ASSESSING THE IMPACT OF THE EU EMISSIONS TRADING SYSTEM ON CO_2 EMISSIONS: A SYNTHETIC CONTROL APPROACH

by

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ABSTRACT

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Keywords: the EU ETS, climate policy, policy evaluation, synthetic control method

The EU Emissions Trading System (EU ETS) is not only the key climate change policy of the EU but also the first multinational cap-and-trade system. However, there are many critics on the effectiveness of the scheme. This study aims to evaluate the effectiveness of the EU ETS in terms of carbon dioxide emissions abatement during the 2005-2014 period using the synthetic control method. The synthetic control method eliminates the potential bias that can be caused by wrong comparison case selection for comparative case studies by using a data-driven procedure. The study firstly estimates per capita carbon dioxide emissions scenario in the absence of the EU-ETS for the EU-15 average. This counterfactual scenario is reproduced with weighted combination of per capita carbon dioxide emissions values of Japan, Israel and the United States. The difference in per capita carbon dioxide emissions between the actual and the counterfactual EU-15 gives the emissions reduction led by the EU ETS. The results show that the emissions during the first two years of the EU ETS are slightly higher than its synthetic counterpart. Although there are ups and downs in the emissions abatement led by the EU ETS, the observed emissions are lower than the amount that would have been in the absence of the policy between 2007 and 2014.

ÖZET

AVRUPA BİRLİĞİ EMİSYON TİCARETİ SİSTEMİNİN CO_2 SALIMINA ETKİSİNİN İNCELENMESİ: SENTETİK KONTROL YAKLASIMI

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Prof. Dr. Meltem Müftüler-Baç, Tez Danışmanı

Anahtar Kelimeler: AB emisyon ticareti sistemi, iklim politikası, politika değerlendirmesi, sentetik kontrol method

AB Emisyon Ticareti Sistemi sadece AB'nin temel iklim politikasi değil aynı zamanda ilk çokuluslu emisyon üst sınırı ve ticareti sistemidir. Ancak bu politikanın etkinliği konusunda pek çok eleştiri mevcuttur. Bu çalışma sentetik kontrol metodunu kullanarak 2005-2014 dönemi boyunca AB Emisyon Ticareti Sistemi (AB ETS)'nin carbon dioxide salımının azaltılması açısından etkinliğini değerlendirmeyi amaçlamaktadır. Sentetik kontrol metodu veriye dayalı bir teknik kullanarak karşilaştırmalı vaka analizi çalışmalarında yanlış karşılaştırma vakası seçiminden kaynaklanabilecek potansiyel yanılmayı engeller. Bu çalışma ilk olarak AB ETS'nin olmadığı durumdaki AB-15 ülkelerinin ortalama kişi başına düşen carbon dioxide salımlarının ne olabileceğini hesaplamaktadır. Bu karşıolgusal senaryo Japonya, İsrail ve ABD'nin kişi başına düşen carbon dioxide salımı değerinin ağırlıklı kombinasyonuyla oluşturulmuştur. Gerçek ve karşıolgusal senaryo arasında kişi başına düşen carbon dioxide miktarı farkı AB ETS kaynaklı carbon dioxide salımının miktarını verir. Sonuçlar AB ETS'nin ilk iki yılındaki salım miktarının, sentetik karşılığındakinden kısmen daha fazla olduğunu göstermiştir. AB ETS kaynaklı salım azalmasında iniş çıkışlar olmasına rağmen 2007-2014 yılları arasında gözlemlenen salım miktarı politikanın yokluğunda salınabilecek emisyon miktarından daha azdır.

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CHAPTER 1

INTRODUCTION

Everything around the world from cloths to the foods requires the consumption of energy that comes from fossil fuels. On the one hand energy contributes global development and took many people out of poverty. However, the CO_2 that comes from the consumption of fossil fuels create greenhouse effect and warms the earth. The pre-industrial time scientists state that when the earth warms about 2°C, its impact will be dangerous. To stop or to control CO_2 emissions level in the earth, the Conference of Parties (COP) has taken place since 1992 and parties try to put together a common action plan for climate change. The latest one, COP21 held in Paris on December 2015. More than 190 countries came together to discuss a possible new global agreement on climate change. Many people from different groups joined to this conference in Paris such as lobbyists, government delegates and representatives of industry, business and agriculture. The purpose of the conference is limiting the CO_2 emissions, while allowing the economic development of the countries. Also it aims to provide assistance to the countries that are affected by the increasing temperatures. The increasing impacts of the climate change, increase the importance of multi-national agreements and climate policies day to day. The EU Emissions Trading System (EU ETS) as a first attempt and multi-national policy to control CO_2 emissions, the effectiveness of the policy and lessons learned from the 11 years experience are crucial for the rest of the world to design an effective climate policy.

The EU ETS is the first multi-national and the largest cap-and-trade system, which is designed in order to meet the targets of the Kyoto Protocol with minimal cost. It is a market based policy which cover 13.500 installation and 200 airline companies within the 28 EU member states plus Norway, Iceland, and Liechtenstein (Ellerman et al., 2016). Main objectives of the EU ETS are reducing CO_2 emissions in a cost effective way and promoting low carbon investments and the use of renewable energy resources (Grubb et al., 2012). The structure of the scheme has changed much in accordance with requirements and problems since the beginning of the policy, from method of allocation to the sectors covered by the scheme. The EU ETS is the key climate policy of the EU since 2005 and the 2030 Framework, which reaffirms the EU ETS as the main policy to meet GHG emissions target, is approved by the European Council in 2014. However, the framework states the necessity of a reform for solution of current problems (Healy et al., 2015).

