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CALCULATION OF THE MACROECONOMIC CARBON REBOUND EFFECT OF THE EUROPEAN UNION EMISSION TRADING SYSTEM

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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BY

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ABSTRACT

CALCULATION OF THE MACROECONOMIC CARBON REBOUND EFFECT OF THE EUROPEAN UNION EMISSION TRADING SYSTEM

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Doctor of Philosophy, Earth System Science
Supervisor : Prof. Dr. Bülent G. Akınoğlu
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Emission trading systems are currently the most popular market–based instruments in the combat against climate change. The European Union Emission Trading System is the world's oldest and most mature ETS application. Having announced its net zero targets in February 2022, it is on Türkiye's agenda to implement an ETS application to meet the country's net zero targets. While there is rich literature showing the benefits of ETS applications from different perspectives, very few studies question their efficiencies, and no empirical study has tried to measure the macroeconomic rebound effect of an ETS application. Recent econometric methods and novel estimators are used in this study to calculate a possible macroeconomic carbon rebound effect that may exist due to the applications of EU – ETS, a causality analysis is employed and policy suggestions are made at the end of the study.

Keywords: ETS, Carbon Rebound Effect, EU, Panel Data, Econometrics

ÖZ

AVRUPA BİRLİĞİ EMİSYON TİCARET SİSTEMİ'NİN MAKROEKONOMİK KARBON GERİ TEPME ETKİSİNİN HESAPLANMASI

Bolat, Cankut Kaan
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Emisyon ticaret sistemleri, günümüzde iklim değişikliğine karşı mücadelede kullanılan en popüler piyasa temelli mekanizmalardır ve Avrupa Birliği Emisyon Ticaret Sistemi de bu sistemlerin en eski ve en olgun uygulaması olarak ön plana çıkmaktadır. Şubat 2022'de net sıfır hedeflerini açıklayan Türkiye'nin gündeminde de, bu hedeflere ulaşabilmek adına bir ETS uygulaması yer almaktadır. Literatürde ETS uygulamalarının avantajlarının birçok farklı açıdan ele alındığı görülmekle beraber, bu uygulamaların verimliliğini analiz eden pek az çalışma bulunmaktadır, ampirik veriler kullanılarak bir ETS'nin makroekonomik karbon rebound etkisinin araştırıldığına ise rastlanmamıştır. Bu çalışmada, güncel ekonometrik yöntemler ve ileri düzey tahminciler kullanılarak, AB – ETS uygulamasından doğan olası bir makroekonomik karbon rebound etkisinin varlığı araştırılmış, nedensellik analizi yapılmış ve çalışma sonunda da birtakım politika uygulaması önerileri sunulmuştur.

Anahtar Kelimeler: ETS, Karbon Geri Tepme Etkisi, AB, Panel Veri, Ekonometri

To my family

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LIST OF ABBREVIATIONS

ABBREVIATIONS	
ALL	Annual Emissions Allowance Data
ARDL	Autoregressive Distributed Lag Cointegration
ARMA	Autoregressive Moving Average
ARIMA	Autoregressive Integrated Moving Average
CBAM	Carbon Border Adjustment Mechanism
CCE	Common Correlated Errors
CD	Cross-Sectional Dependency
CGE	Computational General Equilibrium
DiD	Difference in Differences
DOLS	Dynamic Ordinary Least Squares
EMI	Annual CO2 Emissions Data
EACEI	Annual Survey of Industrial Energy Consumption
EU	European Union
ETS	Emission Trading System
FCF	Annual Fixed Capital Formation Data
FE	Fixed Effects
FRED	Federal Reserve Economic Data
GDP	Gross Domestic Product

GHG	Greenhouse Gas
GMM	Generalized Method of Moments
GTAP	Global Trade Analysis Project
IEA	International Energy Agency
IFE	Interactive Fixed Effects
INSEE	French National Institute of Statistics and Economics Studies
INT	Annual Energy Intensity Data
ISIS	Integrated Sustainability Assessment System
I-O	Input – Output
IPCC	Intergovernmental Panel on Climate Change
LAB	Annual Labor Data
LED	Light-Emitting Diode
LEPA	Low Energy Precision Application
LM	Lagrange Multiplier
MSR	Market Stability Reserve
NASA	National Aeronautics and Space Administration
NBS	National Buerau of Statistics
NDC	Nationally Determined Contribution
OECD	Organization for Economic Co-Operation and Development
OLS	Ordinary Least Squares
PSM	Propensity Score Matching
SAM	Socially Accounting Matrix

SDG	Sustainable Development Goals
SUR	Seemingly Unrelated Regressions
TGC	Tradable Green Certificates
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USDA	The United States Department of Agriculture
VAR	Vector Autoregression
VAT	Value Added Tax
VECM	Vector Error Correction Mod

LIST OF SYMBOLS

SYMBOLS	
α_i	Individual Fixed Effect Term
β	OLS Coefficient of the Corresponding Dependent Variable
Δ	First Difference
Σ	Summation
ε_{it}	Error Term
ϕ	Granger Causality Coefficient of the Independent Variable
F_t	Vector of Unobserved Common Factors
λ_i	Vector of Factor Loadings
ln	Natural Logarithm
H0	Null Hypothesis
i	Cross-Sectional Dimension
j	Year 2005
p	Year 2019
t	Time Dimension

CHAPTER 1

INTRODUCTION

The combat against climate change started officially with the foundation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, which was then followed by a series of milestones on the way. The signing and announcement of the United Nations Framework Convention on Climate Change (UNFCCC), and the Earth Summit in Rio, in 1992 were two of the biggest milestones achieved. Kyoto Protocol (signed in 1998, entered into force in 2005) and Paris Agreement (signed in 2015) are the other two most important achievements under the scope of combat against climate change.

1.1 Current Situation of the Combat Against Climate Change

There is a variety of methods applied currently for the fight against climate change in the literature, which can be classified under two subjects; adaptation to climate change, and mitigation of greenhouse gases. The first series of measures taken against climate change, namely adaptation to climate change, addresses the impacts of climate change. Activities such as increasing infrastructure security, landscape restoration, and reforestation, preparation for weather extremes all are taken into consideration under adaptation to climate change. Concepts such as nature-based solutions, green infrastructures, and ecosystem-based adaptation are all consequences of these activities. The second group of measures is named mitigation of greenhouse gases, targeting the main causes of climate change. These measures

include activities and tools such as practicing energy efficiency, increasing the use of renewables, increasing transport efficiency, and pricing carbon.
Carbon pricing is one of the vital and most effective measures that can be taken for the mitigation of greenhouse gases, and it can be done using a variety of tools; feed-in tariffs, carbon taxing, and emission trading systems (ETS) are some of the most popular market – based instruments that are used to price carbon. By reducing emissions relatively effectively, supporting renewables and letting every party get involved (households as well as business owners), and allowing governments to fund their investments in public services by revenue recycling, carbon pricing has drawn attention recent years. The World Bank States and Trends Report (2022) shows that currently 68 countries are using different carbon pricing methods with an expected coverage of 11.83 gigatons of CO2 equivalent emissions, with 80 more jurisdictions have stated that they are planning on implementing, and the expected revenue from carbon pricing in the year 2017 alone has reached to $33 billion (State and Trends Report of the World Bank, 2018).

Emission trading systems are a relatively newer and more effective carbon pricing method, including industrial producers, households, and voluntary participants, which also increases the flexibility of the mechanism. The mechanism can be implemented region-based (European Union Emission Trading System), country-based (New Zealand, South Korea, Switzerland), or province/state-based (China, the US). By providing tradable emission trading certificates, or green certificates, per unit of electricity produced from renewables; the ETS allows the market dynamics to determine the price of carbon, increasing the market's efficiency. Figure 1.1 shows the current state of the ETS applications in the world, while Figure 1.2 shows the total emissions coverage since the beginning of the combat against climate change.

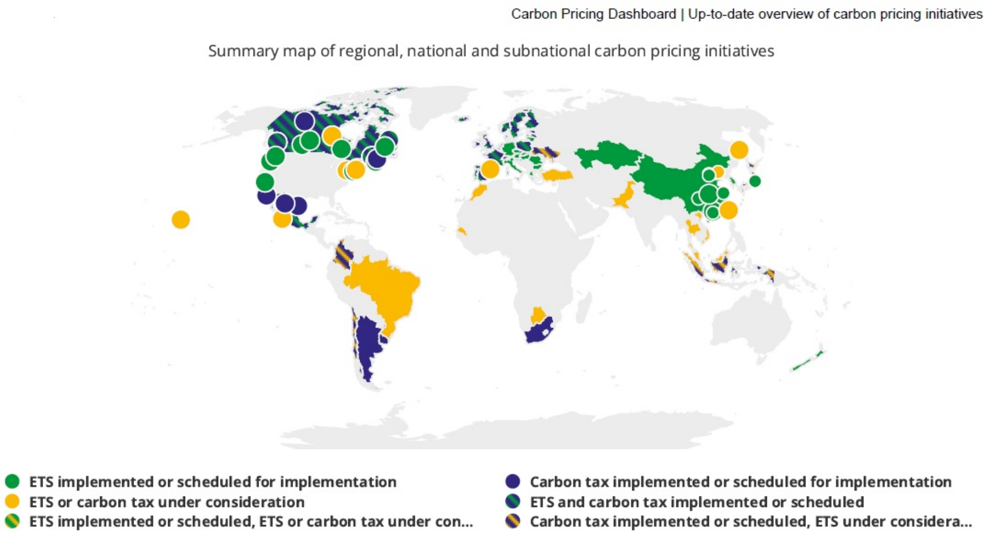

Figure 1.1. Carbon Pricing Map by the World Bank (States and Trends Report, 2022)

Although seen as relatively advanced compared to other market–based instruments, ETS also has serious drawbacks (or inefficiencies) when the practical application is considered. Carbon leakage, which can be defined as the pricing out of business outside the ETS zone due to low caps and high prices of carbon, is one of the biggest concerns regarding the mechanism; some industrial producers choose to move their businesses away from the ETS zone where emissions are regulated and priced, to regions where there is little or no regulations, which results in an overall increase of the greenhouse gas emissions. The effort of developed nations and industrial producers moving their businesses abroad to find the cheapest alternatives in terms of labor, resources, and of course, without an ETS is called the pollution haven hypothesis (Levinson, Arik, and Taylor 2008). Moreover, a study by Laing et al. in 2014 showed that a serious number of companies had gained large amounts of unearned revenue due to the emission allowances within the scope of EU – ETS (Laing, Sato, Grubb, and Comberti 2014). It is foreseen for an efficiently working ETS market, that the price per unit of carbon would be "cheap," which allows companies to “cheat”; the biggest setback of ETS mechanisms is that (even if it is up to certain limits or “caps” sometimes) they allow companies to pay their ways out and keep on polluting, which can in return increase GHG emissions. The New Zealand ETS Evaluation Report in 2016 gives similar conclusions about the scheme and recommends implications for the ETS policies of the country.

1.2 The Objective and Scope of the Thesis

The studies tackling the market–based instruments from the macroeconomic perspective are very low in number. Considering the combat against climate change, Europe’s Green Deal, and net zero targets added with the sustainable development goals (SDG) of UNFCCC, accurate analysis of the policy implications of global governing bodies is vital. Practicing energy efficiency, transport efficiency, and implementing carbon pricing policies are not solely enough; these applications and policies should be quantitatively and qualitatively analyzed, improved, and modified accordingly.

This dissertation focuses on a possible rebound effect arising from the implementation of the EU – ETS, how it can be measured and defined, what affects the rebound effect and how the policy implications can be improved. Yearly data covering the 2005-2019 period for 26 European countries were collected from various sources. CO2 emissions and emissions allowances are obtained from European Environment Agency. Gross Domestic Product, labor, and fixed capital formation are obtained from FRED Database. Finally, electricity consumption is sourced from the International Energy Agency.

The dissertation aims to calculate the macroeconomic rebound effect arising from the EU – ETS using empirical data by defining the factors related to the rebound effect and using panel data estimation methods.

The purpose is to make contributions not only to the rebound effect literature but also to the global perspective of policy implications such as the EU – ETS. For these purposes, the types of rebound effects are defined, and the variables that may affect the macroeconomic rebound are identified in the study. Using a variety of econometric analyses and tests, an accurate model is constructed and applied to the collected data. Finally, in accordance with the model results and readings from the results, policy implications and further applications are suggested.

This thesis is made up of five chapters. Chapter 2 gives a deeper insight into the literature by defining ETS and examining the studies on ETS efficiency, describing what the rebound effect is and the types of rebound effect as well as the methods to measure rebound effect, and combining the rebound effect literature with the market – based instruments literature. Chapter 3 explains which type of data was determined to be collected, the source of the data, and the methodological approach to use this empirical data for the research purposes of this study. Chapter 4 gives the empirical results of the study. Chapter 5 revolves around the discussion of these results and gives some policy recommendations as well as conclusions at the end.

1.3 Significance of the Study

The Ministry of Energy and Natural Resources in Türkiye published an Energy Efficiency Strategy Paper with a scope of ten years in 2012. In February 2022, after ratifying the Paris Agreement in October 2021, the Ministry of Environment and Urbanization in Türkiye announced a net zero target for 2053. The country is currently working on the legislation of a climate law to help achieve its net zero targets and announced that it would update its nationally determined contribution (NDC). They expect to implement a long term low GHG emission development strategy by the end of 2022. Türkiye is not only aiming to increase energy saving and efficiency practices but also transitioning into a greener energy mix. A safe, secure, and less externally dependent energy mix that is in compliance with the combat against climate change, and the net zero targets of the EU and the world are vital parts of the country’s energy strategies.

As of today, Türkiye still has not decided whether to implement a carbon pricing instrument on top of the current feed-in tariff applications. By exploring the current applications in the world today, one can see that an ETS is a preferable approach compared to a carbon tax. Moreover, the EU – ETS is currently the oldest and most mature emission trading system application in the world. Transitioning to a greener energy mix using carbon pricing and different policy implications is one of the main targets of all the developed and most developing countries, and an ETS application is one of the highly prioritized topics, therefore a highly likely possibility, in Türkiye's 2053 action plan.

The success of Türkiye's targets depends highly on the efficacy of the carbon pricing policies, especially the ETS, and how they are implemented. However, the macroeconomic rebound effect of any ETS application has never been considered since the first ever ETS, EU – ETS, was implemented. It is common knowledge that the rebound perspective is of crucial importance when energy efficiency and policy transitions are taken into consideration. This study draws attention to the macroeconomic rebound caused by the EU – ETS and makes mere policy suggestions to shed light on the different carbon pricing applications in the world, addressing a global efficacy problem for future applications by other countries such as Türkiye. The study is the first to directly consider the macroeconomic carbon rebound effect caused by the EU – ETS. A vast amount of evidence suggests that ETS improves economic and emission performances in several industries, cities, and regions. However, the ETS efficiency studies at the sectoral and regional levels do not provide an overall picture. In the face of large macroeconomic rebound effects, localized solutions alone may not be adequate or fast enough to reach the ambitious carbon emission targets.

CHAPTER 2

LITERATURE REVIEW

This part reveals the results of a deep examination of the literature. The section is divided into three categories. The first part is focused on the efficacy of ETS in the literature. The second part comprises quantitative methodological approaches to define and measure the rebound effect. The third and final part is dedicated to the studies in literature combining market–based instruments and the rebound effect.

2.1 ETS Effectiveness

The European Union ETS (EU - ETS) has officially been a part of our lives since 2005 and has become the primary weapon for mitigation applications against climate change. Several studies have investigated its role in mitigation, from the earliest stages of the mechanism to its mature stages. The EU - ETS has gone through 4 phases. Phase 1 (2005-2007) is the pilot phase, in which almost all allowances were allocated gratis. In Phase 2 (2008-2012), a tighter cap was introduced, and two new countries joined, Norway and Lichtenstein. An increased non-compliance penalty also marks this phase. Auctions became the allowance allocation mechanism in Phase 3 (2013-2020). Phase 4 (2021-2028) started in January 2021, and yearly allowances were reduced to 2.2%, compared to 1.7% in previous phases. While the oldest and, therefore, more mature ETS is operating in the European Union, there are many studies conducted on ETS in China, ETS in Australia, and New Zealand. Moreover, thee studies tackle the matter from numerous angles. This study tries to cover all relevant studies regardless of the ETS they focus on. Firstly, the efficacy of the ETS applications is discussed in this section.

