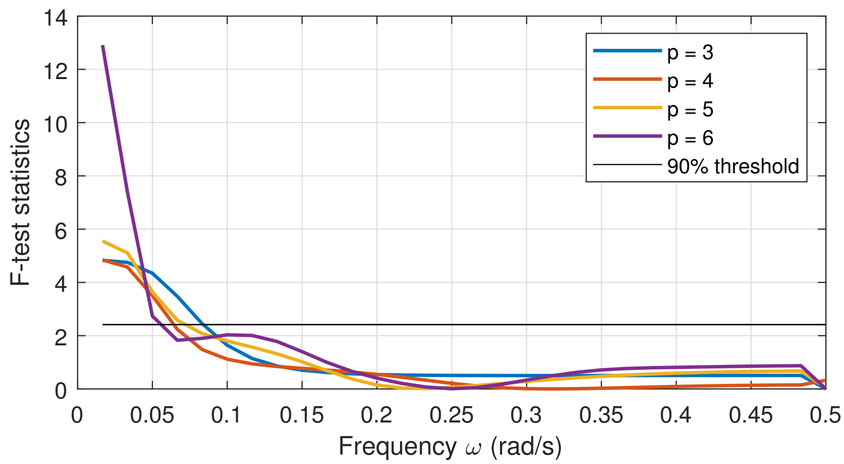

Figure 2: Evolution with the frequency of the F-test results of the frequency domain Granger causality tests of the Finnish carbon tax on the carbon intensity.

Table 6: Empirical analysis – Finland: frequency domain unconditional Granger causality of the Finnish carbon tax on the carbon intensity for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
$p = 3$	**4.75****	**2.44***	0.86	0.51	0.01
$p = 4$	**4.58****	1.47	0.84	0.32	0.33
$p = 5$	**5.10*****	2.07	1.32	0.06	0.04
$p = 6$	**7.38*****	1.90	1.78	0.01	0.00

4.1.2 Conditional Tests

The Granger causality is first analysed by considering, in turn, each climate policy as cause variable while the remaining two condition the tests. Table 8 provides the resulting test statistics for

Table 7: Empirical analysis – Finland: frequency domain conditional Granger causality of the Kyoto Protocol and EU ETS on the carbon intensity for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
			Kyoto Protocol		
$p = 3$	0.65	0.65	0.66	0.67	0.04
$p = 4$	1.52	1.20	1.11	0.31	0.52
$p = 5$	0.31	0.78	1.17	0.87	1.71
$p = 6$	0.26	0.72	1.00	0.77	1.09
			EU ETS		
$p = 3$	0.48	0.98	**2.55***	**3.44****	**5.67*****
$p = 4$	0.31	1.36	**2.87***	**3.87****	2.07
$p = 5$	0.56	0.93	1.02	**4.99****	1.96
$p = 6$	1.42	0.45	0.52	**6.79*****	**3.37****

the carbon tax, endorsing its long-run effect on the carbon emissions with additional detected frequencies below or equal to 0.133 (rad/s). As indicated in Table 9, the impact of the EU ETS is also confirmed. Furthermore, the Kyoto Protocol is still considered ineffective for the emission reduction. Indeed, the two values passing the significance tests are obtained for a lag order of six, which features the worst VAR model information criteria. These conclusions are further validated by the conditional tests that also include the economic indicators, as stated in Table 10.

Table 8: Empirical analysis – Finland: frequency domain conditional Granger causality of the Finnish carbon tax on the carbon intensity, conditioned by the Kyoto Protocol and the EU ETS, for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
$p = 3$	**13.21*****	**12.62*****	**9.34*****	2.37	0.06
$p = 4$	**25.36*****	**21.42*****	**10.05*****	1.77	0.34
$p = 5$	**23.60*****	**16.27*****	**6.06*****	1.90	0.05
$p = 6$	**36.32*****	**12.58*****	1.97	1.47	0.02

Table 9: Empirical analysis – Finland: frequency domain conditional Granger causality of the Kyoto Protocol and the EU ETS on the carbon intensity, conditioned by the two remaining climate policies, for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
Kyoto Protocol conditioned by the carbon tax and the EU ETS					
$p = 3$	1.61	1.51	1.27	0.91	0.09
$p = 4$	2.38	2.31	2.29	2.11	0.48
$p = 5$	1.21	0.53	0.51	1.35	1.83
$p = 6$	**10.42*****	**2.95***	0.83	1.93	1.36
EU ETS conditioned by the carbon tax and the Kyoto Protocol					
$p = 3$	1.31	0.83	0.34	1.45	**5.73****
$p = 4$	1.38	0.32	0.25	**2.65***	**8.71*****
$p = 5$	**2.88***	2.11	0.38	1.11	**10.13*****
$p = 6$	**6.63*****	**3.96****	1.57	0.11	**12.52*****

4.1.3 Discussion

Unlike their time counterparts, the unconditional and conditional frequency domain causality tests demonstrate the effectiveness of the Finnish carbon tax in reducing the underlying emissions. This conclusion is in line with previous empirical studies [Lin and Li, 2011, Fernando, 2019, Mideksa, 2021]. The social welfare of Finns has however also be shown to be negatively affected by the additional costs they face as a result of the carbon tax [Khastar et al., 2020].