Since the beginning of the EU ETS, many aspects of the scheme have been discussed not only by policy makers but also scholars. The most important indicator of the efficiency of a cap-and-trade policy is the abatement in emissions. However, simply observed reduction in emissions does not mean that the policy is successful. To measure the abatement in emissions led by the EU ETS, many researchers conducted studies using different techniques. Most of the studies in the literature estimate what the emissions would be in the absence of the EU ETS, generally by using traditional econometric models (Ellerman and Buchner, 2008; Delarue et al., 2008; Anderson and Di Maria, 2011; Abrell et al., 2011; Ellerman and Feilhauer, 2008; Delarue et al., 2008; McGuinness and Ellerman, 2008; Declercq et al., 2011; Egenhofer et al., 2011; Laing et al., 2013; Grubb et al., 2012; Kettner et al., 2011; Gloaguen and Alberola, 2013). Common problems of these studies are the lack of accurate baseline emissions data for sectors covered by the EU ETS and the difficulty to control CO_2 emissions led by the 2008 economic crisis. Moreover, there are a few analyses look into the impact of new allocation method “auctioning” which is a fundamental technic as of phase III.

Similar to other studies in the literature, the aim of this study is to measure the impact of the EU ETS on CO_2 emissions during 2005-2014 period by estimating the counterfactual scenario. However, different than the other researchers that use econometric models, this study uses a comparative case study method. The synthetic control method is a comparative case study method that reproduces a synthetic control unit, which is a weighted combination of many comparison units. To evaluate the effectiveness of the EU ETS, this study estimates what per capita CO_2 emissions would have been in the absence of the policy by forming a synthetic EU-15, which composed of weighted combination of ten control countries.

Chapter 2 firstly explains the origin and main characteristics of the emissions trading system. The technical details of the cap-and-trade system are presented. In the second part of this chapter technical details and the main characteristics of the EU ETS are explained. The features of the three phases of the EU ETS are summarized.

Chapter 3 is a summary of the existing literature on the evaluation of the EU ETS in terms of CO_2 emissions. This chapter is classified as pre-financial crisis and post-financial crisis because 2008 financial crisis is critical for the evaluation of the emissions abatement. Almost all quantitative studies in the literature are ex-post analysis and estimate business-as-usual scenarios. Only, Hu et al. (2015) makes an ex-ante evaluation of the EU ETS that looks into the impact of the EU ETS on emissions for the 2013-2030 period. In addition to quantitative evaluations, small number of researchers conduct surveys and interviews in order to evaluate the effectiveness of the scheme with regards to CO_2 emissions.

In the Chapter 4, after a short summary of the comparative case studies, counterfactuals, difference-in-difference method and the details of the synthetic control method are discussed. Finally, two studies that implement synthetic control method, are summarized. The first study, conducted by Abadie et al. (2015), looks into the impact of the German reunification on the economics of the West Germany. The second one discusses the impact of the Kyoto Protocol on domestic CO_2 emissions.

In Chapter 5, the design of this research is explained in detail. While the treated unit is the mean of the EU-15 countries, the donor pool is composed of Argentina, Brazil, Canada, Chile, Israel, Japan, Korea, Mexico, Turkey and the United States. The outcome variable is chosen as per capita CO_2 emissions, and the predictors of this outcome variables are selected as alternative and nuclear energy share, energy use per capita, electric power consumption per capita, energy intensity of industrial sector, GDP per capita and population growth.

In Chapter 6, the results of the study are illustrated. The difference between the synthetic and actual EU-15 demonstrates that there is an increase in emissions during the first two years of the EU ETS. Although the emissions abatement shows an alteration during the analysis period, the continuous emissions reduction is observed from 2007 onwards. However, large gap between the observed emissions value and counterfactual scenario cannot be explained only with the EU ETS when the low carbon prices and high amount of surplus allowances are taken into consideration. The impact of the increasing national renewable energy and energy efficiency policy may contribute emission reduction; however, the selected methodology for this study remains incapable to measure the impact of the ETS after 2010 due to the changing dynamics within the Europe.

CHAPTER 2

HISTORY AND STRUCTURE OF THE EU ETS

The European Union is one of the leading actors that make a great effort in order to reduce the greenhouse gases (GHG) emissions. The EU was also one of the main actors spending time for internal coordination and the content of the Protocol during the Kyoto negotiations. After Kyoto, each member state and the Community have quantitative emissions targets. The EU's aim was 8% reduction of GHG emissions by 2012 from the level in 1990. To reduce its GHG emissions and meet the Kyoto targets cost-effectively, the European Union has developed emissions trading system.