The literature on ETS performance is abundant with sectoral studies. These studies focus on specific industries governed by different ETS applications and examine how ETS policies affect economic and energy performances (Barbot et al., 2014; Barragan – Beaud et al., 2018; Cao et al., 2019). For example, Barbot et al. (2014) focus on the airline industry in the EU. The ETS policies make it harder for a new competitor to enter the market in equilibrium in their game theoretical model. Barragan-Beaud et al. (2018), on the other hand, study the electricity sector in Mexico to compare ETS to carbon tax by using a bottom-up cost optimization model. They show that ETS is preferable to a tax. They provide support for their findings via political feasibility analyses. Cao et al. (2019) analyze a proposed hybrid system for China where the electricity and cement sectors are governed by an ETS, while carbon tax was applied to the rest of the industry. They employ a dynamic recursive economic energy model and show that a hybrid model achieves the same reductions in emissions with lower permit prices. The partial equilibrium analysis focusing on specific industries may miss the larger picture. What matters for effective climate change mitigation is the overall performance of the ETS.

Some studies compare the application methods used within the ETS mechanisms. Wang et al. (2019) and Carratu et al. (2020) analyze how the ETS is regulated and compare the application methods. Wang et al. (2019) used a game-theoretical analysis to compare the grandfathering method to auctioning for ETS in China. They show that the auctioning mechanism works better than the grandfathering approach. Carratu et al. (2020) focus on whether auctioning should be applied during the third phase of EU - ETS for permit allocations to prevent the companies from having free allowances. They use a propensity score matching approach and conclude there is no significant change when the allocation method changes. The method comparisons include studies pointing out certain flaws in ETS, such as Berrittella et al. (2017) and Creti et al. (2017). Berrittella et al. (2017) underline the VAT fraud in EU - ETS and show how it affects ETS operations and the economy using a computational general equilibrium model. Creti and Joets (2017), on the other hand, develop recursive right-sided unit root approaches to show the volatile behaviors in the EU - ETS market and try to define the core reasons behind bubbles. These studies do not limit themselves to specific industries. They point out very specific problems associated with ETSs, and just like sectoral studies, they do not aim to examine the overall efficacy of the ETS in reducing GHG emissions.

There are several efficacy studies on ETS itself. Zhao et al. (2017), Cludius et al. (2019), and Pan et al. (2020) stand out among these studies. Each study follows a different approach. For example, Zhao et al. (2017) focus on four representative cities in China and evaluate the ETS efficacy using a fair game model. Their results point out a weaker efficacy during the early stages, which gets stronger in time. They suggest policies that can help strengthen the system. Cludius et al. (2019), on the other hand, assess the EU – ETS considering the cost efficiency of the mechanism; the authors measure the efficacy of the mechanism using ex-post efficiency estimation methods. After testing different policy options, they concluded that the business–as–usual scenario is more efficient than the alternatives they considered. Pan et al. (2020) construct a system dynamics simulation model focusing on China's Guangdong Province. They analyze the efficacy of the ETS mechanism in China and make projections. They propose various improvements to the ETS to achieve a higher reduction in emissions, lower energy usage, and less harm to the economy. Zhang et al. (2019), Zhang et al. (2020a), and Zhang et al. (2020b) also examine the Chinese ETS but with different coverage or methodologies. Zhang et al. (2019) use difference in differences methods to analyze the economic efficiency of the ETS in China and measure the emission reduction effects and development mechanisms. The authors underline that the ETS achieves a meaningful reduction in GHG emissions while also being economically efficient. Employing the same methodology but utilizing regional data from 30 provinces, Zhang et al. (2020a) test the system's efficacy on the economy and the environment. The conclusion is that the mechanism achieves significant emissions reduction and economic efficiency. The other Zhang (2020b) study divides the ETS mechanism in China into three different periods. They investigate the efficacy of eight different carbon markets using robust variance ratio test methods. Results indicate that the ETS starts with high market volatility, and the volatility becomes moderate over time. All three studies on the efficacy of Chinese ETS suggest policies to improve the carbon reduction potential of the ETS mechanism. This suggests that there is room for improving the effectiveness of the ETS application. These studies do not explicitly check the role of the energy and carbon rebound effects.

Studies combining ETS efficacy and rebound effects make up a rapidly growing line in the literature (Ciarreta et al., 2017; Meyer et al., 2018; Flaschland et al., 2020; Tang et al., 2020; Colmer et al., 2020). Ciarreta et al. (2017) employ a game-theoretical model to compare the feed-in tariff mechanism to green certificates using panel data. They conclude that green certificates would rebound less compared to the feed-in tariff mechanism. Meyer et al. (2018) developed an input-output model to define and express the rebound effects of efficiency improvements on regional and worldwide energy consumption. They suggest various policy implications such as ETS to tackle the rebound effects. Flaschland et al. (2020) focus on the rebound effects caused by the interactions of EU - ETS with other policies in the region. They suggest a price floor to avoid possible rebound effects, drawing attention to the efficacy of the Market Stability Reserve. Tang et al. (2020) consider the 273 cities in China for the pilot ETS application using panel data and difference in differences method. They suggest a transition from regional to national ETS as the mechanism seems to be successful, underlining that this transition might also help reduce the rebound effects arising from technological progress and energy improvements. Colmer et al. (2020) discuss the possibility of carbon leakage by the manufacturing companies in France using the difference in differences method. Their results show that EU - ETS helped mitigate climate change. They argue that EU - ETS did not cause any leakage, but these results do not guarantee the overall efficacy of ETS as the study focuses only on the manufacturing industry. On the other hand, the study of Koch and Mama (2019) reports a limited carbon leakage in Germany. The EU is recently considering to implement carbon border adjustment mechanisms as an alternative to free allowances to prevent carbon leakage.

The theory behind ETS seems to be clear, yet it gets tricky to prove its effectiveness using empirical work. Some scholars took the challenge and contributed to the literature by proving that ETS has positive effects such as Klemetsen et al. (2020), who provide weak evidence that there is a carbon reduction coming with the EU – ETS, and Colmer et al. (2019) underlining that regulated firms are reducing more compared to unregulated ones as explained earlier in this section. The studies such as the one conducted by Löschel et al. (2019), indicating a positive impact of ETS on German manufacturing firms, and Marin et al. (2018), highlight a positive impact of ETS on a variety of firm-level indicators for a large sample of European firms, also support these findings. Not only the studies on the EU – ETS, but studies on other regions also report positive feedback; Yang et al. (2020) reveal that the Chinese ETS did more than reduce emissions by improving employment on the side, Kim and Bae (2022) also report that ETS resulted in the manufacturing firms in Korea to improve energy efficiency practices in addition to firms generating electricity transitioning from fossil fuels to clean energy sources.

There are studies, on the other hand, failing to find that ETS reduces carbon emissions. Calel (2020), for example, shows that despite improving economic performance, the EU – ETS did not provide emissions reductions in the UK firms, and he adds that there is a promising positive impact on low carbon patenting as well as research and development expenditures. Chen et al. (2021) reveal that the ETS in China did not work as expected when regional rebound effects are considered.

Reviewing the ETS literature reveals that there are three main problems with ETS applications; leakage (Baranzini et al., 2017), bubbles (Creti and Joets, 2017), and backlash (Pahle et al., 2022). Industrial producers tend to move their carbon-intensive activities outside of the ETS region to avoid extra carbon prices they are asked the pay, and this phenomenon is called leakage. The term bubbles, on the other hand, points to the highly volatile price per unit of carbon, resulting in an increased risk premium for transitioning to low-carbon technologies by causing uncertainty. Some applications implemented by the decision makers get negative feedback from the stakeholders within those industries and within the region, or they just turn out to be inefficient after being implemented; when these applications are softened or razed due to negative feedback or inefficiency, it is called backlash.

The macroeconomic carbon rebound effect for ETS, on the other hand, is not explicitly modeled or estimated in empirical work. To choose or develop an appropriate approach for this purpose, the applied studies are reviewed next.

2.2 Rebound Effect

The inefficiencies caused by a variety of reasons for the ETS may be due to the "Rebound Effect" of ETS as a carbon pricing instrument. Rebound Effect (Jevons Paradox or Backfire Effect) can be defined as a reduction in the expected gains from new technologies that increase energy efficiency, due to behavioral or other systematic responses, and it is usually expressed as a ratio of the lost benefit compared to the expected environmental benefit while holding consumption constant (Brookes, 1979; Khazzoom, 1980; Grubb, 1990). While there are various definitions, usages, and explanations for the rebound effect (Peters et al., 2012; Turner, 2013), it can be divided into four categories; direct rebound, indirect rebound, economy-wide rebound, and macroeconomic rebound (Greening et al., 2000).

Direct rebound occurs when the energy consumption of the energy service increases due to improved energy efficiency; increasing energy efficiency simply decreases the price per unit of energy, which increases the energy usage per capita, which is called the direct rebound effect (Chitnis et al., 2013). Indirect rebound occurs when other goods and services are affected by the energy efficiency improvements; in other words, when consumers spend the money they save from energy efficiency improvements on other goods and services (Ghosh and Blackhurst, 2014). Economy-wide rebound occurs when prices, demand quantities, and production are affected by energy improvements (Freire – Gonzalez, 2017; Herring and Roy, 2012) and it includes both direct and indirect rebound (Peters et al., 2012). The combination of economy-wide rebound and indirect rebound is called the macroeconomic rebound effect (Barker et al., 2009); while providing macroeconomic growth, energy efficiency improvements can also increase the energy consumption led by this growth, hence a mix of economy-wide and indirect rebound (Zhang and Lawell, 2017).

Measuring the rebound effect of different policy implications, energy efficiency improvements or technology advancements has become a vital activity for policymakers since it improves forecast accuracy and provides a means for the correct assessment of policy and technology performance in mitigating climate change; therefore, it is important to measure the rebound effect for carbon pricing and ETS. There are various examples in the literature regarding rebound effect studies. The rebound effect studies can be classified according to the use or production of energy-efficient products, methodologies employed, or regions and policies employed. This summary classifies the rebound effect literature based on the methodologies employed to make it more straightforward why a specific method is chosen for the study and to find out the most appropriate method for estimating the rebound effect of emission trading systems. To the extent of our knowledge, no other studies are considering, let alone measuring the rebound effect of an ETS; hence, the choice of methodology for this pioneering study is important.

2.2.1 Statistical Methods

Statistical methods are tools that are applicable in almost every field of scientific study, including economic studies, and therefore rebound effect. From simple statistical methods such as the usage of descriptive statistics (used to identify a series of data), to more complex methods such as discriminant analysis (used for forming groups by choices of individuals).

The study conducted by Pakusch et al. (2018), a technology-based rebound effect study, is a good example of using statistical methods for analyzing the rebound effect; the study focuses on the rebound effect of autonomous driving. Using discriminant analysis by categorizing the 302 volunteer participants by their ages, education, and gender; the researchers found out that autonomous driving might drive people away from public transport, and increase private ownership and car sharing, which will increase GHG emissions.

Bieser et al. (2018) have focused on the rebound effects of information and communication technologies in their study to find out that virtual goods, shared platforms and smart technologies all come with their rebound effects. Using various methods including descriptive statistics, they have concluded that more empirical studies are needed for clearer results. The same study also includes different methods such as life cycle assessment (a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling), basic regressions and system dynamics (an approach to understanding the nonlinear behavior of complex systems over time using stock flows, internal feedback loops, table functions, and time delays).

2.2.2 Economic Modeling Methods

Economic modeling is one of the powerful tools to analyze economic processes using a set of variables and logical quantitative relationships between them. Input/Output (I-O) analysis, computational general equilibrium (CGE) modeling and stochastic frontier analysis are some of the widely used economic modeling and analysis methods.

Bach et al. (2002) combined a multi-sector econometric simulation and forecast model named PANTHA RHEI, which includes 58 production sectors in accordance with the input-output system within the country, with a general CGE model named LEAN to analyze the environmental fiscal reform in Germany. The authors concluded that the German fiscal reform to reduce CO2 emissions is effective, and it has no substantial adverse effect on economic growth.

The study by Anson and Turner (2009) reveals the rebound effect of energy supply and demand on the Scottish transport sector. Using a CGE model, the authors calculated the economy-wide rebound effect to be 36.4% in the short run and 39.2% in the long run, for the total refined oil for an energy efficiency improvement of 5%.

Yu, Moreno-Cruz and Crittenden (2015) investigated and compared the economy-wide rebound effect of a variety of different sectors they named epicenters in Georgia, USA, to find out that; production sectors, energy production sectors, transport sectors, and sectors with high production elasticities are expected to suffer from large rebound effects when an energy efficiency improvement is introduced. The authors have used a CGE model with two different scenarios, a uniform energy efficiency improvement in all sectors and an epicenter-based energy efficiency improvement, to conduct numerical analysis.

Categorizing the rocks and minerals, chemicals, ceramics, steel, nonferrous metals, and secondary raw materials in accordance with their final demands, consumption, and investment in these sectors; Pfaff and Sartorius (2015) have conducted an I-O analysis to analyze the economy-wide rebound effects for non-energetic raw materials in Germany. The authors have used the Integrated Sustainability Assessment System (ISIS), that is developed by Walz et al. (2001) at Fraunhofer Institute for Systems and Innovation Research, and the 2007 revision data from the German Federal Statistical Office (Destatis) with 71 production sectors. While the average rebound effect was calculated as 3.8% for final demand, consumption, and investment; it was calculated to vary between 2.5 – 10.5% for different sectors.

Using a modified input – output (I-O) analysis, Li and Jiang (2016) calculated the economy-wide rebound effect of subsidies in China between the years 2007 – 2010. Using data from the National Bureau of Statistics (NBS) in China, the authors integrated the 42 sectors given by NBS into 28 sectors to find out the aggregated rebound effect of energy subsidies to be 1.9% during the given period. Having stated that the removal of subsidies will decrease the energy consumption, hence the rebound would decrease to 1.53%, the authors suggest new policies such as limiting coal usage, cooperation between energy saving technology improvements and energy price reforms, and an urgent development for energy saving technologies on specific sectors such as transport or mining.

Focusing on the Norwegian Economy, Bye, Faehn, and Rosnes (2017) have used a multi-sector CGE model to calculate the economy-wide rebound effects of Norway's 2030 residential energy efficiency goals. Using the data taken from Global Trade Analysis Project (GTAP) for 41 production sectors, households, and cross-border trade interactions, the authors analyzed 5 production sectors for 18 final goods. Calculating a possible rebound effect of 40%, they also showed that introducing energy efficiency policies increase CO_2 emissions, and introducing carbon pricing simultaneously only irritates the problem.

Lu, Liu, and Zhou (2017) calculated the economy-wide rebound effect in China for 135 different production sectors and 5 different energy sources. Using a static CGE model and imposing a 5% energy improvement in each of the energy sources; the authors analyzed coal, crude oil, and gas, electricity and steam supply, refined petroleum, and gas supply to find out that energy efficiency improvements in these sources might cause a negative rebound in the short term. Long-term effects, on the other hand, are suggested by the authors to be further analyzed.

Wu et al. (2018) conducted a quasi – dynamic I-O analysis to investigate the changes in water use among different sectors in Zhangye city of China, between the years 2002 and 2012. Using the data from the National Bureau of Statistics of China, Zhangye Statistics Yearbooks, Statistics Bureau of Gansu, and Zhangye Water Works Authority; the authors have observed that while the water-saving technologies have reduced agricultural water usage between 2002 and 2007, they have also induced a rebound to total water use between the years 2007 and 2012.