Table 10: Empirical analysis − Finland: frequency domain conditional Granger causality of the Kyoto Protocol and the EU ETS on the carbon intensity, conditioned by the two remaining climate policies and the economic indicators, for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
Finnish carbon tax | Climate policies & economic indicators					
$p = 3$	**2.72***	**2.98***	**2.81***	1.19	0.81
$p = 4$	**4.42***	**4.17***	2.30	0.54	0.14
$p = 5$	**99.34*****	**63.39*****	**17.58*****	1.66	0.23
$p = 6$	**201.12*****	**80.21*****	**11.65*****	**6.05*****	**10.26*****
Kyoto Protocol | Climate policies & economic indicators					
$p = 3$	0.87	1.14	1.38	1.11	0.11
$p = 4$	1.85	1.98	2.04	2.21	0.27
$p = 5$	1.47	0.44	0.37	0.87	2.01
$p = 6$	**2.82***	2.29	1.16	0.84	1.32
EU ETS | Climate policies & economic indicators					
$p = 3$	1.47	1.16	1.76	**4.79****	**10.25*****
$p = 4$	1.99	**4.89****	**9.08*****	**9.07*****	**23.52*****
$p = 5$	**3.24****	**6.29*****	**7.04*****	**3.93****	**27.97*****
$p = 6$	**7.31*****	**5.73****	1.96	1.31	**36.79*****

4.2 Norway

4.2.1 Unconditional Tests

On the one hand, as in the case of Finland, the causality tests performed in time domain for Norway, whose results are listed in Table 11, do not expose any influence, in the Granger sense, of the three climate policies under analysis on the carbon emission reduction.

Table 11: Empirical analysis – Norway: time domain unconditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity for different lag orders p.

	Carbon tax	Kyoto Protocol	EU ETS
$p = 3$	0.79	0.39	0.76
$p = 4$	0.57	0.39	0.53
$p = 5$	0.46	0.27	0.42
$p = 6$	0.33	0.19	0.38

On the other hand, long-term effects of the Norwegian carbon tax and the Kyoto Protocol on the carbon intensity are demonstrated through the frequency domain Granger causality tests, as indicated in Table 12. By contrast, the European Union emission trading system exhibits no statistically significant impact on it.

4.2.2 Conditional Tests

The conditional tests performed based on the different climate policies corroborate the fact that Kyoto Protocol Granger cause the Norwegian carbon intensity, as does the carbon tax for which numerous low frequencies are detected at a high confidence level, as shown in Table 13, whereas the failure of the EU ETS is confirmed for Norway. As highlighted in Table 14, introducing the economic indicators as control variables in the Granger causality tests carried out in frequency domain does not alter the previous observations, underlining their robustness.

4.2.3 Discussion

The lag order p has almost no impact on the frequencies featuring a causal effect, endorsing the reliability of the conclusions. Specifically, the Norwegian carbon tax is shown to be effective for emission reduction, as already reported in [Bruvoll and Larsen, 2004, Mideksa and Kallbeken, 2012]. The empirical analysis also indicates that the European Union emission trading system is inefficient in Norway, which is consistent with the literature and could be explained by an over-allocation of free allowances in the first phases [Klemetsen et al., 2020].

Table 12: Empirical analysis − Norway: frequency domain unconditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity for different lag orders p and frequencies ω.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
		Norwegian carbon tax			
$p = 3$	**10.28*****	**6.21*****	1.92	0.37	0.29
$p = 4$	**8.26*****	2.26	0.68	0.44	0.22
$p = 5$	**7.96*****	0.55	0.29	0.54	0.04
$p = 6$	**4.82****	0.44	0.22	0.40	0.02
		Kyoto Protocol			
$p = 3$	**3.84****	2.63	0.89	0.17	0.14
$p = 4$	**4.47****	0.77	0.06	0.07	0.58
$p = 5$	**3.88****	0.47	0.06	0.04	0.50
$p = 6$	**2.58***	0.09	0.00	0.00	0.77
		EU ETS			
$p = 3$	1.14	1.54	1.54	1.27	1.02
$p = 4$	0.88	0.83	0.91	1.20	0.39
$p = 5$	0.35	0.51	0.88	0.94	0.11
$p = 6$	0.38	0.56	0.56	0.97	0.03