The EU ETS puts limits on the emissions of energy intensive sectors and power plants. Within the frame of this system, companies can sell and buy CO_2 allowances when they need. The EU ETS gives enterprises an opportunity to cut their emissions in a cost-effective way in 28 EU member states, Iceland, Liechtenstein and Norway. Under this scheme, the options of the companies are investing on more efficient technologies, using low-carbon energy resources and purchasing allowances from the market.

The system covers about 13.500 power plant and manufacturing companies and also the GHG share covered by the system is 45% of the total EU emissions (Ellerman et al. 2016). In the first period (2005-2007), the system includes power and heat generating sector and energy-intensive industry sectors, such as combustion plants, oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, bricks, ceramics, pulp and paper. In the second period (2008-2012), in addition to the previous period, nitrous oxide (NO_2) emissions from the production of nitric acid is included to the scheme. At the beginning of the third period (2013-2020), the CO_2 emissions from the civil aviation is included to the EU ETS. The civil aviation companies of all nationalities need emissions allowance for their flights from, to or within the EU. Also, perflourocarbons (PFCs) from aluminum industry is covered by the scheme.

2.1. Emissions Trading System

The Kyoto Protocol that emerged from the United Nations Framework Convention on Climate Change is the first international agreement targets to reduce the GHG emissions. The protocol was signed in Kyoto, Japan, on December 1997 and it could not be put into force until 2005 because the total emissions of the approving parties should have been at least 55% of total worldwide GHG emissions in order for the protocol to be enacted. With the ratification of Russia on November 2004, the 55% requirement was satisfied. A substantial reduction in global emissions took place after the Protocol became an international law. The average emissions reduction aim was 5.2% by 2012 as compared to the CO_2 emissions level of 1990 (Kyoto Protocol, 1997). To achieve this objective, three main mechanisms were central: Joint Implementation, Emissions Trading (ET) and the Clean Development Mechanism.

2.1.1. The Development of Emissions Trading

The idea of the ET is originated from The Problem of Social Cost, which is written by Ronald Coase in 1960 (Convery, 2009). According to Coase, the pollution issue is related to property rights and the solution of this problem should be left to the market dynamics. In 1968, John Dales formed the main principles of the cap-and-trade system, and he theorized the relation between the market competition and the pollution reduction cost within the frame of cap-and-trade system on pollution (Hahn & Stavins, 2010).

The first cap and trade applications were;

- The early Environmental Protection Agency (EPA) Emissions Trading programs (in 1970s).
- The Lead Trading program for gasoline (in the 1980s).
- The Acid Rain program for electric industry sulfur dioxide (SO_2) emissions, and the Los Angeles air basin (RECLAIM) programs for nitrogen oxides (NO_X) and SO_2 emissions (in the mid-1990s).
- The federal mobile source averaging, banking, and trading (ABT) programs (in the early 1990s).

- The Northeast NO_X Budget trading program (in the late 1990s) (Schmalensee & Stavins, 2015)

After the analysis of these initial applications, Ellerman et al. (2003) concludes that properly prepared and conducted emissions trading systems are successful in reducing the cost of meeting emissions goals.

2.1.2. Cap-and-trade System

Designing an effective ETS requires making decisions on the allocation methods, type of the system, determination of cap, the coverage of the system and compliance. The "emissions trading" refers to three different types of trading programs: (1) reduction credit trading, (2) emissions rate averaging, and (3) cap-and-trade programs (Ellerman et al., 2003). The EU ETS is a cap-and-trade emissions trading system, so this section analyzes the features of the cap-and-trade system.

In cap-and-trade systems, governments decide which sectors or gasses are covered by the system, and they determine emissions target or cap for covered emissions (Pew Center, 2008). This cap is the sum of allowed emissions from all installations. The covered installations have to submit their emissions allowance. Allowance trade occurs between the installations, which emit different level of emissions. The companies that can implement low-carbon technologies more easily and in an inexpensive way than the others, buy less allowance or sell their allowance surplus to the companies that face with high emissions reduction cost (Pew Center, 2008). The installations that can reduce their emissions relatively in an inexpensive way prefer to invest on new technologies; however, the other group that cannot make abatement in a profitable way chooses to benefit from relatively low prices of emissions permit in the market for compensating their excessive emissions instead of adopting expensive implications for reduction (Buckley et al., 2004).

2.1.2.1. Coverage of Cap-and-trade

According to Skjærseth and Wettestad (2008) the sectors, gasses and the companies which will be included in the scheme should be determined in the design phase of the ETS. They state that another important decision in terms of coverage issue is whether the scheme will be mandatory or voluntary. Even if it is a mandatory system, the system still may include the right of opt-out from some sectors and installations. Expanding the coverage of the system in terms of gasses, sectors and installations is the cheapest way for emissions reduction. Butsengeiger et al. (2001) also emphasize the importance of the coverage of the ETS by stating that the broader coverage means the more efficient and environmentally effective system.

Additionally, Skjærseth and Wettestad (2008) notes that whether the system targets fossil-fuel producers and consumers or end-users of energy is another essential decision. Finally, accountability is another issue within the scope of coverage. The measurability of the GHG covered by the system has crucial importance in order for understanding the effectiveness of the policy. The uncertainty about measurement or estimation of the emissions makes the scheme dysfunctional (Lefevere, 2005).