One study on the direct rebound effect of Swedish Heavy Industry, using the panel data between 2000 – 2008, is a good example of economic modeling analysis (Amjadi et al. 2018); they have used stochastic frontier analysis to find out whether using energy efficiency policies alone may result in rebound effects so they should be supported with complementary policies such as emission caps or taxes.

Bjelle et al. (2018) studied Norwegian households to evaluate 34 behavioral actions in 48 different regions and with 200 products using 2007 as the base year and I-O modeling. They have found out that the expected 58% reduction in carbon footprint declines to 24 – 35% when rebound effects are considered when total expenditure is assumed to be constant.

The rebound effect of smartphone reuse was investigated for the first time by Font Vivanco et al. (2018), and the researchers focused on two main aspects; imperfect substitution between the recycled and new products, and re-spending due to economic savings. Focusing on four iPhone models; they have taken the greenhouse gas (GHG) emission and product price data from the official Apple web page, the data regarding the GHG emissions caused by resale transportation is taken from EXIOBASE 3 and resale price data was taken from eBay. Using the data, researchers have conducted an environmentally extended input-output analysis to quantify the magnitude of the rebound effect for life cycle GHG emissions. The environmental rebound effect was found to be 29% on average, varying between 27% and 46% between the specific models, meaning that it could reset almost half of the benefits of smartphone reuse. The re-spending causing the rebound effect was usually done on purchases of food, nondurable goods, and transportation services, causing almost an offset of the benefits of reuse. The average effect of imperfect substitution seems to be a small 4% when all models are considered, even though there is a dramatic difference between specific models. Overall, the first of its kind study shows that there is a 30% decrease in the benefits of smartphone reuse when environmental rebound effects are considered, and this can go up to 100% in some cases; the authors suggest the internalization of externalities on the prices of the products via methods such as carbon tax, and greener designs of these products.

Zhou et al. (2018) have developed a two-stage decomposition method and equipped a CGE model to analyze the economy-wide rebound effect of 135 different production sectors in China. Using the data from the 2007 Input Output Table of China and compiling it with the National Bureau of Statistics of China, the authors have concluded that improving the efficiency of coal technologies would have the smallest rebound with 22% while improving gas supply has the largest rebound with 51.5%. Moreover, they have observed that energy-producing sectors are the major rebound contributors, and the substitution effect is the main dominant mechanism for a rebound at the sector level in the short run. Finally, the authors make the following policy suggestions; improving energy efficiency technologies, especially coal if decreasing the rebound is aimed, targeting the consumers of efficiency-exposed energy sources to implement mitigation measures, and taking precautions to prevent inter-fuel substitutability to increase the efficiency of energy efficiency policies, paying attention to the rebound that is induced by the household consumption and designing the energy efficiency policies accordingly.

Duarte et al. (2018) calibrated their dynamic CGE model using the Spanish I-O framework for three different scenarios using data for the period from 2005 to 2015, and extended the model for the period between 2005 and 2030, to investigate the rebound effect arising from Spain's measures taken towards a low carbon economy. Disaggregating energy in 34 economic activities into four sectors, the authors evaluate improvements in the electricity sector, improvements in the transportation sector, and a combination of the first two scenarios. Results show that the economy-wide rebound effect of electricity is 70.52%, fuel use is 51.01%, and the combination of electricity and fuel use is 55.85%, indicating that more than 50% offset direct reductions. The authors finally suggest that rebound effects must be taken into consideration while implementing environmental policies, that renewables should be promoted as rebound effects come from additional usage of energy due to savings coming from energy efficiency technologies, and that a continuous and softer environmental policy is more preferable compared to a short term radical one.

Somuncu and Hannum (2019) constructed two energy-economy CGE models, one incorporating and one not incorporating the energy theft, to evaluate the role energy theft plays in determining the rebound effect size in developing countries using regulation in Türkiye that compensates the energy theft in the country. Constructing two socially accounting matrices (SAMs) based on Türkiye's I-O table from World I-O Database, the authors have aggregated five industry categories in their first model, while the SAM is expanded to nine industries by including informal categories in their second model to reflect a more realistic overview of the situation. Results show that energy theft results in a smaller direct rebound as efficiency gains will go unnoticed by the users but cost recovery mechanisms regarding energy theft might have indirect effects on energy use, resulting in a larger rebound than the direct effects. Since energy efficiency policies in the service sector in Türkiye disproportionately affect legal energy sales, a uniform surcharge of energy theft recovery costs associated with the policy results in a negative rebound.

The study on Iran's energy-efficient household lighting by Barkhordar (2019) evaluates the government's suggestion of free-of-charge LED lamps for households to reduce household electricity demand. Using the dynamic CGE model GREMI, which was developed and defined by Barkhordar and Saboohi (2013), the author constructed two scenarios to evaluate the economy-wide rebound effect within the country; the comparison between the business-as-usual scenario and efficiency enhancement scenario gives a 31.7% percent rebound for the potential electricity savings from lighting, and an average rebound of 43.8% when the economy-wide effects are considered. Yet, despite the rebound effects calculated, the program seems to be profitable and expenses arising from the avoidance of energy subsidies can be covered within two years; moreover, the program seems to be able to decrease energy consumption and lower the energy production cost.

Another CGE approach was made by Peng et al. (2019) to the energy excise taxes implemented in Jiangsu province of China. Constructing an open model with three types of consumers added to the rest of the world, the authors disaggregated 42 different sectors in Jiangsu into 52 energy-related and 6 non-energy sectors, including renewable energy. The results show that GDP losses are 0.27%, 0.66%, and 1.13% for tax levels of 5%, 10%, and 15%, respectively; using the tax revenue for compensation of the consumers' losses would result in a double dividend effect where energy is saved and income is increased. On the other hand, simulation results showed that a 5% increase in energy efficiency would result in a 142% increase in energy consumption, indicating a vast amount of rebound effect, and the authors suggest levying an energy excise tax on energy efficient technologies, with the consideration of fairness and correct tax level, to offset the rebound effect.

2.2.3 Time Series or Panel Data Methods

Panel data can be defined as a multidimensional data set, whereas time series can be defined as a series of data points indexed in time order. There is a large number of methods using time series or panel data for numerous analytical purposes; vector autoregression (VAR) functions, cointegration methods, vector error correction models (VECM), autoregressive moving average (ARMA), autoregressive integrated moving average (ARIMA) are namely some of many of these methods.

Meyer, Distelkamp and Ingo (2007) used PANTHA RHEI, an environmental macro econometric model proposed by the authors themselves, to calculate the economy-wide rebound effect of climate policies in Germany. Using the data between the years

1991 – 2000 that is taken from Wuppertal Institute, the authors generated 3481 input coefficients for 59 different production sectors, to conclude that the strong rebound effect arising from the country's policies and the country is far from reaching the 2020 reduction targets. The study was repeated by Meyer, Meyer, and Distelkamp (2012) using the data between 1995 – 2004 and the same methodology to come up with similar results.

In a study conducted in Türkiye, Topallı and Buluş (2012) focus on the residential buildings to calculate the energy efficiency rebound effect using the time series data for Türkiye between the years 1964 – 2009. Including residential energy consumption, residential real electricity price index, real gross domestic product (GDP), and the population to their ARDL regression; the authors find out the rebound effect to be 18%.

Using two-stage dynamic panel data for energy price index between 1980 – 2010 with stochastic frontier analysis for 55 countries, Adetutu, Glass, and Weyman-Jones (2015) calculated the economy-wide rebound effect of possible energy efficiency improvements in these countries, focusing on magnitude and model. Employing real GDP, capital stock, labor, and total energy consumption and using material extraction as variables; they acquired the necessary data from different sources such as IEA, Sustainable Europe Research Institute, World Development Indicators, UNDP, and Penn World Tables. Having concluded that an energy efficiency improvement of 100% would result in a 90% rebound in the short run, the authors underline that the long-term results will show a 36% decrease in energy consumption.

Fan, Luo, and Zhang (2016) have worked on the Spatio-temporal heterogeneity and economy-wide rebound effect in China, using the data between 1995 – 2011. Applying the Geographically and Temporally Weighted Regression Model for five driving factors of the evolutionary model of the energy intensity, the authors calculated the rebound effect at both national and provincial levels, as well as considering the higher energy efficiency improvement rate after the year 2000. Using GDP, Foreign Direct Investment, energy price, energy purchasing price index, and the proportion of total imports to exports in GDP in their analysis, the authors have acquired the data from China's Statistical Yearbook and China Economic Information Net Statistics Database. They have calculated the rebound effect to be 16.48% before 2000, 29.04% after 2000, and 25.39% on average.

The game theoretical approach of Ciarreta et al. (2017) comparing feed-in tariffs to green certificates with hourly data between 2008 – 2013 is another good and relative example examining carbon pricing policies and rebound effects. Their theoretical model indicates that had it been implemented after 2009, a TGC system would have a lower cost of incentives compared to a feed-in tariff scheme. Moreover, they compare how a TGC system reacts to market activities with their model, contrary to a feed-in tariff scheme where the system does not react to any market activities, to conclude that the incentives should be changing according to market dynamics and should be supported with other market mechanisms.

Fukui et al. (2017) study on the rebound effect of aviation fuels and emissions taxes on the US airlines industry, where they used the panel data between 1995 – 2003, is another example; by regressing jet fuel consumption rate on the tax rate, control variables, time effects, and unobserved time constant factors they found out that jet fuel consumptions are negatively elastic for taxes both in the short and long run. However, they also underlined that the rebound effects may offset the jet fuel reductions in the long run from 0.14% to 0.008%.

Using panel data between 2003 and 2013 for 14 cities, Ouyang et al. (2018) estimated the rebound effect magnitude in Yangtze River Delta Urban Agglomeration. Applying dynamic ordinary least squares (DOLS) and seemingly unrelated regression (SUR) methods to the empirical data collected from the China Statistical Yearbook, China Urban Life and Price Yearbook, and the price yearbooks of the 14 cities; the authors concluded the direct rebound effect to be 40.04%, in addition to a

70.49% price elasticity between labor and energy. Finally, looking at the results, the authors suggested that the government should increase support for special funds for renewable and new energy technologies, to achieve clean energy breakthroughs.

Chen et al. (2018) have worked on the manufacturing industry of China using trans-log cost function; by applying Dynamic Ordinary Least Squares (DOLS) and Seemingly Unrelated Regression (SUR), the researchers built up a model to calculate the direct rebound effect as 44.2% from the year 1991 to 2013. They obtained the data from CEIC Database, China Statistical Yearbook, China Energy Statistical Yearbook, and BP Energy Statistical Yearbook; the researchers then transferred the price indexes of the four factors (capital, labor, energy, and intermediate input) to the 1978 year base to be able to obtain and compare their proportions in the total production costs. The researchers suggest the following policy implications in the end; energy prices should reflect the externalities so that they are not underestimated and less market-oriented, the Chinese manufacturing industry should change its traditional development strategies so that the companies consume less energy, and finally it is suggested that the Chinese government implements a carbon tax or an emission trading system to control and decrease energy consumption.

Another example of employing the trans-log cost function can be seen in the study of Wang et al. (2018) where the authors study the iron and steel industry of China to unveil the relationship between technical progress and the rebound effect. Using the panel data taken from the CEIC Database, China Statistical Yearbook, and China Energy Statistical Yearbook for the years 1985-2015 and converting all the prices into 1985 level, the authors built up a three-input trans-log cost function to analyze the effect of technical progress. They have observed negative price elasticities for the input factors, substitute relationships between energy and capital as well as energy and labor, and an average energy rebound of 73.88% for China's iron and steel industry with a downward trend until the eleventh five-year period with an increase after. Finally, the authors make a variety of policy suggestions to deal with this rebound such as; working on faster improvement of the energy saving technologies, reducing the energy price regulation to increase the prices of fossil fuels so that the energy consumption is decreased, implementing fossil energy and subsidy reforms to cut down the energy subsidies, and promoting clean energy policies that aim to substitute capital and labor to energy input.

The study by Belaid et al. (2018) on French residential gas demand is a good example of rebound effect analysis using time series. Using the annual time series data between 1983 – 2015, Belaid and coworkers conducted their analysis with standard OLS and ARDL regression and using the key assumption of household reactions to energy efficiency being the same as reactions to changes in prices. They have regressed the natural gas consumption on price, income, population, and the heating degree to find out that there is a 60% short-run and 63% long-run rebound effect with 40% realized energy efficiency.

The study of (Schusser et al. 2018) comparing EU – ETS to Swedish – Norwegian Tradable Green Certificates (TGC) System using the panel data between 2005 – 2015 with a multivariate VAR approach is a very close example of what this study aims; because the study empirically examines the interplay between three markets (EU – ETS, Norwegian TGC and electricity price in the Nord Pool) and questions whether they affect each other negatively. The authors found out that an increase in carbon prices positively affects TGC prices in the short run. They used the Nord Pool, ICE Futures Europe, and SKM as their data sources. They conclude that, in contrast to the common opinion, EU – ETS and Swedish – Norwegian TGC systems do not affect each other negatively in the short run; however, if both systems keep existing for the next ten years, the authors suggest long-term interactions should be studied in the future. Finally, the recommended new theoretical studies are trying to integrate the actual market features for carbon emissions and green certificates.

Li and Zhao (2018) have conducted a joint estimation analysis on the rebound effect of new irrigation technologies in Kansas, USA. Using panel data taken from USDA Natural Resources, Kansas Water Office Conservation Service, and NASA between

1991 and 2010, the authors have developed a joint model for water use and water rights preservation using the wells as units of analysis. They have concluded that new technologies such as low energy precise applications (LEPA) cause undesired rebound effects, and these effects can be diminished by decreasing farmers' water rights; a decrease of 10% in the water rights results in a decrease of 5% water use on the average in the long run while cutting off all the water rights results in a decrease of 15.4% in the rebound effect caused by LEPA.

Su (2019) has analyzed Taiwan's residential electricity demand using right skewed regression models using survey data of 7677 households between the years 2013 – 2017. Appliance-specific electricity usage covering air conditioner, lighting, television, and the refrigerator was analyzed as well as household usage; to obtain the rebound effect, appliances with and without energy efficiency labels were also studied. Collecting the data on house type, energy expenditure, appliance size, appliance specific usage times in and out of summer via the survey; the author employed 30 variables and regressed them on electricity consumption, choosing electricity consumption as the dependent variable. The author found out that appliances with energy efficiency labels had less electricity consumption compared to appliances without energy efficiency labels, however actual electricity savings were not close to the expected savings, showing a rebound effect; the rebound effect was found to be 72% for air conditioners, 70% for refrigerators, 11% for lighting and 3% for television usage. Moreover, the rebound effect was found to be caused by the change in consumer behavior due to the savings coming from energy efficiency appliances; extending the air conditioner usage time, lowering the temperature of the air conditioner during summer, and replacing the current refrigerator with a larger one are some of the reasons causing the rebound effect, which was found to be 33% overall in Taiwan's residential sector.

Borozan (2019) investigated the effects of energy taxes on residential final energy consumption across different levels within the European Union. The author has used the panel data taken from Eurostat from 2005 to 2016 to build up quantile panel regression models and analyze the direct and indirect effect of energy taxes as well as other explanatory variables. Results reveal that EU countries with higher GDP consume more energy, there is a higher rebound in these countries as a result of energy taxes, there exists an Environmental Kuznets Curve for the less energy-consuming (or lower GDP) countries, and the residential final energy consumption is inelastic for energy price in the short run. The author finally suggests the implementation of different energy policy programs for different energy-consuming groups of countries, empowerment of economic growth and development for less energy-consuming countries while ensuring greener energy usage during this development, recycling of fiscal gains coming from energy taxes in a more environmental way and creating an efficient network of clean energy technologies where the know-how is improved and shared among the countries.