Table 13: Empirical analysis − Norway: frequency domain conditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity, conditioned by the two remaining climate policies, for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
Norwegian carbon tax conditioned by the Kyoto Protocol and the EU ETS					
$p = 3$	**23.30*****	**23.11*****	**18.37*****	**4.43****	0.87
$p = 4$	**24.40*****	**21.02*****	**10.03*****	1.60	0.84
$p = 5$	**36.10*****	**21.59*****	**5.29*****	0.94	1.03
$p = 6$	**19.59*****	**10.08*****	**3.41***	1.41	0.19
Kyoto Protocol conditioned by the carbon tax and the EU ETS					
$p = 3$	1.70	1.84	1.76	0.79	0.41
$p = 4$	**4.02****	**3.39****	1.63	0.25	0.00
$p = 5$	**4.11****	**3.27***	1.27	0.25	0.00
$p = 6$	**13.03*****	**6.41*****	1.07	0.00	0.05
EU ETS conditioned by the carbon tax and the Kyoto Protocol					
$p = 3$	0.62	0.58	0.56	0.86	1.18
$p = 4$	0.74	0.71	0.63	0.64	0.96
$p = 5$	0.29	0.45	0.58	0.71	1.12
$p = 6$	0.53	0.67	0.58	0.47	0.78

Table 14: Empirical analysis − Norway: frequency domain conditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity, conditioned by the remaining climate policies and the economic indicators, for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
Norwegian carbon tax | Climate policies & economic indicators					
$p = 3$	0.92	1.13	1.27	0.75	0.84
$p = 4$	**15.71*****	**12.19*****	**4.87****	0.61	0.07
$p = 5$	**87.02*****	**57.44*****	**17.76****	**3.27****	0.03
$p = 6$	**110.96*****	**55.45*****	**13.46*****	**25.28*****	0.00
Kyoto Protocol | Climate policies & economic indicators					
$p = 3$	**4.26****	**3.62****	2.24	0.19	0.54
$p = 4$	**4.62****	**4.04****	**2.45***	0.08	0.11
$p = 5$	**25.26*****	**19.85*****	**3.22****	0.88	0.03
$p = 6$	**11.25*****	**7.03*****	**2.75***	1.24	0.06
EU ETS | Climate policies & economic indicators					
$p = 3$	0.14	0.12	0.14	0.44	1.08
$p = 4$	0.56	0.46	0.29	0.36	1.22
$p = 5$	0.30	0.42	0.44	0.25	1.63
$p = 6$	0.02	0.04	0.07	0.17	0.19

4.3 Denmark

4.3.1 Unconditional Tests

The time domain Granger tests are, as for Finland and Norway, unable to detect any significant causal relationship of the carbon tax, the Kyoto Protocol and the EU ETS on the gas emissions regardless of the selected lag order p, as reported in Table 15.

Table 15: Empirical analysis – Denmark: time domain unconditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity for different lag orders p.

	Carbon tax	Kyoto Protocol	EU ETS
$p = 3$	0.38	0.85	0.83
$p = 4$	0.62	1.87	0.30
$p = 5$	2.43	0.70	0.66
$p = 6$	2.43	0.60	0.90

Table 16 provides the F-test results of the frequency domain causality, revealing that the domestic carbon intensity reduction is, among others, caused, in the Granger sense, by both the Danish carbon tax and the Kyoto Protocol in the long run. In contrast, the EU emissions trading system is considered to have no impact on it since only the highest lag order leads the lowest significance level test to be passed at a frequency close to the border.

4.3.2 Conditional Tests

Using the non-targeted climate policies as control variables in the conditional tests allows to confirm the Granger causality of the carbon tax and the Kyoto protocol through high confidence F-test results, summarised in Table 17. It also strengthens the observation that the Danish carbon emission reduction is not be attributable to the EU ETS.

On the other hand, while the tests taking into account the effect of the economic indicators consolidate the conclusions drawn for the Danish carbon tax and the Kyoto Protocol, namely their long-term impact, they further disclose that the EU ETS Granger causes the carbon emission reduction, as shown in Table 18. This result contradicts the previous ones and therefore implies that the effect of this climate policy was drown in that of the economic indexes, leading to F-test values below the confidence levels for the causality tests. Consequently, it demonstrates the importance of properly selecting the conditioning variables, even outside the direct field of the cause variable.