2.1.2.2. Setting the Cap

Setting the caps is one of the main phases of the ETS design; it determines the strictness of the system and also affects the outcomes and effectiveness of the system. In a cap-and-trade system, the cap also determines scarcity level of the allowances and the carbon price. In the process of setting caps, national, regional and international policies; changes and the competitiveness in the market and economic conditions should be taken into account (Brohé et al., 2009).

2.1.2.3. Methods of Allocation

The total emissions allowed under the emissions trading system can be distributed as emissions “allowance”, “permits” or “rights” (Lefevere, 2005). The allowance distributed to the installations and the process of distribution is called “allocation”. Allocation of allowance is politically the most problematic phase of the ETS design because allocation determines which actor gets the economic value of the emissions rights. Hence, the negotiation process on allocation of allowances is the most time consuming part of the ETS design (Lefevere, 2005). There are two main allocation methods for emissions trading: free allocation and auctioning. These methods can be implemented individually or both of them can be combined (Goulder et al., 2010).

Free Allocation

Basically, there are two kinds of free allocation methods that are used practically in the ETS. These methods differ from each other in terms of their emissions allowance calculation methodologies.

The first approach is "grandfathering" which considers the historical emissions data in order to determine the amount of allowance allocations to the installations covered by the scheme. The industry usually is a favour of this approach because they do not have to pay for allocation but they can make a gain by selling their surplus (Lefevere, 2005). Although it is easier to convince the actors from industrial sector to use this method, there are concerns about the efficiency and fairness of this method. First of all, the past emissions amount may differ according to the sector, the energy type they consumed, the technology they used or their energy efficiency level. Hence, a more energy efficient installation may be punished with less allowance. This situation may create unfairness and conflict (Lefevere, 2005). Moreover, De Larragán (2008) notes that the grandfathering system based on past emissions data may reduce willingness for emissions abatement. Since they will get emissions permit in the future according to their current performance, they might not perform ambitiously for emissions reduction. The installations want to get more allowance, and the allowance demand of the installations create over inflated measures. Consequently, the "grandfathering" approach may cause "over-allocation" problem (Chlistalla and Zähres, 2010). Another source of over-allocation is the wrong allowance estimations of the regulators for new entrants to the system (Lefevere, 2005). The reduction in emissions as a conclusion of economic crises may be another reason of over-allocation problem (Chlistalla and Zähres, 2010). Over-allocation hinders the functioning of the system efficiently by causing excessive supply of emissions allowance (McAllister, 2009).

The second approach of the free allocation methods is the "benchmarking". Betz et al. (2007) notes that "under benchmarking, allocations is based on specific emissions values per unit of production (e.g., kilogram of CO_2 per megawatt hour electricity or ton of CO_2 per ton of cement clinker) for a particular group of products or installations". Behn states that under the benchmarking, the amount of allowance can be linked to actual production instead of historical data and this approach allows for updates of caps when the production changes. According to economists benchmarking is more advantageous than grandfathering (Beth, 2009). However, grandfathering is simpler to implement than benchmarking. The benchmarking requires essential emissions standards, knowledge of best available techniques (BATs) and sensitive information (Sépibus, 2007).

Auctioning

Auctioning is other allocation method in which the allowances are distributed as a result of auction conducted by the authority regularly. Since it is the most transparent and easy to implement in theory, economists advocate to use auctioning. However, in practice it is difficult to implement this method due to the opposition from the industry (Lefevere, 2005). For the installations, buying allowance means paying for their asset which they get free under the free allocation system.

The auctioning increases the macroeconomic efficiency of the system, decreases the price volatility and negative consequences related to free allocation, and has almost no negative impact on competitiveness; however, implementation of auctioning requires high management attention (Hepburn et al., 2006). Moreover, auctioning requires lower administrative cost than free allocation methods (Cramton & Kerr, 2013).

2.2. The EU Emissions Trading Scheme

The EU ETS inspires the development of the regional and national emissions trading systems in various parts of the world. This section explains baxground and technical details of the EU ETS.

2.2.1. The Background of EU ETS

In Kyoto, the EU was one of the main actors spending time for internal coordination and the content of the Protocol. After the Kyoto Protocol, each member state and the Community have quantitative emissions targets. The EU members sign the Burden-sharing Agreement in 1998 in order to set emissions levels for each member state. Table 1 shows the emissions reduction targets under the 1998 Burden-sharing Agreement.

The first steps towards to the emissions trading system were 1998 and 1999 Communications of the Commission on the implementations of the Kyoto strategies. As a second step, the Commission prepared a Green Paper on the EU Emissions Trading which includes design of system in 2000 and following this step the European Climate Change Programme (ECCP) was constituted within a month. The report of the ECCP is published in

June 2001 and the Commission's emissions trading directive proposal is submitted in October 2001, which initially only includes CO_2 emissions in power industry (Christiansen and Wettestad, 2003, as cited in Skajerseth & Wettestad, 2008). The Council adopted the proposal in October 2003. The design of National Action Plans (NAPs) is a central task which is the national implementation part of the emissions trading. These plans include setting total allowances and the distribution of this total allowances among the companies which covered by the emissions trading. Although NAPs and national CO_2 allowance allocations could not be completed, the scheme started in 2005.