2.3 Market – Based Instruments and Rebound Effect

The literature reveals a variety of studies analyzing and comparing different carbon pricing instruments using different methods. Yet, it can also be seen that there are not too many studies in this field, as the area and the applications are relatively new.

Giljum et al. (2008) have modeled three different scenarios to investigate methods for more sustainable use of natural resources in Europe. By extending a global energy efficiency modeling method, the authors compared a base scenario without additional policy intervention to two different sustainability scenarios where interventions such as CO_2 emissions and transport taxing, measures to increase metal recycling, and a consulting program to raise material productivity of industrial production. Using time series data for 188 countries over the period between 1980 – 2002, the authors grouped the 200 different extracted material categories into six groups for 56 countries, namely biomass, coal, crude oil, natural gas, metal ores, and industrial and construction minerals. The results show that contrary to the common view, environmental policy measures might not increase the costs for enterprises and reduce economic performance. In addition, the paper says that focusing on increasing material and energy efficiency in the production sphere does not necessarily lead to a reduction in emissions on the macro level; there might be rebound effects causing increases in production growth, which in turn overcompensates the savings coming from efficiency studies. The authors, therefore, suggest extra measures taken such as the input of a carbon tax, material input tax, or other fiscal interventions.

Meyer et al. (2018) used an environmentally extended multi-regional I-O model, encompassing 35 industries for 59 products in 38 national economies to analyze how current policies and efficiency improvements are performing in terms of decoupling tendencies in global and regional energy consumption. The authors conclude that there will be a need for financial aid in the corresponding sectors to achieve the aimed efficiency improvements as they cannot be achieved without consultancy, which results in an increase in prices in return, and therefore extra policy supports such as subsidies to the enterprises or taxation of material use is a must to achieve the targeted emissions reductions. The authors underline the fact that while policy implications such as emissions trading systems combined with energy improvement studies are effective in reducing global and regional emissions, extra policy implications on raw material extraction will be necessary to achieve long-term reduction goals as there are expected rebound effects arising from energy efficiency improvements.

Zapff, Pengg and Weindll(2019) analyzed the weaknesses of carbon pricing and presented possible reduction paths in their paper, and offered a global uniform and cross-sectoral carbon pricing system to meet the 1.5ºC target with an exponential or logistic decrease. The authors show that a tax on emission trading is more preferable than a tax on the price itself, as the volume cap of an ETS will prevent possible rebound effects from leading to emissions increases, via the comparison of marginal abatement costs and Weitzman's Rule (Weitzman (1974); Nordhaus (2007)). Moreover, they suggest that a system with a combination of price and quantity control will be more effective, saying that a cap-and-trade system with a price ceiling will be a good approach for meeting the UNFCCC and Paris Agreement targets with current technological capabilities. Finally, the authors suggest that free allocation of permits using grandfathering should be abandoned as it was proven to be ineffective at EU – ETS and they suggest further analysis on issues such as structuring a global ETS, possible solutions to carbon leakage, and green paradox, which is defined as the acceleration of climate change due to expected future reduction in carbon consumption (Sinn, 2015).

Flaschland et al. (2020) debated the need for a price floor for the EU – ETS to prevent the main issues of the system such as credibility due to the political nature of allowance supply, market myopia, waterbed, and rebound effects arising from policy interactions. These issues had been defined by Edenhofer et al. (2019) in their policy paper. Market myopia was defined as the lack of long-term regard of market participants, resulting in ETS prices being determined with short-term considerations instead of long-term. The waterbed effect is defined as the rebound effect arising from the interaction of EU – ETS with other policy implications; reduced allowance demand will result in lower prices in the allowances, which will lead to an increase in emissions at other facilities. In both articles, the authors argue that implementing an EU – ETS price floor would enhance political and economic stability by presenting a more stable allowance price, in addition to showing that it is legally feasible and already being used by Market Stability Reserve (MSR) as well as some European countries such as The Netherlands, Germany, and France.

Tang and coworkers (2020) have conducted an empirical analysis on China's pilot carbon trading markets, the first ETS in developing economies, to observe the changes in city-based emissions. The research was done on 273 prefecture-level cities in the country between the years 2010 – 2016, using a combination of statistical methods propensity score matching (PSM), and difference in differences (DiD), on the panel data collected from China Statistical Yearbook, China Energy Statistical Yearbook, China Urban Statistical Yearbook, and China Electric Power Yearbook.

Results show that the ETS applications reduced the carbon intensity, and the authors suggest a transition from regional to national ETS. Moreover, the article suggests regulating the highly carbon-intensive sectors while supporting the development of tertiary low-carbon industries. Finally, it is argued that these policy implications could aid in controlling the rebound effects caused by technological advancements and energy improvements.

Jarke – Neuert and Perino (2020) demonstrate that energy savings coming from efficiency improvements are less than technically feasible by using an analytical general equilibrium model. They are distinguishing the conventional energy rebound from carbon rebound by defining the former as a result of the energy-intensive electricity sector and the latter as a result of other activities; basing this distinction on the fact that an ETS is applied only to the electricity sector, the authors underline the fact that it is much harder to calculate the carbon rebound compared to the energy rebound. The paper concludes a 100% direct carbon rebound is added with an unambiguously positive indirect rebound when such a distinction is considered. The authors finalize their paper by suggesting a carbon tax that can be defined as a lump – sum or an income tax for the producers, instead of a cap-and-trade system, as it can be more effective in combatting the rebound effects defined in the article. The suggestion was based on the implementation of MSR within the EU – ETS, as the authors define the operation as an application close to taxation.

Colmer et al. (2020) released a discussion paper focused on the effects of EU – ETS on French manufacturing firms between the years 2001 – 2012. Having collected the data from a variety of resources such as the Annual Survey of Industrial Energy Consumption (EACEI), French National Institute of Statistics and Economics Studies (INSEE), French Ministry of Economy and Finance, and French Customs; the authors applied the European Commission's approach to calculating the carbon intensity of each sector, using a fixed price of €30/tCO_2 and divided the total price to the gross value of each sector. Using the difference in differences (DiD), a statistical technique used in econometrics by comparing the average changes in a treatment group with a control group, the authors conclude that there was no carbon leakage; meaning that the EU – ETS helped mitigate global climate change, adding that these results should not be taken granted to promote only using market – based instruments for regulation. The lack of suitable data to analyze whether the costs of reducing emissions have resulted in a reduction in the profits, or the producers managed to pass these costs on to the customers in the form of higher product prices, does not allow for a proper conclusion on the issue. The authors finish their paper by saying that their results do not guarantee the efficient operation of EU – ETS as they have not analyzed factors such as credit constraints, transaction costs, and possible sources of market failure.

The literature review conducted for this study reveals that while studies are comparing and analyzing the policies and carbon pricing instruments using certain methods, there is a lack of studies focusing on the analysis of these carbon pricing instruments with macroeconomic rebound effects arising from these instruments in the center. The literature is rich in examining market-based instruments, evaluating the ETS efficiencies from different perspectives, as well as considering energy rebound effects in different sectors, regions, technologies, and behaviors. However, in the end, the key element for meeting ambitious net zero targets is the overall emissions. The empirical studies mostly focus on sectors, rather than the whole picture of macroeconomics. The ETS encourages energy efficiency, yes, but the positive impact of ETS on the economic performance of the firms and industries also imposes a macroeconomic energy rebound effect, resulting in a carbon rebound effect. This macroeconomic carbon rebound effect, and its scale if it exists, can be crucial to the efforts to achieve the net zero goals. The energy and carbon rebound effects depend on energy intensity and energy mix, respectively. With the fact that ETS is the main climate change mitigation tool that countries rely on, this study will bring a unique contribution to the literature by analyzing the market – based carbon pricing instruments from a rebound effect perspective; asking the questions of whether such rebound effects exist, and if so, how they can be measured.

CHAPTER 3

METHODOLOGY AND DATA

Econometric analysis was conducted within the panel data framework to examine the macroeconomic carbon rebound effect of the EU - ETS. Specifically, the panel regression constructed in this study is based on a growth specification of CO2 emissions, defined as

$$\Delta lnEMI_{it} = \alpha_i + \beta_1 \Delta lnGDP_{it} + \beta_2 \Delta lnLAB_{it} + \beta_3 \Delta lnFCF_{it} + \beta_4 \Delta lnALL_{it} + \beta_5 \Delta lnINT_{it} + \varepsilon_{it} \quad (1)$$

where EMI is CO2 emissions, GDP is the gross domestic product, LAB is labor, FCF is fixed capital formation, ALL is emissions allowances, and INT is energy intensity, i=1,…, N denotes the cross-sectional dimension, t=1,…, T denotes the time dimension, α_i are individual fixed effects, and ε_{it} is the error term. As it is clear from using the log-differenced form (Δln where Δ and ln denote the first difference and natural logarithm operators, respectively), all the variables are employed in growth rates.

The unobservable fixed effects in panel data estimations and related disturbances are mostly eliminated by employing the error component model (Baltagi, 2013). When dealing with a panel data that is comprising a specific set of N individuals, European countries in the case of this study, estimating model (1) via an appropriate fixed-effect model is usual as pooled OLS ignores the unobservable fixed effects in estimations. While a random-effects model was also introduced just for comparison, the fixed-effect model was chosen as Baltagi (2013) suggests employing an error component model with fixed effects when handling a constant set of individuals within the panel data framework. Increasing N for a fixed T results in inconsistent estimations and invalid statistical inference due to Nickell bias (Nickell, 1981), leading to a possible correlation between the regressors and regression errors, known as endogeneity problem; therefore, there is a chance that the panel data model defined in equation (1) might face such problems. The usage of generalized method of moments (GMM) estimators, and the system GMM approach suggested by Blundell and Bond (1998), is very common in the empirical literature, when dealing with the Nickell bias.

When dealing with such models, some common factors may influence the cross-sectional units in the panel, once again resulting in the inconsistency and invalid statistical inference problems, and this phenomenon is called cross-sectional dependence. Therefore, the study focuses on estimating the panel data models under cross-sectional dependence. The common factor representation of the regression error can be defined as:

$$\varepsilon_{it} = \lambda_i' F_t + u_{it} \qquad (2)$$

where F_t is a vector of unobserved common factors and λ_i is a vector of factor loadings. The factor representation of equation (1) can be written as:

$$\Delta lnEMI_{it} = \alpha_i + \beta_1 \Delta lnGDP_{it} + \beta_2 \Delta lnLAB_{it} + \beta_3 \Delta lnFCF_{it} + \beta_4 \Delta lnALL_{it} + \beta_5 \Delta lnINT_{it} + \lambda_i' F_t + u_{it} \qquad (3)$$

The above equation is called common correlated effects (CCE) model (Pesaran, 2006) or interactive fixed effects (IFE) model (Bai, 2009). Model (3) was estimated using different estimators, on the basis of the method of estimation of the unobservable common factor F_t. While Bai (2009) applies the method of principal components to the estimated residuals $\hat{\varepsilon}_{it}$ to estimate F_t, Pesaran (2006) takes on the cross-sectional averages of dependent and explanatory variables as common factors. The approach of Bai (2009) includes the usage of fixed-effect estimates as initial values, and introducing a consistent iteration procedure to estimate the common factor as well as the factor loadings.

With the identification of the macroeconomic determinants of CO2 emissions growth, the long-run relationship between the emissions growth and these determinants is settled and the dynamic causality between CO2 emissions, GDP, emissions allowances and energy intensity is further enquired. The causality analysis of this study follows the Granger procedure (Granger, 1969) by employing a panel vector autoregression (VAR) specification of model (1), in order to pinpoint the presence and direction of a possible causality.The panel VAR model can be written as

$$\begin{aligned}\Delta lnEMI_{it} = a_{1i} &+ \sum_{j=1}^{p} \phi_{11j} \Delta lnEMI_{it-j} + \sum_{j=1}^{p} \phi_{12j} \Delta lnGDP_{it-j} \\ &+ \sum_{j=1}^{p} \phi_{13j} \Delta lnLAB_{it-j} + \sum_{j=1}^{p} \phi_{14j} \Delta lnFCF_{it-j} \\ &+ \sum_{j=1}^{p} \phi_{15j} \Delta lnALL_{it-j} + \sum_{j=1}^{p} \phi_{16j} \Delta lnINT_{it-j} + v_{1it} \quad (4.1)\end{aligned}$$

$$\begin{aligned}\Delta lnGDP_{it} = a_{2i} &+ \sum_{j=1}^{p} \phi_{21j} \Delta lnEMI_{it-j} + \sum_{j=1}^{p} \phi_{22j} \Delta lnGDP_{it-j} \\ &+ \sum_{j=1}^{p} \phi_{23j} \Delta lnLAB_{it-j} + \sum_{j=1}^{p} \phi_{24j} \Delta lnFCF_{it-j} \\ &+ \sum_{j=1}^{p} \phi_{25j} \Delta lnALL_{it-j} + \sum_{j=1}^{p} \phi_{26j} \Delta lnINT_{it-j} + v_{2it} \quad (4.2)\end{aligned}$$

$$\Delta lnALL_{it} = a_{3i} + \sum_{j=1}^{p} \phi_{31j}\Delta lnEMI_{it-j} + \sum_{j=1}^{p} \phi_{32j}\Delta lnGDP_{it-j}$$
$$+ \sum_{j=1}^{p} \phi_{33j}\Delta lnLAB_{it-j} + \sum_{j=1}^{p} \phi_{34j}\Delta lnFCF_{it-j}$$
$$+ \sum_{j=1}^{p} \phi_{35j}\Delta lnALL_{it-j} + \sum_{j=1}^{p} \phi_{36j}\Delta lnINT_{it-j} + v_{3it} \quad (4.3)$$

$$\Delta lnINT_{it} = a_{4i} + \sum_{j=1}^{p} \phi_{41j}\Delta lnEMI_{it-j} + \sum_{j=1}^{p} \phi_{42j}\Delta lnGDP_{it-j}$$
$$+ \sum_{j=1}^{p} \phi_{43j}\Delta lnLAB_{it-j} + \sum_{j=1}^{p} \phi_{44j}\Delta lnFCF_{it-j} + \sum_{j=1}^{p} \phi_{45j}\Delta lnALL_{it-j}$$
$$+ \sum_{j=1}^{p} \phi_{46j}\Delta lnINT_{it-j} + v_{4it}. \quad (4.4)$$

The coefficients of the independent variables through equations (4.1) – (4.4) can be exposed to significance tests each, to examine the direction of the causation. The null hypothesis of "No Granger causality from GDP growth ($\Delta lnGDP$) to CO2 emissions growth ($\Delta lnEMI$), for example, is defined as H0: ϕ_{12j} = 0 for all j in equation (4.1) and is tested based on the Wald principle.

Introducing dummy variables into the model helps decide whether the previous years have an effect on the coming years in terms of rebound. The EU – ETS phases are observed to see whether they affect each other depending on the years the data was collected, by employing dummies in the model. Taking Phase 1 as the default phase, dummy variables for Phase 2 (Dum2) and Phase 3 (Dum3) are added to the model. The interaction terms for allowances and dummy variables are calculated as ALLxDum2 and ALLxDum3, to see whether the results are consistent with expectations.

Annual data covering the 2005-2019 period for 26 European countries is collected for this study, and 360 observations from these 26 individual countries in total were modeled. CO_2 emissions (EMI) and emissions allowances (ALL) are measured by millions of tons of CO_2 equivalent ($MtCO_2eq$) and obtained from European Environment Agency. Gross Domestic Product (GDP) is measured as millions of chained 2010 Euros, labor (LAB) is measured by the number of people, and fixed capital formation (FCF) is measured as a percentage share of GDP, which is obtained from the FRED Database. Finally, electricity consumption to construct energy intensity (INT) is measured by terawatt-hours (TWh) and sourced from the International Energy Agency.