Finally, it should be pointed out that the causality tests do not provide any results for lag order higher than five due to the detection of an almost perfect fit. This has however no impact on the conclusions since VAR model information criteria lead to lower number of lags.

4.3.3 Discussion

The conditional Granger causality tests uncover the effectiveness of the three climate policies for reducing domestic carbon emissions. These results are in accordance with earlier empirical studies for the carbon tax and the Kyoto Protocol [Lin and Li, 2011, Grunewald and Martinez-Zarzoso, 2016, Fernando, 2019] whereas no study to compare with was found for the EU ETS.

Table 16: Empirical analysis − Denmark: frequency domain unconditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity for different lag orders p and frequencies ω.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
			Danish carbon tax		
$p = 3$	0.69	0.77	0.83	0.84	0.37
$p = 4$	**3.46**$**$	1.99	1.91	0.93	0.24
$p = 5$	**6.41**$***$	**7.21**$***$	**4.88**$**$	0.93	0.24
$p = 6$	**7.19**$***$	**7.53**$***$	**5.90**$***$	2.39	1.87
			Kyoto Protocol		
$p = 3$	**4.92**$**$	**4.15**$**$	**2.55**$*$	1.76 0.38	
$p = 4$	**4.53**$**$	2.12	1.67	1.68	0.28
$p = 5$	**4.14**$**$	1.46	1.66	0.76	0.44
$p = 6$	**3.92**$**$	1.12	1.72	0.72	0.78
			EU ETS		
$p = 3$	1.16	1.72	1.63	1.25	1.31
$p = 4$	1.34	2.13	1.74	1.04	0.72
$p = 5$	1.79	1.40	0.72	0.96	0.28
$p = 6$	**3.02**$*$	0.78	0.01	2.12	1.21

Table 17: Empirical analysis – Denmark: frequency domain conditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity, conditioned by the two remaining climate policies, for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
Danish carbon tax conditioned by the Kyoto Protocol and the EU ETS					
$p = 3$	1.47	1.19	0.64	0.10	0.36
$p = 4$	**7.46*****	**5.35*****	**2.77***	0.24	0.04
$p = 5$	**46.26*****	**27.57*****	**13.13*****	**8.34*****	**4.65****
Kyoto Protocol conditioned by the carbon tax and the EU ETS					
$p = 3$	**8.19*****	**8.36*****	**7.55*****	**3.67****	0.54
$p = 4$	**20.55*****	**18.28*****	**10.46*****	**3.81****	1.61
$p = 5$	**16.67*****	**9.69*****	1.79	0.08	2.50
EU ETS conditioned by the carbon tax and the Kyoto Protocol					
$p = 3$	1.38	1.58	1.85	1.74	1.3
$p = 4$	0.98	1.35	1.94	2.02	1.16
$p = 5$	1.85	2.30	**2.53***	1.57	1.89

Table 18: Empirical analysis – Denmark: frequency domain conditional Granger causality of the carbon tax, the Kyoto Protocol and the EU ETS on the carbon intensity, conditioned by the remaining climate policies and economic indicators, for different frequencies ω and lag orders p.

	$\omega = 0.033$	$\omega = 0.083$	$\omega = 0.133$	$\omega = 0.250$	$\omega = 0.500$
Danish carbon tax | Climate policies & economic indicators					
$p = 3$	1.95	1.58	0.89	0.33	0.61
$p = 4$	**12.02*****	**8.71*****	**3.66****	1.99	0.04
$p = 5$	**148.11*****	**88.87*****	**44.36*****	**33.59*****	2.21
Kyoto Protocol | Climate policies & economic indicators					
$p = 3$	**9.79*****	**9.77*****	**8.43*****	**3.7****	0.27
$p = 4$	**38.06*****	**33.28*****	**16.87*****	**2.93***	1.90
$p = 5$	**22.09*****	**13.20*****	**7.91*****	**6.00*****	**7.68*****
EU ETS | Climate policies & economic indicators					
$p = 3$	1.47	1.68	1.97	1.81	1.32
$p = 4$	1.82	**2.38***	**2.92***	**2.36***	1.25
$p = 5$	**3.84****	**4.58****	**5.09****	**3.28****	**4.23****

5 Conclusion

Given the severe climate change that Earth is facing and the adoption of national and international climate policies to mitigate it, this master thesis aimed to determine whether the domestic carbon taxes, the Kyoto Protocol and the European Union emissions trading system have had an impact on the carbon dioxide emission reduction from their entry into force to the present day. To that end, an empirical analysis was carried out on three Nordic countries, namely Finland, Norway and Denmark, pursuing the research work initiated in [Candelon and Hasse, 2023] for Sweden.