Member-state	**Target share**
Austria	-13%
Belgium	-7.5%
Denmark	-21%
Finland	0%
France	0%
Germany	-21%
Greece	+25%
Ireland	+13%
Italy	-6.5%
Luxemburg	-28%
The Netherlands	-6%
Portugal	+27%
Spain	+15%
Sweden	+4%
United Kingdom	-12.5%

Table 1. Member-state goals under the 1998 Burden-sharing Agreement.

2.2.2. The Technical Features of the System

2.2.2.1. Phase I (2005-2007)

Within the framework of the EU ETS, every enterprise has verified amount of allowance allocation. For the first two periods, every member state allocates a certain amount of allowance to the enterprises in the direction of their NAPs. NAPs include the amount of allocations at both countrywide and installation level. The member states have to prepare their NAPs according to the Commission Directive. After the design of NAPs, the Commission has to approve the NAPs prepared by the member states in order to ensure the appropriateness of the allocation plans (Skajerseth & Wettestad, 2008). However, as a result of lobbying of industry and lack of historical emissions data, NAPs were designed generously for Phase I. The major impact of over-allocation was a decrease in carbon prices. The carbon price reached to the zero in 2007 because of the supply excess of carbon allowances (Brohé et al., 2009).

During this period, 95% of the allowances were allocated free of charge with grandfathering method, but some member states auctioned 5% of total allowance. For phase I, benchmarking was used for new entrants to the market. The companies can trade carbon in the market with the enterprises and brokers from other member states in order to balance their actual emissions and allowed emissions.

2.2.2.2. Phase II (2008-2012)

Because of the over-allocation problem in the first period, the Commission cut the amount of allowances in the second phase and many installations got less emissions allowances than they had in phase I. Although the Commission cuts the amount of allowances, the carbon price fell during the second period because of economic crisis.

Similar to the first period, most of the allowances allocated freely with grandfathering method and 10% of total allowances were distributed with auctioning.

2.2.2.3. Phase III (2013-2020)

The third phase is more centralized system compare to the first two phases. According to the plans, cap will decline by at least 1.74% per year and total reduction will be at least 21% in 2020. The metal industry and also some other GHGs in addition to CO_2 are included to the EU ETS. Moreover, the scheme is extended to the aviation industry which includes all flights taking off and landing in the EU from January 2013 onwards.

Both free allocation and auctioning are used in the third phase. The Commission adopted the use of benchmarking for free allocation due to the comparative advantage over grandfathering in terms of competitiveness and fairness (Chlistalla and Zähres, 2010). During the third period, the power generation sector gets all of their allowance with auctioning. The auction is conducted by member states and the all revenue goes to the states but they have to use at least 50% of this revenue for climate change policies.

The EU ETS Features	
Parties	28 EU member states, Iceland, Liechtenstein and Norway
Caps	• Phase I: Cap is set by member state in NAPs • Phase II: Similar to Phase I • Phase III: Centralized EU-wide cap: 2.04 billion tCO2 in 2013, reduced by, 1.74% annually from the average annual total quantity of allowances issued by the Member States in 2008-2012. The 2020 target is 1.78 billion tCO2.
Covered GHGs	CO_2, N_2O, PFC (starting in 2013)
Covered Sectors	• Phase I: Power stations and other combustion plants, and industrial installations (oil refineries, coke ovens, iron and steel plants and installations producing cement, glass, lime, bricks, ceramics, pulp, paper and board). • Phase II: Phase I covered sectors, plus aviation (since 2012) • Phase III: Phase II covered sectors, plus installations undertaking the capture, transport and geological storage of greenhouse gases; CO_2

	emissions from additional industrial installations (petrochemicals, ammonia, non-ferrous metals, gypsum and aluminum sectors); N_2O emissions from the production of nitric, adipic and glyoxylic acid; and PFC emissions from aluminum production.
Trading Period	• Phase I, 2005-2007 • Phase II, 2008-2012 • Phase III, 2013-2020
Allocation Method	• Phase I: Largely free allocation through grandfathering • Phase II: Similar to Phase I with some benchmarking for free allocation and some auctioning • Phase III: Auctioning as principal allocation method (100% for power sector) and free allocation for industry based on ambitious benchmarks

Table 2. Summary of basic features of the EU ETS.

The structure of the EU ETS has evolved so much since the beginning of the policy with the impact of problems and requirements. Although, it is an innovative climate policy in theory, it is extremely difficult to implement such a large-scale policy which includes power sector and many energy-intensive industrial sectors in 31 countries. Considering the increasing importance of the climate change problems and global attention to possible solutions for global warming, the evaluation of the current climate policies is critical. There is substantial amount of research on the climate change and policies. However, political scientists do not contribute much to the literature, despite the significance of the politics on adaptation to climate change (Javeline, 2014). The implementation of large-scale climate policies and the complexity of international climate negotiations require the contribution of political scientists (Keohane, 2015).