CHAPTER 4

RESULTS

The results from pooled OLS, fixed effects model, system GMM, common correlated errors and interactive fixed effect modelare given in Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5, respectively:

. reg dlnemi dlngdp dlnlab lnfcf dlnall dlnint

Source	SS	df	MS
Model	.737203113	5	.147440623
Residual	2.69717815	354	.007619147
Total	3.43438126	359	.009566522

Number of obs	=	360
F(5, 354)	=	19.35
Prob > F	=	0.0000
R-squared	=	0.2147
Adj R-squared	=	0.2036
Root MSE	=	.08729

dlnemi	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
dlngdp	1.270848	.1593437	7.98	0.000	.9574687	1.584227
dlnlab	-.4479532	.2950741	-1.52	0.130	-1.028272	.1323655
lnfcf	-.0418173	.0241745	-1.73	0.085	-.0893609	.0057264
dlnall	.0806963	.0320459	2.52	0.012	.0176721	.1437206
dlnint	1.240968	.1565118	7.93	0.000	.9331577	1.548777
_cons	.102008	.0736176	1.39	0.167	-.0427748	.2467908

Figure 4.1. Pooled OLS Estimation Results

```
. xtreg dlnemi dlngdp dlnlab lnfcf dlnall dlnint, fe

Fixed-effects (within) regression               Number of obs      =       360
Group variable: id                              Number of groups   =        26

R-sq:                                           Obs per group:
     within  = 0.2288                                         min =         12
     between = 0.0001                                         avg =       13.8
     overall = 0.2074                                         max =         14

                                                F(5,329)           =     19.53
corr(u_i, Xb)  = -0.1461                        Prob > F           =    0.0000

------------------------------------------------------------------------------
      dlnemi |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      dlngdp |   1.342432   .1679976     7.99   0.000     1.011947    1.672917
      dlnlab |  -.2773454   .3641394    -0.76   0.447    -.9936807      .43899
       lnfcf |  -.0850676   .0334727    -2.54   0.011    -.1509151   -.0192201
      dlnall |   .0678612   .0327199     2.07   0.039     .0034945    .1322278
      dlnint |   1.289466   .1614729     7.99   0.000     .9718168    1.607116
       _cons |   .2325703   .1019857     2.28   0.023      .031944    .4331965
-------------+----------------------------------------------------------------
     sigma_u |  .02132865
     sigma_e |  .08832622
         rho |  .05509782   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(25, 329) = 0.67                     Prob > F = 0.8862
```
Figure 4.2. Fixed Effects Model Estimation Results

```
. xtabond2 dlnemi dlngdp dlnlab lnfcf dlnall dlnint, gmm(L.dlnemi) iv(dlngdp dlnlab lnfcf dlnall d
> lnint) robust twostep diffsargan
Favoring space over speed. To switch, type or click on mata: mata set matafavor speed, perm.
Warning: Number of instruments may be large relative to number of observations.
Warning: Two-step estimated covariance matrix of moments is singular.
  Using a generalized inverse to calculate optimal weighting matrix for two-step estimation.
  Difference-in-Sargan/Hansen statistics may be negative.

Dynamic panel-data estimation, two-step system GMM
------------------------------------------------------------------------------
Group variable: id                              Number of obs      =       360
Time variable : year                            Number of groups   =        26
Number of instruments = 96                      Obs per group: min =        12
Wald chi2(5)  =    127.80                                      avg =     13.85
Prob > chi2   =     0.000                                      max =        14
------------------------------------------------------------------------------
             |              Corrected
      dlnemi |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      dlngdp |   1.284722   .2463006     5.22   0.000     .8019812    1.767462
      dlnlab |  -.3089237   .2695179    -1.15   0.252     -.837169    .2193216
       lnfcf |   -.028225   .0258026    -1.09   0.274    -.0787971    .0223472
      dlnall |   .0748168   .0295217     2.53   0.011     .0169553    .1326782
      dlnint |   1.196768   .2942554     4.07   0.000     .6200381    1.773498
       _cons |   .0589402   .0800694     0.74   0.462    -.0979929    .2158733
------------------------------------------------------------------------------
Instruments for first differences equation
  Standard
    D.(dlngdp dlnlab lnfcf dlnall dlnint)
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    L(1/14).L.dlnemi
Instruments for levels equation
  Standard
    dlngdp dlnlab lnfcf dlnall dlnint
    _cons
  GMM-type (missing=0, separate instruments for each period unless collapsed)
    D.L.dlnemi
------------------------------------------------------------------------------
Arellano-Bond test for AR(1) in first differences: z =  -3.61  Pr > z =  0.000
Arellano-Bond test for AR(2) in first differences: z =  -1.66  Pr > z =  0.096
------------------------------------------------------------------------------
Sargan test of overid. restrictions: chi2(90)   = 154.15  Prob > chi2 =  0.000
  (Not robust, but not weakened by many instruments.)
Hansen test of overid. restrictions: chi2(90)   =  18.38  Prob > chi2 =  1.000
  (Robust, but weakened by many instruments.)

Difference-in-Hansen tests of exogeneity of instrument subsets:
  GMM instruments for levels
    Hansen test excluding group:     chi2(78)   =  18.38  Prob > chi2 =  1.000
    Difference (null H = exogenous): chi2(12)   =  -0.00  Prob > chi2 =  1.000
  gmm(L.dlnemi, lag(1 .))
    Hansen test excluding group:     chi2(0)    =   0.00  Prob > chi2 =      .
    Difference (null H = exogenous): chi2(90)   =  18.38  Prob > chi2 =  1.000
  iv(dlngdp dlnlab lnfcf dlnall dlnint)
    Hansen test excluding group:     chi2(85)   =  20.97  Prob > chi2 =  1.000
    Difference (null H = exogenous): chi2(5)    =  -2.59  Prob > chi2 =  1.000
```

Figure 4.3. System GMM Model Estimation Results

```
. xtcce dlnemi dlngdp dlnlab lnfcf dlnall dlnint, pooled


Common Correlated Effects Estimation - Pooled OLS

Pooled Estimation                               Number of obs     =        360
Group variable: id                              Number of groups  =         26

                                                Obs per group:
                                                              min =          .
                                                              avg =          .
                                                              max =          .

                                                Wald chi2(5)      =      55.71
                                                Prob > chi2       =     0.0000

------------------------------------------------------------------------------------
                 dlnemi |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------+-----------------------------------------------------------
                 dlngdp |   1.387767   .3902537     3.56   0.000     .6228839     2.15265
                 dlnlab |   .3847995   .6368171     0.60   0.546    -.8633391    1.632938
                  lnfcf |  -.1493049   .0729366    -2.05   0.041     -.292258   -.0063518
                 dlnall |    .064093   .0753424     0.85   0.395    -.0835754    .2117614
                 dlnint |   1.999737   .2822288     7.09   0.000     1.446578    2.552895
```

Figure 4.4. CCE Model Estimation Results

```
. regife dlnemi dlngdp dlnlab lnfcf dlnall dlnint, ife(id year, 1)

REGIFE                                            Number of obs   =        360
Panel structure: id, year                         F(   6,     314) =      27.45
Factor dimension: 1                               Prob > F        =     0.0000
Converged: true                                   Root MSE        =     0.0777
                                                  Iterations      =         26
------------------------------------------------------------------------------
      dlnemi |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _cons |   .1341296   .0731077     1.83   0.067    -.0097132    .2779724
      dlngdp |   1.386004   .1525684     9.08   0.000     1.085818    1.686189
      dlnlab |  -.3116269   .2907726    -1.07   0.285    -.8837358     .260482
       lnfcf |  -.0523806   .0239768    -2.18   0.030     -.099556   -.0052052
      dlnall |   .0837558   .0307717     2.72   0.007      .023211    .1443006
      dlnint |   1.350919    .152853     8.84   0.000     1.050174    1.651665
------------------------------------------------------------------------------
```

Figure 4.5. IFE Model Estimation Results

All the results of the applied models are summarized in Table 4.1 for easy comparison. Using alternative methods allows to the assessment of the robustness of estimations to different assumptions. Analyzing the pooled OLS gives the point estimations highlighting that the impact on CO2 emissions of GDP, emissions allowances, and energy intensity is significant and positive; fixed capital significant and negative; labor insignificant. The pooled OLS results may be biased as unobserved individual effects of European countries are not accounted for by this method, and these effects may play a crucial role in the growth of CO2 emissions. Considering this possibility, the fixed effects (FE) model was introduced, and the results show that the sign and significance of the explanatory variables are in line with those from pooled OLS, with a slight difference in the magnitudes of the coefficients.

Table 4.1 Results from Panel Estimations[1]

	Pooled OLS	FE	System GMM	CCE	IFE
$\Delta lnGDP$	1.270***	1.342***	1.313***	1.387***	1.386***
	(7.98)	(4.78)	(5.27)	(3.56)	(9.08)
$\Delta lnLAB$	-0.447	-0.277	-0.322	0.384	-0.311
	(-1.52)	(-0.69)	(-0.96)	(0.60)	(-1.07)
$\Delta lnFCF$	-0.041*	-0.085**	-0.037	-0.149**	-0.052**
	(-1.73)	(-2.38)	(-1.36)	(-2.05)	(-2.18)
$\Delta lnALL$	0.080**	0.067*	0.076**	0.064	0.083***
	(2.52)	(2.03)	(2.31)	(0.85)	(2.72)
$\Delta lnINT$	1.240***	1.289***	1.269***	1.999***	1.350***
	(7.93)	(4.24)	(4.30)	(7.09)	(8.84)

The possible endogeneity problem between the regressors and regression errors, or Nickel Bias in short, may still cause inconsistent and invalid statistical deductions in the results from the fixed-effects model. To overcome this problem, the two-step system GMM estimator (Blundell and Bond, 1998) is employed by using two lagged

[1] Pooled OLS: Pooled ordinary least squares estimator.
FE: Panel fixed effects model.
System GMM: Two-step system GMM estimator of Blundell and Bond (1998). The two lagged values of dependent variable and levels of the explanatory variables are used as the instrumental variables. Hansen statistic is 20.08 with p-value=1.000 for validity of the over-identifying restrictions. AR(2) statistic is -1.64 with p-value=0.101 for second order autocorrelation.
CCE: Common correlated effects model of Pesaran (2006). The cross-sectional averages of the dependent and explanatory variables were used as the estimated common factors.
IFE: Interactive fixed effects model of Bai (2009). The common factors were estimated by the method of principal components applied to the estimated residuals $\hat{\varepsilon}_{it}$.
The t-statistics in parentheses were estimated with the corrected standard errors of Windmeijer (2005) for system GMM, and with the HAC standard errors of Newey and West (1987) for pooled OLS, FE, CCE, and IFE.

values of the dependent variable and levels of the explanatory variables as the instrumental variables. It should be noted that the system GMM estimation should meet the validity of instrumental variables and the absence of second-order autocorrelation in the regression residuals. The Hansen statistic is 20.08 (p-value=1.000), which supports the validity of the instrumental variables. The AR(2) statistic is -1.64 (p-value=0.101), indicating that the second-order autocorrelation problem is insignificant. Compared to pooled OLS and FE models, the estimations from system GMM indicate that GDP, emissions allowances, and energy intensity keep their significant and positive effects with similar magnitudes. In contrast, the significant negative impact of fixed capital formation is insignificant.

Knowing cross-correlations across individuals are not considered within the framework of pooled OLS, fixed-effects model, and system GMM estimations, and that there is a chance of inconsistency and invalid statistical inference when these potential cross-correlations are ignored, the results coming from these models were handled with carefulness. Before benefiting from the estimation methods with cross-sectional dependence, the significance of cross-correlations is tested with a battery of tests by using the LM (Lagrange Multiplier) test (Breusch and Pagan, 1980), and CD_{LM} and CD tests (Pesaran, 2021). The cross-section dependency tests, reported at the bottom of Table 4.2, reject the null hypothesis of no cross-sectional dependence at one percent, indicating significant cross-correlations across the European countries for CO2 emissions growth.

Table 4.2 Cross-Sectional Dependency Test Results from Panel Estimations[2]

	Cross-sectional dependency tests
LM	392.691***
	[0.006]
$\mathrm{CD}_{\mathrm{LM}}$	2.655***
	[0.000]
CD	17.043***
	[0.000]

Acknowledging that there is cross-section dependence in the CO2 emissions growth model, the common correlated effects (CCE) model (Pesaran, 2006) and the interactive fixed effects (IFE) model (Bai, 2009) are introduced. As outlined before, the CCE approach uses the cross-sectional averages; and the IFE method estimates unobserved common factors by the method of principal components. The results from the CCE show that GDP and energy intensity have significant and positive effects; fixed capital formation has a significant and negative effect; labor and emissions allowances do not significantly affect CO2 emissions. The IFE approach reveals similar results to the CCE method by unveiling the significant impact of emission allowances.

While the estimations based on equation (1) highlight significant results, equation (1) does not allow dynamic interactions among all variables, including the independent variables. The VAR system introduced in equation 4 was used to

[2] Cross-section dependency tests: LM test of Breusch and Pagan (1980) has chi-square distribution with N(N-1)/2 degrees of freedom, $\mathrm{CD}_{\mathrm{LM}}$ and CD tests of Pesaran (2021) have standard normal distribution. The tests were based on the OLS residuals from the equation (1). The numbers in brackets are the p-values of test statistic.
***, **, and * indicate statistical significance at 1, 5, and 10 percent level of significance, respectively.

determine which variables Granger cause the others. The results from the panel causality analysis are presented in Table 4.3:

Table 4.3 Panel Causality Analysis Results[3]

	Independent variables			
	$\Delta lnEMI$	$\Delta lnGDP$	$\Delta lnALL$	$\Delta lnINT$
$\Delta lnEMI$		10.17***	13.18***	10.42**
		[0.017]	[0.004]	[0.015]
$\Delta lnGDP$	4.73		6.39*	9.27**
	[0.192]		[0.094]	[0.025]
$\Delta lnALL$	22.16***	14.61***		11.78***
	[0.000]	[0.002]		[0.008]
$\Delta lnINT$	13.53***	11.33**	1.71	
	[0.003]	[0.010]	[0.635]	

Following Costantini and Martini (2010), an instrumental variable estimator was used to eliminate the correlation between the error term and the lagged dependent variables in the dynamic panel model. The panel VAR model was estimated by the GMM procedure (Arellano and Bond, 1991). The number of lags in the panel VAR

[3] The table above should be read in rows. For instance, statistic 10.17 tests for the null hypothesis of no Granger causality from GDP growth to EMI growth. Wald statistics are reported for zero restrictions, and the figures in brackets are the p-values corresponding to Wald statistics. Panel VAR model is estimated with the GMM estimation procedure as outlined in (Arellano and Bond, 1991). The number of lags in the panel VAR model is determined to ensure the serially uncorrelated error terms, and 3 lags are used accordingly. ***, **, and * indicate statistical significance at 1, 5, and 10 percent significance levels, respectively.

model is determined to ensure the validity of over-identifying restrictions and serially uncorrelated error terms; hence, three lags are used. The results show two-way causal flows for CO2 emissions-emissions allowances, CO2 emissions-energy intensity, GDP-emissions allowances, and GDP-energy intensity. In particular, emissions-allowances-GDP links exhibit a complex, self-enforcing, and dynamic association that supports a macroeconomic carbon rebound effect.. On the other hand, a unidirectional causality from GDP to CO2 emissions and energy intensity to emissions allowances is observed.

The dummy variables and their interactions with allowances do not significantly enter the model, meaning that the phases do not have a meaningful effect on the rebound effect. Therefore, the model is used without the dummies.

CHAPTER 5

CONCLUSION AND DISCUSSION

Starting from the foundation of IPCC and UNFCC, the world has realized how important the combat against climate change is, and the ambition of the targets for this purpose have been increased over the years. Being one of the primary weapons for the fight against climate change, the efficiency of ETS applications today is vital to meet the net zero targets of the future, and an ETS application is highly considered to be implemented within the next two years as a primary carbon pricing tool for Türkiye's net zero targets.