The second section reviewed the studies analysing the causal impact of climate policies on greenhouse gas emission reduction, pointing out that commonly employed methods do not dissociate short and long-term effects. On this basis, the literature related to the Granger causality and the associated statistical tests, both in time and frequency domains, was subsequently surveyed.

The third section was dedicated to the methodological approach. The problem statement and the underlying hypotheses were first formulated. The dataset, encompassing the carbon intensity, the climate policies as well as economic control variables, and the underlying data sources were then described. The statistical tools used to test the causal effect of the climate policies, namely vector autoregressive models and the Granger causality, were presented.

The fourth section was dedicated to the empirical analysis performed to test the formulated hypotheses. On the one hand, the Granger causality tests achieved in time domain demonstrated their inability to detect any causal relationship between the climate policies under study and the carbon dioxide emission reduction. On the other hand, the frequency domain unconditional tests highlighted the long-term effectiveness of the carbon taxes for the three countries. They also revealed that, contrary to the results obtained for Sweden, the Kyoto Protocol Granger causes the Norwegian and Danish carbon intensity reduction in the long run while statistically significant causality of the European Union emissions trading system is proved for Finland. These results were endorsed through conditionals tests carried out using the non-targeted climate policies as well as economic indexes, namely the unemployment rate and a recession indicator, as control variables. Unlike their unconditional counterparts, these tests further stressed the long-term causal effect of the EU ETS for Denmark, underlining the importance of properly selecting the conditioning variables.

This master thesis provides political decision-makers with a preliminary econometric analysis for assisting them define future climate policies aiming to reduce greenhouse gas emissions, for instance to reach the Paris Agreement objectives.

The present empirical investigation also opens the way for perspectives. The reasons leading to a different impact of the Kyoto Protocol and the EU ETS on each country should be examined. The influence of the starting year of the Kyoto Protocol could be studied to assess the result robustness. The Granger causality could be tested for higher frequencies, based on the Gretl package developed for [Breitung and Schreiber, 2018], to explore the potential short-run effects. The tests statistics could be compared to those obtained with the variant derived in [Farne and Montanari, 2022] to identify the most prominent causalities among significant ones. Finally, an identical testing approach could be applied to analyse the causal relationship of these climate policies, especially those related to carbon pricing, on competitiveness, innovation and macroeconomic effects.

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Abstract :

Given the severe climate change that Earth is facing and the adoption of national and international climate policies to mitigate it, this master thesis aims to determine whether the domestic carbon taxes, the Kyoto Protocol and the European Union (EU) emissions trading system (ETS) have had an impact on the carbon dioxide emission reduction from their entry into force to the present day. To that end, an empirical analysis is carried out on three Nordic countries, namely Finland, Norway and Denmark, based on unconditional and conditional Granger causality tests in frequency domain. It demonstrates the effectiveness in the long run of the carbon tax for the three countries. The Kyoto Protocol is also proved to impact Norwegian and Danish carbon emissions whereas a long-term causal relationship of the EU ETS on those of Finland and Denmark is detected. This preliminary econometric investigation could assist policy-makers in defining future climate policies to reduce greenhouse gas emissions and therefore to reach the Paris Agreement objectives.

Résumé :

Compte tenu de la gravité du changement climatique auquel la Terre est confrontée et de l'adoption de politiques climatiques nationales et internationales pour l'atténuer, ce mémoire vise à déterminer si les taxes carbone nationales, le Protocole de Kyoto et le système d'échange de quotas d'émission de l'Union européenne (UE) ont eu un impact sur la réduction des émissions de dioxyde de carbone depuis leur entrée en vigueur jusqu'à aujourd'hui. À cette fin, une analyse empirique est réalisée sur trois pays nordiques, à savoir la Finlande, la Norvège et le Danemark, sur la base de tests de Granger causalité inconditionnels et conditionnels dans le domaine des fréquences. Elle démontre l'efficacité à long terme de la taxe carbone pour les trois pays. Il est également prouvé que le protocole de Kyoto a un impact sur les émissions de carbone norvégiennes et danoises, tandis qu'une relation de causalité à long terme du système européen d'échange de quotas d'émission sur la Finlande et le Danemark est détectée. Cette étude économétrique préliminaire pourrait ainsi aider les décideurs politiques à définir les futures politiques climatiques visant la réduction des émissions de gaz à effet de serre et donc à atteindre les objectifs de l'Accord de Paris.

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