The first two phases of the EU ETS are criticized mainly because of the allocation method and highly decentralized characteristics of the scheme. The main method of allocation during the first two phases is free allocation. In addition to over-allocation problem caused by the free allocation, this method also provides “windfall profit” to the installations. The companies that can reduce their emissions easier than the others make profit by selling their excess allowances that are allocated to them free. However, Ellerman et al. (2016) emphasizes the necessity of decentralized free allocation system in order for the participation of all member states. Although, the European Parliament is in favor of auctioning as allocation method, the 95% of the total allowances in the first period and the 90% of the allowances in the second period are allocated freely. Although the carbon price reaches to 30€ in 2006, it falls until 0.10€ at the end of the Phase I. After the failure in Phase I, the allowances are cut by the Commission and the banking is introduced to encourage enterprises to decrease their emissions for transferring their emission allowances to the next phase. The CO_2 price recovers to more than 20€ at the beginning of the Phase II as a result of new restrictive emissions allowances. The economic crisis erupted in 2008, again pulls the price back to around 10€ and after a slight recovery at the beginning of 2009, the CO_2 price falls to 4€ at the end of the Phase II. In addition to the failure caused by the economic crisis in Phase II, the high amount of surplus allowances is carried to the Phase III. The surplus emissions reach to 2.1 billion tons at the end of 2013. The most important change in the Phase III is the initiation of auctioning but this new method of allocation cannot solve the accumulation of surplus problem and carbon price is still around 6 to 8€. There is substantial amount of surplus allowances in the market and as a result, the carbon price cannot be back on track. The discrepancy between the significant emissions reduction in the EU and the large amount of surplus allowances in the market with low level carbon price requires more explanation.

CHAPTER 3

LITERATURE REVIEW

The European Union Emissions Trading System (EU ETS) is the major climate policy of the EU launched in 2005, in order to meet the emissions abatement targets which set in the Kyoto Protocol. The scheme is the most comprehensive environmental policy of the world which covers approximately 13.500 power plants and manufacturing companies in energy intensive sectors such as iron, steel, coke, cement, glass, lime, bricks, ceramics, oil refinery, paper, pulp and board (Ellerman et al, 2016). Its far reaching sphere of influence and innovative design not only attract policy makers, climate change policy specialist and researchers in Europe but also in all over the world.

Since the beginning of the scheme, it has been one of the highly debated issues by environmental economics and policy scholars and policy makers regarding its impact on GHGs emissions, renewable energy and energy efficiency investments and economic activities of the manufacturing sector. Although large amount of emissions reduction has been observed since 2005, most of the abatement has taken place after the economic crisis erupted in 2008. The figure 1 shows the relationship between the economic activity and emissions. The two measures of the economic output: gross domestic product (GDP) and gross value added (GVA), and emissions from sectors covered by the EU ETS in the EU-25 are normalized to 2004 in the graph (Ellerman et al., 2016).

In order to understand the impact of the EU ETS independent from other changes, the studies on the evaluation of the EU ETS are crucial. In the literature, studies are classified under three topics: the impact of the scheme on emissions reductions, low-carbon technology investments and economic performance (Laing et al., 2013; Martin et al., 2012). This chapter reviews the literature on the EU ETS in terms of its impact on emissions abatement.

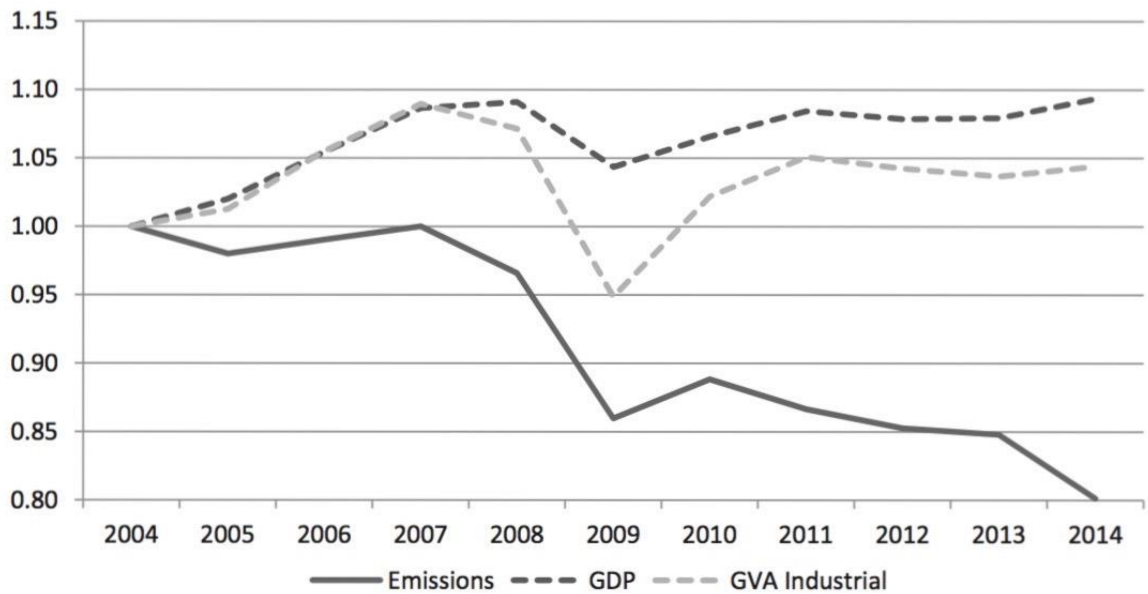

Figure 1. Emissions and economic output in the EU25 countries, 2004-2014. Retrieved from Ellerman et al. (2016).