Numerous sectoral studies have shown that ETS applications help reduce emissions in industries that fall under their jurisdiction. These studies also highlight the positive effects of ETS on economic performance at both sectoral and firm levels. However, they are partial equilibrium analyses and do not consider the overall macroeconomic impact. The macroeconomic rebound of the ETS is not studied much, even though, ultimately, total emissions matter for climate change. Significant rebound effects may hamper the efficacy of ETSs and the ability to meet ambitious climate targets on time. This study attempts to help fill that gap.

It is found that a 1% change in allowances results in a 0.07-0.08% increase in emissions. In addition, the study reveals that information on past allowances helps improve the predictions of current emissions and vice versa. The bi-directional causality also exists between economic growth and allowances. The results show that a carbon rebound effect of the EU - ETS exists at the aggregate level. This rebound is attributed to the simple human behavior approach; the more allowances the producers get, the more they choose to pay their way out instead of actually reducing. The Granger causality is bidirectional, suggesting a self-enforcing carbon rebound effect in the longer run as the countries will grow and therefore demand more allowances, which in turn will result in more growth, more allowances and therefore larger rebound.

The findings from this study suggest that the macroeconomic carbon rebound effect must be considered when assessing an ETS's efficacy and revisiting climate policies. This rebound effect may become more intensified on a global scale. Therefore, countries must step up green transition plans to meet their emission targets. Similar results may hold for other ETS applications worldwide since studies show positive economic impacts of other ETSs at the firm, sectoral, and regional scales.

In addition, a unidirectional causality running from economic growth to emissions and energy intensity to allowances is observed in the analysis. Energy intensity occupies a significant role in emissions directly and indirectly via the macroeconomic rebound effect. Energy intensity and allowances lead to economic growth, meaning that EU economic output is not entirely decoupled from energy use. Decoupling economic growth from emissions requires a faster green energy transition. If decoupling is unsuccessful, countries may need to forgo economic growth and focus on developing well-being. It is essential to point out that the marginal impact of economic growth on societal well-being, especially in developed countries, may be insignificant. Hence, prioritizing the well-being of society as an overall goal rather than focusing on economic growth may result in a more beneficial framework in terms of straightening the priorities.

It is common knowledge that the EU is trying to increase the functionality of the ETS by constantly implementing new policies and reforms, such as the Market Stability Reserve, to provide price stability. Moreover, as mentioned earlier, there are various regional ETS applications and carbon clubs worldwide. It can also be seen that economic development requires energy intensity and cause more emissions. As a policy implication, having a single ETS worldwide can be suggested to decrease the macroeconomic rebound. With a similar approach such as Paris Agreement; a World ETS, the single cap and trade system valid for all countries and regulated by an authority including representatives from all joined countries such as the UN, can determine the emissions limits and allowances according to The World Bank

Development Indicators and OECD data. The system might work when the developed countries exceed the cap. They will have to buy emissions allowances from the developing countries, with a price factor again determined by the UN. The price factor can be arranged where developing countries are favored if they invest in renewables with the extra revenue. This would allow developing countries to invest more in green technologies and renewables with the extra revenue from emissions trading. As a result, it might decrease the rebound caused by regionally operating ETSs. Although a global carbon market can work in theory, it seems hardly possible to achieve with the current state of international politics, especially considering the energy crisis that has taken over the world in the year 2022 with the Russian – Ukrainian war. So these policy suggestions might start with mild sanctions and commitments, and the applications may gain popularity over time as satisfaction from the results increases. Carbon taxes may seem more promising, on the other hand, but they are getting less and less popular, and they may be subject to resistance from society. Treating a global challenge such as climate change as a market failure may not be appropriate. Alternatives to carbon pricing must be employed. Regardless of the methods to be introduced, however, political events in 2022 have showed once again that the world needs to set its priorities right as the war has caused an international energy crisis and Europe started to turn back to conventional fossil fuel sources to address the immediate energy demand within the continent.

Furthermore, climate change is not the only problem, and it has close links to the sustainable development goals of the United Nations. A holistic perspective is needed to align sustainability strategies where the market failure perspective does not work. It can be seen that tailormade approaches such as the one suggested by (Borozan, 2019) are vital for this perspective; specifying the energy policy programs according to the needs and dynamics of each energy consuming groups in countries as well as regions, encouraging the economic growth and development of less energy-consuming countries and making sure of a green transition during the development, improving and sharing the know-how of cleaner technologies with the aid of revenue recycling might be good ways to initiate a holistic approach and remedy the effects of climate change. Nevertheless, these approaches must involve industrial sectors as well as regional handling, which in turn might result in a policy approach that is hard to implement. A good start can be combining a holistic approach with the support of carbon border adjustment mechanisms (CBAM), an example of which by the EU is being planned to take effect in 2026, which are expected to deal with the leakage problem to some extent. CBAM can briefly be defined as a type of carbon tax that is applied at the border of a region or a country by the EU on a imported carbon intensive product such as iron, steel, cement, electricity or certain plastics, in order to descend the carbon leakage from the countries without a carbon pricing policy (Gore, 2021). Yet, the regulation methodology is critical to prevent bubbles and political backlash (Eicke et al., 2021) as the EU currently plans to determine the level of the prices according to the allowance prices from the EU – ETS according to the UNCTAD report (2021).

Among the issues raised throughout this study and in this chapter, the stance of Türkiye plays a vital role. The country must take a step and determine the approach to its carbon pricing strategies; a sectoral approach where some sectors are subjected to carbon tax, while an ETS is implemented gradually might be a good start. Nevertheless, an ETS still seems like the most advanced and useful application for Türkiye's net zero targets. However, it must be noted that this potential ETS should be compatible with the EU – ETS in the minimum, as the integration of ETS applications will be necessary in the long run to avoid leakage and rebound effects; in addition to be acknowledging and trying to bring new perspectives to the problems that the EU – ETS has been facing to this day.

Finally, follow-up studies are suggested, including a forecast analysis on Phase 4 of EU – ETS to see whether the expectations comply with these results. In addition, similar analyses on other ETS applications, such as those in China, Australia, and New Zealand, and regional applications in the US can be conducted using the approach from this study to see whether there is a macroeconomic rebound coming from the ETS itself. A rebound analysis on CBAM, that is similar to the one conducted in this study, might be helpful to assess the strong and weak sides of the upcoming application. Considering the possible applications in Türkiye, a CGE analysis comparing a carbon tax application to an ETS, and various mixtures of these two might shed light to policymakers on where and how to take action.

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APPENDICES

A. Stata Data

Country	id	year	emi	gdp	fcf	lab	all	ele	pop
Austria	1	2005	33.373	69202	23.052	4.0e+06	3.1e+07	66.02	8.2e+06
Austria	1	2006	32.384	71671	22.601	4.0e+06	3.3e+07	67.7	8.3e+06
Austria	1	2007	31.751	74322	22.917	4.1e+06	3.2e+07	67.6	8.3e+06
Austria	1	2008	32.079	75433	23.276	4.2e+06	3.3e+07	68.3	8.3e+06
Austria	1	2009	27.36	72592	22.413	4.2e+06	3.3e+07	66.3	8.3e+06
Austria	1	2010	30.92	73844	21.597	4.2e+06	3.1e+07	70.21	8.4e+06
Austria	1	2011	30.599	76145	22.472	4.2e+06	3.1e+07	70.5	8.4e+06
Austria	1	2012	28.387	76710	22.649	4.3e+06	3.1e+07	71.9	8.4e+06

Belgium	Belgium	Belgium	Austria	Austria	Austria	Austria	Austria	Austria	Austria
2	2	2	1	1	1	1	1	1	1
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
52.795	54.775	55.363	29.562	28.404	30.556	28.994	29.486	28.049	29.799
89676	86499	84346	84679	83454	81460	79581	78032	77307	76684
23.293	22.325	22.154	24.684	23.984	23.625	23.096	22.697	22.661	23.04
4.7e+06	4.6e+06	4.6e+06	4.5e+06	4.5e+06	4.5e+06	4.5e+06	4.4e+06	4.3e+06	4.3e+06
6.0e+07	6.0e+07	5.8e+07	2.6e+07	3.4e+07	3.2e+07	3.1e+07	3.1e+07	3.7e+07	3.1e+07
91.5	91.6	89.17	74.1	74.2	74.4	72.1	71.89	71.3	72.1
1.1e+07	1.1e+07	1.0e+07	8.9e+06	8.8e+06	8.8e+06	8.7e+06	8.6e+06	8.5e+06	8.5e+06

Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium
2	2	2	2	2	2	2	2	2	2
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
43.773	43.656	44.714	43.853	45.231	43.007	46.203	50.104	46.207	55.462
99661	98072	96846	94908	93433	93006	92324	90785	88257	90075
23.279	23.278	22.963	22.806	22.173	22.962	23.01	22.123	22.785	24.118
5.0e+06	5.0e+06	5.0e+06	5.0e+06	4.9e+06	4.9e+06	4.8e+06	4.9e+06	4.8e+06	4.8e+06
5.8e+07	5.5e+07	5.3e+07	5.2e+07	6.3e+07	6.8e+07	5.7e+07	5.6e+07	5.7e+07	5.5e+07
89	88.1	87.01	86.5	89.2	88.9	89	92.3	85.3	91.3
1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07

Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Belgium	Belgium
3	3	3	3	3	3	3	3	2	2
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
35.051	39.998	33.525	32.015	38.303	39.182	0	0	44.627	44.183
9814	9764	9540	9410	9740	9187	8594	8051	103655	101473
21.226	20.946	22.317	27.781	33.005	28.306	27.438	25.665	24.193	23.745
3.1e+06	3.1e+06	3.3e+06	3.4e+06	3.6e+06	3.4e+06	3.3e+06	3.2e+06	5.1e+06	5.0e+06
4.3e+07	4.2e+07	3.5e+07	4.1e+07	3.8e+07	4.0e+07	0	0	4.6e+07	5.7e+07
34.8	35.7	33.73	33.4	35	34.1	33.2	31.9	88.3	88.6
7.3e+06	7.4e+06	7.4e+06	7.5e+06	7.5e+06	7.6e+06	7.6e+06	7.7e+06	1.1e+07	1.1e+07

Cyprus	Cyprus	Cyprus	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria
4	4	4	3	3	3	3	3	3	3
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
5.396	5.259	5.079	29.194	31.029	34.908	33.411	36.261	34.305	32.696
4684	4457	4256	11555	11108	10801	10508	10195	9865	9755
25.548	25.078	21.526	18.705	18.793	18.364	18.453	20.909	21.127	21.26
331743	317674	311895	3.4e+06	3.3e+06	3.3e+06	3.2e+06	3.2e+06	3.2e+06	3.1e+06
5.9e+06	5.6e+06	5.5e+06	2.8e+07	3.6e+07	3.6e+07	3.2e+07	3.4e+07	2.6e+07	3.7e+07
4.7	4.4	4.21	35.7	35.9	36.7	35.3	34.87	34	33.7
1.1e+06	1.0e+06	1.0e+06	7.0e+06	7.1e+06	7.1e+06	7.2e+06	7.2e+06	7.2e+06	7.3e+06

Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus
4	4	4	4	4	4	4	4	4	4
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
4.673	4.649	4.369	4.469	4.025	4.384	4.599	5.056	5.362	5.577
5027	4749	4461	4315	4396	4704	4872	4853	4757	4855
21.035	18.115	12.876	13.345	14.115	15.505	19.036	22.452	23.439	27.183
344362	328805	314173	309299	315628	334322	346620	345667	343539	343429
3.4e+06	2.7e+06	3.1e+06	3.4e+06	4.0e+06	6.2e+06	5.8e+06	5.4e+06	5.1e+06	4.8e+06
4.8	4.6	4.32	4.2	4.1	4.6	4.8	5.1	5	4.9
1.2e+06	1.2e+06	1.2e+06	1.2e+06	1.1e+06	1.1e+06	1.1e+06	1.1e+06	1.1e+06	1.1e+06

Czechia	Czechia	Czechia	Czechia	Czechia	Czechia	Czechia	Czechia	Cyprus	Cyprus
5	5	5	5	5	5	5	5	4	4
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
69.316	74.187	75.584	73.785	80.399	87.835	83.625	82.455	4.472	4.586
39847	40130	39435	38560	40380	39392	37318	34891	5594	5314
26.155	26.755	27.149	27.615	29.248	29.933	28.444	28.788	19.411	19.194
5.3e+06	5.2e+06	5.3e+06	5.3e+06	5.2e+06	5.2e+06	5.2e+06	5.2e+06	366567	357038
8.9e+07	8.6e+07	8.6e+07	8.6e+07	8.6e+07	9.7e+07	9.7e+07	9.7e+07	2.9e+06	3.8e+06
66.1	66	66.49	64.1	67.5	67.1	66.9	64.92	5	4.9
1.1e+07	1.1e+07	1.1e+07	1.0e+07	1.0e+07	1.0e+07	1.0e+07	1.0e+07	1.2e+06	1.2e+06

Denmark	Denmark	Denmark	Czechia	Czechia	Czechia	Czechia	Czechia	Czechia	Czechia
6	6	6	5	5	5	5	5	5	5
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
29.407	34.2	26.476	62.519	66.913	66.976	67.531	66.648	66.695	67.712
63077	62509	60155	49260	47845	46371	44006	42958	40730	39830
23.513	23.273	21.173	27.073	26.305	24.916	24.943	26.538	25.404	25.36
2.9e+06	2.9e+06	2.9e+06	5.4e+06	5.4e+06	5.4e+06	5.3e+06	5.3e+06	5.3e+06	5.3e+06
2.8e+07	3.2e+07	3.7e+07	4.8e+07	6.5e+07	6.6e+07	6.0e+07	5.7e+07	5.6e+07	7.1e+07
36.4	37.1	36.09	69.6	69.9	69.6	68.3	67.31	66	65.9
5.5e+06	5.4e+06	5.4e+06	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07

Denmark	Denmark	Denmark	Denmark	Denmark	Denmark	Denmark	Denmark	Denmark	Denmark
6	6	6	6	6	6	6	6	6	6
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
15.063	17.22	15.796	18.389	21.602	18.186	21.466	25.266	25.461	26.549
68805	66916	64813	63329	62320	61744	61604	60791	59675	62754
21.226	21.025	19.851	19.164	19.052	18.778	18.158	18.114	20.169	22.944
3.0e+06	2.9e+06	2.9e+06	2.9e+06	2.8e+06	2.9e+06	2.9e+06	2.9e+06	2.9e+06	2.9e+06
2.1e+07	1.9e+07	1.9e+07	1.9e+07	2.5e+07	2.7e+07	2.4e+07	2.4e+07	2.4e+07	2.4e+07
33.9	33.7	33.09	33.1	33.9	33.8	34.4	35.1	34.4	35.9
5.8e+06	5.7e+06	5.7e+06	5.6e+06	5.6e+06	5.6e+06	5.6e+06	5.5e+06	5.5e+06	5.5e+06

Estonia	Estonia	Estonia	Estonia	Estonia	Estonia	Estonia	Estonia	Denmark	Denmark
7	7	7	7	7	7	7	7	6	6
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
13.544	14.809	14.514	10.378	13.541	15.33	12.104	12.622	12.041	14.954
4075	3944	3684	3609	4209	4412	4116	3746	71657	70173
28.751	26.459	21.239	22.685	31.144	36.393	36.854	32.867	21.302	21.727
658475	665475	661475	665700	669550	663800	666525	646975	3.0e+06	3.0e+06
1.4e+07	1.6e+07	1.2e+07	1.2e+07	1.2e+07	2.1e+07	1.8e+07	1.7e+07	1.4e+07	2.0e+07
8.9	8.4	8.66	8	8.5	8.4	7.9	7.49	33.7	33.5
1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.4e+06	5.8e+06	5.8e+06