In order to disentangle the impact of other factors on emissions reduction, most of the studies in the literature prefer to use counterfactual methods. They estimate what would be the emissions level in case of the absence of the EU ETS by using econometric models. In addition to quantitative business-as-usual methods, this chapter includes studies which use qualitative methods such as survey analysis and interviewing. Since the 2008 financial crisis is a break point for the EU ETS, this chapter reviews the literature under two section: pre-financial crisis and post-financial crisis.

3.1.Pre-financial Crisis

The first study on the impact of the EU ETS is conducted by Ellerman and Buchner (2008). They make the analysis of first two years of the EU ETS based on verified emissions data. The CO_2 emissions at the first two-year period was around 60 million tones lower than the allocated allowance amount to the installations. The paper looks for the answer of the question whether the reason of this difference between the allowance amount and observed emissions data is over-allocation or abatement. They make counterfactual analysis; in other word they estimate what CO_2 emissions would be in the absence of the EU ETS. Assuming that their baseline data reflects the reality, the result for counterfactual scenario is between 2.14 and 2.21billion tones of CO_2 for 2005 while the verified amount is 2.01. For 2006, the counterfactual estimate is between 2.17 and 2.25 billion tons of CO_2 but the observed amount is 2.03. Although the difference between the counterfactual and real data is around 130-200 million tones and 140-220 million tones for 2005 and 2006 respectively, when they adjust baseline data and reestimate the counterfactual amount, the difference is getting smaller.

Delarue et al. (2008) estimates the impact of fuel switching on CO_2 emissions amount in power sector under the EU ETS. In their econometric models they use the simulation tool E-Simulate. According to their estimates, the emissions reduction in power sector is 88 million tones for 2005 and 59 million tones for 2006.

Similar to previous studies, Anderson and Di Maria (2011) makes business-as-usual analysis of the first phase of the EU ETS and estimates the difference between the verified data and estimated BAU data. In order to make projection about counterfactual level of CO_2, they use historical data of European industrial emissions, energy prices, weather effects and industrial economic activity levels. The "baseline" period for the study is around 2002. The econometric equation for CO_2 emissions is estimated by using dynamic panel data estimation techniques. They use dynamic models which are mostly used in order to estimate the future demand of electricity, natural gas or other energy resources. According to their results, although the majority of over-allocation occurred in France, Poland and Germany; Italy, Spain and the UK are under-allocated member states. They concluded that there is net emissions reduction during the Phase I of the EU ETS with 247 $MtCO_2$ and 2.8% net abatement.

Abrell et al. (2011) looks for answers to following questions: first of all, is the reason of the observed CO_2 emissions reduction during the 2005-2009 period successful implementation of the EU ETS or the changing economic environment? Second, did the structural change in the phase II alter the abatement behavior? Third, what are the impacts of the first allocations on the emissions reduction behavior of the regulated firms? Finally, how the EU ETS affects the performances of the companies? Unlike other studies, they use the EU-wide firm level emissions data and take into consideration the structural break between first two phases. The firm-level panel data which includes verified emissions and allocation of allowance between 2005 and 2008 are obtained from Community Independent Transaction Log (CITL). The firm level performance data such as employment, profit margin, added value, turnover, labour and fixed capital cost between 2003 and 2008 are obtained from the AMADEUS database. In terms of emissions reduction, they conclude that emissions reduction in 2007-2008 periods is higher than it was in 2005-2006 period when they control factors related to economic environment. In terms of the efforts of the companies, the EU ETS was more effective in 2007-2008 terms than 2005-2006.

Other than European level analysis, separate country level analyses are made in order to evaluate the policy, considering the characteristics of the country. Ellerman and Feilhauer (2008) looks at the impact of the EU ETS in Germany which emits largest amount of CO_2 with 25% of the total coverage in the Europe. They make an upper and lower bound estimation by using the analysis applied by Ellerman and Buchner (2008) for upper bound and the E-simulation applied by Delarue et al. (2008) for lower bound. The top-down approach uses the economic activity, emissions intensity and emissions trends in order to estimate upper bound. For the lower bound they use the bottom-up approach and estimate the CO_2 abatement in the German power sector, which is the most significant sector of the EU ETS by covering 61% of total CO_2 emissions, by looking at simulation results both with the EU ETS and without it. In another single county based analysis, McGuinness and Ellerman (2008) estimates the abatement in the power sector as between 13 and 21 $MtCO_2$ for 2005 and between 14 and 21 $MtCO_2$ for 2006.

An alternative counterfactual study for evaluation of the EU ETS is conducted by Carbon Point (2009) based on the Carbon Survey Data. According to the survey results %54 of the participants from power and heating sector state that the EU ETS has led to abatement. Similarly, more than half of participants from metal and the oil/gas sector report that the EU ETS has caused abatement. Additionally, regulated companies under the EU ETS state that the additional EU allowances (EUA) they need has declined from 37% to 31% from 2008 to 2009. Similarly, the share of companies that has surplus EUAs has increased to 24% from %15. According to web-based survey study conducted by Sandoff and Schaad (2009) in Sweden, 94% of the firms state that they would not lessen their production in order to reduce emissions, instead they make more investments on energy efficiency for abatement. The study of Engels (2009) is based on the survey conducted by University of Hamburg between 2005 and 2007 to all companies included to the EU ETS in the UK, Denmark, Germany and the Netherlands. The survey results show that the companies do not develop a perspective for the EU ETS. As an illustration for this, many of the companies included by the EU ETS do not know their abatement cost.