Finland	Finland	Finland	Estonia	Estonia	Estonia	Estonia	Estonia	Estonia	Estonia
8	8	8	7	7	7	7	7	7	7
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
42.541	44.621	33.1	8.486	13.853	14.671	13.447	11.894	14.968	15.921
49201	46725	44916	5112	4915	4721	4477	4343	4246	4130
24.195	22.764	22.918	25.427	24.695	25.855	24.371	24.434	25.695	27.844
2.6e+06	2.6e+06	2.6e+06	664550	666450	665150	658175	654275	648375	654650
4.5e+07	4.5e+07	4.5e+07	8.9e+06	1.2e+07	1.2e+07	1.0e+07	9.8e+06	9.3e+06	1.3e+07
90.8	90.7	84.56	9.3	9.7	9.7	9.4	8.53	8.9	8.8
5.3e+06	5.3e+06	5.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06

Finland	Finland	Finland	Finland	Finland	Finland	Finland	Finland	Finland	Finland
8	8	8	8	8	8	8	8	8	8
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
25.111	27.198	25.42	28.705	31.417	29.504	35.089	41.297	34.354	36.164
50093	48542	47215	46959	47131	47560	48234	47036	45584	49588
23.349	22.745	21.23	21.472	22.008	23.078	22.616	22.296	22.955	24.494
2.6e+06	2.6e+06	2.6e+06	2.6e+06	2.6e+06	2.6e+06	2.6e+06	2.6e+06	2.6e+06	2.7e+06
3.5e+07	3.2e+07	3.2e+07	3.2e+07	4.0e+07	3.8e+07	3.8e+07	3.8e+07	3.7e+07	3.7e+07
85.2	84.1	82.5	83.3	84.4	85	84.7	88.41	81.4	86.9
5.5e+06	5.5e+06	5.5e+06	5.5e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.3e+06	5.3e+06

France	France	France	France	France	France	France	France	Finland	Finland
9	9	9	9	9	9	9	9	8	8
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
103.661	105.575	115.543	111.093	124.13	126.635	126.979	131.264	23.242	26.221
511449	509546	498396	489402	503418	502844	490951	478379	51344	50664
22.458	22.424	22.105	22.068	23.596	23.183	22.451	21.797	23.742	24.065
2.8e+07	2.8e+07	2.8e+07	2.8e+07	2.8e+07	2.8e+07	2.7e+07	2.7e+07	2.7e+06	2.7e+06
1.3e+08	1.3e+08	1.3e+08	1.3e+08	1.3e+08	1.5e+08	1.5e+08	1.5e+08	2.5e+07	3.3e+07
490.4	479.8	503.16	475.1	492.3	481.3	479.7	483.5	86	87.2
6.6e+07	6.5e+07	6.5e+07	6.5e+07	6.4e+07	6.4e+07	6.4e+07	6.3e+07	5.5e+06	5.5e+06

Germany	Germany	Germany	France	France	France	France	France	France	France
10	10	10	9	9	9	9	9	9	9
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
487.148	478.075	475.052	94.304	97.49	106.842	101.715	99.695	100.273	114.589
647122	627710	603575	563539	553363	543362	530409	525025	519608	514592
20.057	19.803	19.077	23.477	22.893	22.496	21.815	21.499	21.82	22.042
4.1e+07	4.1e+07	4.0e+07	2.9e+07	2.9e+07	2.9e+07	2.9e+07	2.9e+07	2.9e+07	2.8e+07
5.0e+08	5.0e+08	4.9e+08	9.5e+07	1.2e+08	1.2e+08	1.2e+08	1.2e+08	1.2e+08	1.4e+08
595.5	594.8	589.22	475.1	480.2	483.2	485.1	479.39	471	495.2
8.2e+07	8.2e+07	8.2e+07	6.7e+07	6.7e+07	6.7e+07	6.7e+07	6.7e+07	6.6e+07	6.6e+07

Germany	Germany	Germany	Germany	Germany	Germany	Germany	Germany	Germany	Germany
10	10	10	10	10	10	10	10	10	10
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
437.614	452.817	455.626	461.258	481.047	452.595	450.351	454.865	428.295	472.854
732508	711249	696332	687811	672982	669270	665158	639647	614797	651548
20.411	20.298	20.02	20.04	19.901	20.321	20.371	19.543	19.268	20.303
4.2e+07	4.2e+07	4.1e+07	4.1e+07	4.1e+07	4.1e+07	4.0e+07	4.0e+07	4.1e+07	4.1e+07
3.5e+08	3.2e+08	3.0e+08	2.9e+08	3.8e+08	4.7e+08	4.4e+08	4.4e+08	4.3e+08	4.4e+08
574.2	574.2	574.42	569.8	582	583.2	584.6	594.19	559.2	591
8.3e+07	8.2e+07	8.2e+07	8.1e+07	8.1e+07	8.0e+07	8.0e+07	8.2e+07	8.2e+07	8.2e+07

Greece	Greece	Greece	Greece	Greece	Greece	Greece	Greece	Germany	Germany
11	11	11	11	11	11	11	11	10	10
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
61.44	58.838	59.94	63.662	69.854	72.717	69.965	71.268	363.315	422.848
46901	50557	56217	62093	64889	65046	63046	59713	748645	740594
11.529	13.676	16.559	20.791	23.814	26.012	23.686	20.829	21.369	21.057
4.9e+06	4.9e+06	5.0e+06	5.0e+06	5.0e+06	5.0e+06	5.0e+06	4.9e+06	4.2e+07	4.2e+07
7.4e+07	7.6e+07	6.5e+07	6.3e+07	6.4e+07	7.1e+07	7.1e+07	7.1e+07	2.7e+08	3.2e+08
61.1	59.9	59.32	62.5	64.3	63	59.9	58.2	548.9	567.5
1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	8.3e+07	8.3e+07

Hungary	Hungary	Hungary	Greece	Greece	Greece	Greece	Greece	Greece	Greece
12	12	12	11	11	11	11	11	11	11
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
26.837	25.846	26.162	40.476	47.106	49.572	46.3	49.876	55.372	58.633
26218	26136	25104	47525	46753	46083	45502	45727	46040	45699
23.73	23.52	23.882	10.135	10.84	11.732	11.024	10.787	10.827	11.214
4.2e+06	4.2e+06	4.2e+06	4.7e+06	4.7e+06	4.8e+06	4.8e+06	4.8e+06	4.8e+06	4.8e+06
3.1e+07	3.1e+07	3.0e+07	3.4e+07	4.8e+07	4.8e+07	4.2e+07	4.0e+07	3.7e+07	5.1e+07
40	39.1	38.04	54.9	54.3	60.4	59.3	56.59	55.1	55.1
1.0e+07	1.0e+07	1.0e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07

Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary	Hungary
12	12	12	12	12	12	12	12	12	12
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
20.642	19.401	19.65	18.82	19.133	21.266	22.47	22.992	22.401	27.237
29475	28222	27632	26658	25601	25136	25420	24953	24700	26443
22.171	19.516	22.19	22.052	20.838	19.2	19.562	20.109	22.693	23.372
4.6e+06	4.5e+06	4.5e+06	4.4e+06	4.3e+06	4.3e+06	4.2e+06	4.2e+06	4.1e+06	4.1e+06
2.5e+07	2.2e+07	2.1e+07	1.9e+07	2.6e+07	3.2e+07	2.5e+07	2.6e+07	2.4e+07	2.5e+07
42.3	41.1	40.35	39.2	38.5	38.9	38.9	38.77	37.8	40
9.7e+06	9.8e+06	9.8e+06	9.8e+06	9.8e+06	9.9e+06	9.9e+06	9.9e+06	1.0e+07	1.0e+07

Ireland	Ireland	Ireland	Ireland	Ireland	Ireland	Ireland	Ireland	Hungary	Hungary
13	13	13	13	13	13	13	13	12	12
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
16.897	15.771	17.374	17.216	20.383	21.246	21.705	22.441	19.531	20.054
42266	42288	41841	41119	43329	45364	43079	41035	32480	31065
19.571	16.689	17.58	21.163	24.842	28.707	30.987	29.829	27.123	24.776
2.2e+06	2.2e+06	2.2e+06	2.3e+06	2.3e+06	2.3e+06	2.1e+06	2.0e+06	4.6e+06	4.6e+06
2.2e+07	2.2e+07	2.1e+07	2.0e+07	2.0e+07	1.9e+07	2.0e+07	1.9e+07	1.9e+07	2.4e+07
25.8	25.6	26.73	27	28.5	27.9	27.1	25.97	43.5	43
4.6e+06	4.6e+06	4.6e+06	4.5e+06	4.5e+06	4.4e+06	4.3e+06	4.2e+06	9.7e+06	9.7e+06

Italy	Italy	Italy	Ireland	Ireland	Ireland	Ireland	Ireland	Ireland	Ireland
14	14	14	13	13	13	13	13	13	13
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
226.406	227.439	225.989	14.179	15.523	16.898	17.738	16.837	15.956	15.692
422086	416499	408806	74067	70595	64749	59435	58246	46531	42801
21.661	21.58	21.282	53.591	28.242	33.252	35.813	24.096	20.635	18.587
2.4e+07	2.4e+07	2.4e+07	2.4e+06	2.3e+06	2.3e+06	2.3e+06	2.2e+06	2.2e+06	2.2e+06
2.0e+08	2.1e+08	2.2e+08	9.8e+06	1.4e+07	1.4e+07	1.3e+07	1.2e+07	1.1e+07	1.5e+07
339.2	339.2	332.23	29.3	28.9	28	27.7	26.98	26.2	26.2
5.8e+07	5.8e+07	5.8e+07	4.9e+06	4.9e+06	4.8e+06	4.8e+06	4.7e+06	4.7e+06	4.6e+06

Italy	Italy	Italy	Italy	Italy	Italy	Italy	Italy	Italy	Italy
14	14	14	14	14	14	14	14	14	14
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
155.332	154.956	156.206	152.582	164.504	179.07	189.958	191.49	184.882	220.676
401386	394541	389077	386537	386259	393576	405807	402397	395786	418011
17.481	17.171	16.935	16.722	17.205	18.309	19.714	20.024	20.111	21.278
2.5e+07	2.5e+07	2.5e+07	2.5e+07	2.5e+07	2.5e+07	2.4e+07	2.4e+07	2.4e+07	2.4e+07
1.6e+08	1.5e+08	1.4e+08	1.4e+08	1.9e+08	1.9e+08	2.0e+08	2.0e+08	2.1e+08	2.1e+08
314.9	308	309.65	304.1	310.8	321.4	327.5	325.65	317.3	338.7
6.1e+07	6.1e+07	6.1e+07	6.1e+07	6.0e+07	6.0e+07	5.9e+07	5.9e+07	5.9e+07	5.9e+07

Latvia	Latvia	Latvia	Latvia	Latvia	Latvia	Latvia	Latvia	Italy	Italy
15	15	15	15	15	15	15	15	14	14
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
2.74	2.923	3.24	2.49	2.743	2.849	2.941	2.854	140.943	146.482
4958	4620	4514	4747	5538	5697	5162	4606	406253	404604
25.159	21.962	19.121	22.304	31.948	36.253	33.938	31.096	17.963	17.849
1.6e+06	1.6e+06	1.6e+06	1.7e+06	1.7e+06	1.7e+06	1.7e+06	1.7e+06	2.5e+07	2.5e+07
5.0e+06	4.6e+06	4.8e+06	4.9e+06	3.7e+06	4.0e+06	4.1e+06	4.1e+06	1.2e+08	1.6e+08
7.3	6.7	6.78	6.5	7	7	6.6	6.22	314.2	315.6
2.1e+06	2.1e+06	2.1e+06	2.1e+06	2.2e+06	2.2e+06	2.2e+06	2.3e+06	6.0e+07	6.0e+07

Lithuania	Lithuania	Lithuania	Latvia	Latvia	Latvia	Latvia	Latvia	Latvia	Latvia
16	16	16	15	15	15	15	15	15	15
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
5.999	6.517	6.604	2.493	2.613	2.05	2.197	2.313	2.354	2.65
7895	7106	6614	6032	5889	5652	5472	5357	5165	5062
28.605	25.954	23.41	22.216	22.127	20.618	19.316	21.873	22.808	23.026
1.5e+06	1.4e+06	1.4e+06	1.4e+06	1.4e+06	1.4e+06	1.5e+06	1.5e+06	1.5e+06	1.5e+06
1.1e+07	1.1e+07	1.3e+07	3.2e+06	4.2e+06	4.4e+06	4.1e+06	4.0e+06	4.1e+06	5.4e+06
11.5	11	10.59	7.1	7.2	7	7	6.9	7	7
3.2e+06	3.3e+06	3.3e+06	1.9e+06	1.9e+06	2.0e+06	2.0e+06	2.0e+06	2.0e+06	2.0e+06

Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania
16	16	16	16	16	16	16	16	16	16
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
6.283	6.16	6.845	6.864	7.464	5.718	5.606	6.394	5.787	6.104
9029	8668	8444	8278	8000	7719	7436	7007	6898	8085
20.115	19.858	19.611	18.87	18.422	17.324	18.46	16.859	17.885	26.066
1.4e+06	1.4e+06	1.4e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.3e+06	1.4e+06
1.1e+07	1.0e+07	1.0e+07	9.5e+06	1.2e+07	1.1e+07	8.9e+06	8.2e+06	7.6e+06	7.5e+06
12	11.6	11.35	11.2	10.8	10.8	10.7	10.75	11.5	11.9
2.8e+06	2.9e+06	2.9e+06	2.9e+06	3.0e+06	3.0e+06	3.0e+06	3.1e+06	3.2e+06	3.2e+06

Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Lithuania	Lithuania
17	17	17	17	17	17	17	17	16	16
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
1.99	2.052	2.253	2.182	2.099	2.567	2.713	2.603	6.067	5.953
10882	10707	10598	10217	10562	10597	9805	9247	9817	9387
20.163	19.179	17.608	18.405	20.268	18.417	17.612	19.103	21.368	20.951
246475	233950	228650	226525	212600	211200	204600	202300	1.4e+06	1.4e+06
2.5e+06	2.5e+06	2.5e+06	2.5e+06	2.5e+06	3.2e+06	3.2e+06	3.2e+06	8.3e+06	1.1e+07
7.8	8	8.52	7.2	7.8	7.9	7.8	7.27	12.4	12.2
530946	518347	506953	497783	488650	479993	472637	465158	2.8e+06	2.8e+06

Malta	Malta	Malta	Luxemb ourg	Luxemb ourg	Luxemb ourg	Luxemb ourg	Luxemb ourg	Luxemb ourg	Luxemb ourg
18	18	18	17	17	17	17	17	17	17
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
2.027	1.986	1.971	1.496	1.469	1.492	1.503	1.661	1.932	1.847
1573	1501	1464	13211	12790	12536	12373	11785	11522	11227
22.949	22.478	22.837	16.88	16.812	18.76	18.138	18.211	19.967	19.513
156536	153066	150749	304350	294900	285675	276900	273500	257975	250900
2.3e+06	2.2e+06	2.1e+06	1.9e+06	2.4e+06	2.4e+06	2.2e+06	2.2e+06	2.1e+06	2.6e+06
2	2	1.98	7.6	8.2	8.3	8.3	8.21	7.7	7.7
406724	405308	403834	620001	607950	596336	582014	569604	556319	543360

Malta	Malta	Malta	Malta	Malta	Malta	Malta	Malta	Malta	Malta
18	18	18	18	18	18	18	18	18	18
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
.724	.58	.89	1.659	1.697	2.052	1.932	1.878	1.897	2.019
2554	2302	2218	2023	1879	1782	1712	1704	1614	1633
21.706	24.19	24.2	16.66	16.524	17.606	18.162	20.993	18.284	20.037
206924	195956	191138	186675	179027	173116	168293	162806	159772	160115
1.0e+06	819000	733000	646500	1.1e+06	2.2e+06	2.2e+06	2.2e+06	2.1e+06	2.1e+06
2.4	2.2	2.18	2.1	2.1	2.1	2	1.95	1.8	2
467999	455356	445053	434558	425967	420028	416268	414508	412477	409379

Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Malta	Malta
19	19	19	19	19	19	19	19	18	18
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
76.426	79.967	84.736	81.031	83.511	79.872	76.702	80.351	.739	.698
160496	162167	159711	157659	163671	160183	154365	148976	2867	2710
18.761	20.137	19.697	21.306	22.117	23.293	21.041	20.413	21.579	21.045
8.8e+06	8.7e+06	8.7e+06	8.7e+06	8.7e+06	8.5e+06	8.4e+06	8.3e+06	220191	212430
9.1e+07	9.3e+07	9.3e+07	8.4e+07	7.7e+07	8.6e+07	8.6e+07	8.6e+07	619000	988500
115.2	117.9	116.41	113.3	118	117.3	114.8	112.81	2.6	2.4
1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.6e+07	1.6e+07	1.6e+07	1.6e+07	504062	484630

Poland	Poland	Poland	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands
20	20	20	19	19	19	19	19	19	19
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
209.618	209.616	203.15	83.744	87.413	91.419	93.866	94.111	89.064	86.95
81400	76071	71644	181953	178547	174500	169395	165842	162658	160362
22.465	20.405	18.893	21.254	20.426	20.141	20.001	22.106	17.592	18.356
1.7e+07	1.7e+07	1.7e+07	9.3e+06	9.1e+06	9.0e+06	8.9e+06	8.9e+06	8.9e+06	8.9e+06
2.4e+08	2.4e+08	2.4e+08	6.0e+07	7.6e+07	7.7e+07	7.2e+07	7.1e+07	6.9e+07	8.4e+07
139.6	136.7	131.19	116.9	116.7	115.3	114.7	113.71	113.2	114.7
3.8e+07	3.8e+07	3.8e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07

Poland	Poland	Poland	Poland	Poland	Poland	Poland	Poland	Poland	Poland
20	20	20	20	20	20	20	20	20	20
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
202.167	198.052	198.701	197.129	205.735	196.636	203.027	199.727	191.174	204.107
113167	107926	104605	100380	97122	96084	94740	90413	87138	84830
17.526	17.978	20.07	19.833	18.928	19.862	20.704	20.263	21.443	23.106
1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07	1.7e+07
1.6e+08	1.1e+08	1.2e+08	1.3e+08	1.9e+08	2.1e+08	2.1e+08	2.1e+08	2.0e+08	2.0e+08
162.8	159.1	154.08	151	149.8	148.4	147.7	144.45	137	142.1
3.8e+07	3.8e+07	3.8e+07	3.8e+07	3.8e+07	3.8e+07	3.8e+07	3.8e+07	3.8e+07	3.8e+07

Portugal	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal	Poland	Poland
21	21	21	21	21	21	21	21	20	20
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
25.254	25.011	24.167	28.262	29.912	31.197	33.062	36.426	183.691	199.975
42350	44141	44903	44136	45558	45413	44303	43594	124912	119242
15.824	18.42	20.574	21.202	22.852	22.51	22.533	23.127	18.518	18.215
5.3e+06	5.3e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	1.7e+07	1.7e+07
3.3e+07	3.3e+07	3.2e+07	3.1e+07	3.0e+07	3.7e+07	3.7e+07	3.7e+07	1.7e+08	1.4e+08
49.8	51.2	52.43	51.2	51.2	51.6	50.8	49.19	165.7	166.8
1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	1.1e+07	3.8e+07	3.8e+07

Romania	Romania	Romania	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal
22	22	22	21	21	21	21	21	21	21
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
69.612	0	0	21.603	26.289	30.076	25.755	27.957	24.197	24.661
31396	29307	27168	48009	46754	45459	43919	43050	42292	41959
35.343	26.616	23.363	18.153	17.523	16.784	15.493	15.517	15.032	14.752
9.4e+06	9.3e+06	9.1e+06	5.2e+06	5.2e+06	5.2e+06	5.1e+06	5.1e+06	5.2e+06	5.2e+06
7.4e+07	0	0	2.1e+07	2.8e+07	2.8e+07	2.5e+07	2.4e+07	2.3e+07	3.1e+07
52.8	51.9	50.43	51.6	51.9	51.7	50.3	49.79	48.5	49
2.1e+07	2.1e+07	2.1e+07	1.0e+07	1.0e+07	1.0e+07	1.0e+07	1.0e+07	1.0e+07	1.0e+07

Romania	Romania	Romania	Romania	Romania	Romania	Romania	Romania	Romania	Romania
22	22	22	22	22	22	22	22	22	22
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
40.617	39.778	42.396	42.575	42.415	47.857	51.239	47.344	49.062	63.817
40336	37668	35988	34921	33665	32516	31870	31320	32492	34306
22.408	22.947	24.792	24.362	24.701	27.535	27.244	26.073	25.998	37.287
8.7e+06	8.4e+06	8.5e+06	8.6e+06	8.5e+06	8.6e+06	8.5e+06	8.7e+06	9.2e+06	9.4e+06
7.2e+07	6.6e+07	5.5e+07	4.7e+07	7.4e+07	7.6e+07	7.5e+07	7.5e+07	7.4e+07	7.2e+07
54.4	53	52.41	51.5	49.9	52.2	53.2	51.65	48.7	53.5
2.0e+07	2.0e+07	2.0e+07	2.0e+07	2.0e+07	2.0e+07	2.0e+07	2.0e+07	2.0e+07	2.1e+07

Slovakia	Slovakia	Slovakia	Slovakia	Slovakia	Slovakia	Slovakia	Slovakia	Romania	Romania
23	23	23	23	23	23	23	23	22	22
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
20.938	22.223	21.699	21.595	25.337	24.517	25.543	25.232	36.546	39.638
17865	17533	17047	16102	17031	16132	14555	13416	43950	42180
20.309	23.27	21.112	20.801	24.751	25.427	25.578	26.201	22.622	21.052
2.7e+06	2.7e+06	2.7e+06	2.7e+06	2.7e+06	2.6e+06	2.7e+06	2.6e+06	8.7e+06	8.7e+06
3.3e+07	3.3e+07	3.2e+07	3.2e+07	3.2e+07	3.0e+07	3.0e+07	3.0e+07	5.1e+07	6.8e+07
27.8	28.9	28.04	26.7	28.5	28.3	27.7	26.5	54.6	55.3
5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	1.9e+07	1.9e+07

Slovenia	Slovenia	Slovenia	Slovakia	Slovakia	Slovakia	Slovakia	Slovakia	Slovakia	Slovakia
24	24	24	23	23	23	23	23	23	23
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
9.049	8.842	8.721	19.904	22.193	22.063	21.264	21.181	20.918	21.832
9403	8783	8283	21619	21129	20362	19761	19348	18459	17984
28.651	27.746	26.593	21.495	20.935	21.075	20.998	23.717	20.415	20.42
1.0e+06	997500	990900	2.7e+06	2.7e+06	2.7e+06	2.7e+06	2.7e+06	2.7e+06	2.7e+06
8.2e+06	8.7e+06	9.1e+06	2.3e+07	2.9e+07	2.9e+07	2.7e+07	2.6e+07	2.6e+07	3.2e+07
14.4	14.3	13.84	28.4	29.4	29.5	28.4	27.93	27.8	28.2
2.0e+06	2.0e+06	2.0e+06	5.5e+06	5.5e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06	5.4e+06

Slovenia	Slovenia	Slovenia	Slovenia	Slovenia	Slovenia	Slovenia	Slovenia	Slovenia	Slovenia
24	24	24	24	24	24	24	24	24	24
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
6.57	6.479	6.11	6.115	7.39	7.611	7.995	8.13	8.067	8.86
10053	9563	9260	9081	8850	8935	9168	9065	8955	9696
18.32	17.379	18.655	19.108	19.634	19.032	19.944	21.082	24.131	29.443
1.0e+06	982100	991900	990625	989875	996075	998125	1.0e+06	1.0e+06	1.0e+06
6.2e+06	5.4e+06	5.3e+06	5.2e+06	6.8e+06	8.2e+06	8.2e+06	8.2e+06	8.2e+06	8.2e+06
14.9	14.5	14.19	13.9	14	13.8	13.9	13.34	12.5	14
2.1e+06	2.1e+06	2.1e+06	2.1e+06	2.1e+06	2.1e+06	2.1e+06	2.0e+06	2.0e+06	2.0e+06

Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Slovenia	Slovenia
25	25	25	25	25	25	25	25	24	24
2012	2011	2010	2009	2008	2007	2006	2005	2019	2018
135.64	132.688	121.483	136.936	163.462	186.573	179.725	183.627	6.254	6.492
258122	265993	268177	267741	278211	275764	266170	255680	10849	10509
18.528	20.022	21.789	23.113	27.836	29.862	30.027	29.012	19.62	19.262
2.3e+07	2.3e+07	2.3e+07	2.3e+07	2.3e+07	2.2e+07	2.2e+07	2.1e+07	1.0e+06	1.0e+06
1.5e+08	1.5e+08	1.5e+08	1.5e+08	1.5e+08	1.6e+08	1.7e+08	1.7e+08	4.3e+06	6.0e+06
260.7	261.7	265.79	262.1	276.9	273.8	271.1	266.78	14.9	15
4.7e+07	4.7e+07	4.7e+07	4.6e+07	4.6e+07	4.5e+07	4.4e+07	4.4e+07	2.1e+06	2.1e+06

Sweden	Sweden	Sweden	Spain	Spain	Spain	Spain	Spain	Spain	Spain
26	26	26	25	25	25	25	25	25	25
2007	2006	2005	2019	2018	2017	2016	2015	2014	2013
19.041	20.002	19.382	109.523	127.374	136.317	123.557	137.27	124.851	122.808
886645	856193	816299	296719	290658	284154	275948	267830	257937	254416
24.166	23.229	22.412	20.081	19.447	18.671	17.96	18.014	17.78	17.371
4.8e+06	4.8e+06	4.7e+06	2.3e+07	2.3e+07	2.3e+07	2.3e+07	2.3e+07	2.3e+07	2.3e+07
2.3e+07	2.2e+07	2.2e+07	1.1e+08	1.4e+08	1.4e+08	1.3e+08	1.2e+08	1.2e+08	1.6e+08
139.6	138.6	139.34	255.3	260	261.1	255.7	254.27	249	252.2
9.1e+06	9.1e+06	9.0e+06	4.7e+07	4.7e+07	4.7e+07	4.6e+07	4.6e+07	4.6e+07	4.7e+07

Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden
26	26	26	26	26	26	26	26	26	26
2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
19.648	19.736	19.236	19.327	20.143	18.172	19.854	22.661	17.492	20.081
1.0e+06	1.0e+06	994856	954298	928733	918142	920821	891830	843863	881292
25.136	24.211	23.753	23.228	22.445	22.724	22.894	22.49	22.494	24.546
5.4e+06	5.3e+06	5.2e+06	5.2e+06	5.1e+06	5.1e+06	5.0e+06	4.9e+06	4.9e+06	4.9e+06
3.2e+07	3.2e+07	3.2e+07	3.3e+07	3.8e+07	2.3e+07	2.3e+07	2.4e+07	2.1e+07	2.1e+07
135.8	135.7	132.52	130.7	133.2	136	132.6	140.07	131.5	137.1
1.0e+07	9.9e+06	9.8e+06	9.7e+06	9.6e+06	9.5e+06	9.4e+06	9.4e+06	9.3e+06	9.2e+06

Sweden	Sweden
26	26
2019	2018
18.771	19.856
1.1e+06	1.1e+06
24.41	25.18
5.5e+06	5.4e+06
2.6e+07	3.0e+07
131.4	135.6
1.0e+07	1.0e+07

B. Stata Do File

```
// Define Panel Data

xtset id year


// Log-variables

generate lnemi = ln(emi)

generate lngdp = ln(gdp)

generate lnfcf = ln(fcf)

generate lnlab = ln(lab)

generate lnall = ln(all)

generate lnint = ln(ele/gdp)

// Growth rates

generate dlnemi = D.lnemi

generate dlngdp = D.lngdp

generate dlnfcf = D.lnfcf

generate dlnlab = D.lnlab

generate dlnall = D.lnall

generate dlnint = D.lnint

generate L1y = dlnemi[_n-1]

generate L2y = dlnemi[_n-2]
```

```
// Pooled OLS estimation

//==============================================

reg dlnemi dlngdp dlnlab lnfcf dlnall dlnint


// Fixed Effects estimation

//==============================================

xtreg dlnemi dlngdp dlnlab lnfcf dlnall dlnint, fe vce(robust)


// Random Effects estimation

//==============================================

xtreg dlnemi dlngdp dlnlab lnfcf dlnall dlnint, re vce(robust)


// Blundell-Bond Two-Step System GMM estimation

//==============================================

xtabond2 dlnemi dlngdp dlnlab lnfcf dlnall dlnint, gmm(L1y L2y) iv(dlngdp dlnlab
lnfcf dlnall dlnint) robust twostep nodiffsargan


// Pesaran(2006) CCE Estimation

//================================================

xtcce dlnemi dlngdp dlnlab lnfcf dlnall dlnint, pooled

//xtcce dlnemi (dlngdp dlnlab lnfcf dlnall dlnint = L.dlngdp L.dlnlab L.lnfcf
L.dlnall L.dlnint L.dlnemi), gmm pooled
```

```
// Bai (2009) Interactive Fixed Effects
//================================================
regife dlnemi dlngdp dlnlab lnfcf dlnall dlnint, ife(id year, 1)



// Panel Causality Tests
//dependent variable: dlnemi
xtabond D.L(0/3).lnemi D.L(1/3).lngdp D.L(1/3).lnlab D.L(1/3).lnfcf
D.L(1/3).lnall D.L(1/3).lnint, vce(robust) artest(2)
matrix varcov=e(V)
matlist varcov
estat abond

test LD.lngdp L2D.lngdp L3D.lngdp
test LD.lnall L2D.lnall L3D.lnall
test LD.lnint L2D.lnint L3D.lnint


//dependent variable: dlngdp
```

```
xtabond D.L(0/3).lngdp D.L(1/3).lnemi D.L(1/3).lnlab D.L(1/3).lnfcf
D.L(1/3).lnall D.L(1/3).lnint, vce(robust) artest(2)

matrix varcov=e(V)

matlist varcov

estat abond


test LD.lnemi L2D.lnemi L3D.lnemi

test LD.lnall L2D.lnall L3D.lnall

test LD.lnint L2D.lnint L3D.lnint



//dependent variable: dlnall

xtabond D.L(0/3).lnall D.L(1/3).lnemi D.L(1/3).lnlab D.L(1/3).lnfcf
D.L(1/3).lngdp D.L(1/3).lnint, vce(robust) artest(2)

matrix varcov=e(V)

matlist varcov

estat abond


test LD.lnemi L2D.lnemi L3D.lnemi

test LD.lngdp L2D.lngdp L3D.lngdp

test LD.lnint L2D.lnint L3D.lnint
```

```
//dependent variable: dlnint

xtabond D.L(0/3).lnint  D.L(1/3).lnemi D.L(1/3).lnlab D.L(1/3).lnfcf
D.L(1/3).lngdp D.L(1/3).lnall, vce(robust) artest(2)

matrix varcov=e(V)

matlist varcov

estat abond


test LD.lnemi L2D.lnemi L3D.lnemi

test LD.lngdp L2D.lngdp L3D.lngdp

test LD.lnall L2D.lnall L3D.lnall
```

CURRICULUM VITAE

Surname, Name: Bolat, Cankut Kaan

EDUCATION

Degree	Institution	Year of Graduation
MS	METU, Chemical Engineering	2017
BS	METU, Chemical Engineering	2014
High School	ÇEAŞ Anadolu High School, Adana	2009

FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

HOBBIES

Quidditch, Podcasting, Singing, Acting, Stand – up