Another group of qualitative studies are case-based analyses. Ikkatai et al. (2008) presents the results of interviews with companies in the Netherlands and Belgium about the impacts of the EU ETS. The company officers point out that many problems in Phase I such as over-allocation of the allowances and shortness of the period cause failure. Similarly, Fazekas (2009) makes interviews with the managers of two third of the installations included in the scheme in Hungary. The results show that there is no attributable emissions reduction in Hungary.

In short, based on evaluation studies summarized above although it is difficult to estimate exact abatement because of the lack of emissions data before beginning of the policy and the influence of other factors to emissions, they estimate some small level of abatement. However, qualitative studies show that there is no clear evidence regarding the positive impact of the policy.

3.2.Post-financial Crisis

The economic recession erupted in 2008 not only affected the European industry but also decreased the CO_2 emissions level. The effects of financial crisis make conducting business-as-usual evaluation studies more complex mostly because of lack of data (Laing et al., 2013).

The slowing down in industrial activities causes significant decrease in energy demand and thus decline in carbon emissions. Declercq et al. (2011) estimates the effect of the 2008 financial crisis on power sector CO_2 emissions after identifying the influence of the recession on energy demand, carbon and fuel prices. To determine the impact of the recession, they compare the current scenario based on observed historical data with counterfactual scenario based on determinants such as electricity demand, fuel price and CO_2 price by using a simulation model. The simulation model used for evaluation is E-simulate which is developed at K.U. Leuven and this model is also used in order to evaluate first phase of the EU ETS (Delarue et al., 2008). The results of the simulation show that the 2008-2009 economic crisis causes significant reduction of energy demand in the European power sector. The CO_2 emissions level was 175 Mt less than the amount that would be in the absence of an economic recession in the power sector. The low CO_2 price as a result of economic recession, increases the CO_2 emissions level by 30 Mt compare to the case of CO_2 price would continue around 25€/ton. Since it is hard to forecast fuel prices in the absence of the recession, it was difficult to set up counterfactual analysis design. However, they found that lower oil price cause 17 Mt reduction in CO_2 emissions. They estimated that the overall CO_2 emissions in power sector is about 150 Mt less than what would have been in the absence of the recession.

Egenhofer et al. (2011) makes the evaluation of the first two years of the Phase II. They use the approach used by Ellerman, Convery, de Perthius (2010) and extend their analysis to 2008 and 2009. In order to find the abatement in carbon level, they estimate BAU scenario based on the CO_2 intensity and compare the improvement in emissions intensity between the actual output and estimated counterfactual results. This method allows to estimate the impact of the EU ETS on emissions abatement. This abatement is different than the emissions caused by changes in production levels. While emissions intensity change is around 1% per annum in the 2006-2007 period, it is much higher than the previous period between 2008 and 2009 with 1.3% and 5.4% respectively. They also make the same analysis by using sector level data for industrial emissions and conclude that while the emissions intensity level increase by 1.9% in 2008, it decreases 2.8% in 2009.

Another study from New Carbon Finance concludes that just 40% of the 3% reduction in emissions abatement is caused by the EU ETS in 2008 and more than 30% of total reduction in emissions caused by economic recession (Laing et al., 2013).

The report published by Sandbag in 2009 emphasizes on the high amount of surplus CO_2 allowances mostly caused by over-allocation in Phase I and financial crisis in Phase II. The report states that 77% of the all installations in the EU ETS have surplus allowances and 637 $MtCO_2$ of 855 $MtCO_2$ excess allowances from Phase II are carried to Phase III. The steel and cement sectors are the ones that have accumulated the highest amount of permit in 2008-2010 period. The amounts which have accumulated in Phase II are 165 $MtCO_2$ worth €2.6 billion and 143$MtCO_2$ worth €2.3 billion for steel and cement respectively. They suggest that inclusion of aviation sector may contribute to increase the demand for excess allowances from Phase II in Phase III.

Grubb et al. (2012) examine emissions and energy intensity in order to estimate the impact of the EU ETS on emissions of the power sector by using data from IEA and CITL.

They present some evidences in order to illustrate the significant impact of the economic crisis on emissions and energy intensity.

Kettner et al. (2011) makes a sector-level evaluation and looks into emissions reductions in seven sectors which are covered by the EU ETS. Similar to other analyses they conclude that the reason behind the significant fall in emissions abatement in 2009 is financial crisis.

Gloaguen and Alberola (2013) used fixed effect regression model in order to evaluate the effect of the policy for 21 European countries between 2005 and 2011 by comparing the actual scenario with the counterfactual one. In sum, although policies implemented in order to meet European targets lead to 600-700 $MtCO_2$ emissions abatement in time period between 2005 and 2011, carbon pricing plays small role in the observed reduction. In parallel with other studies economic downturn has a significant impact on the decreasing emissions amount.

As opposed to ex-post analysis summarized above, Hu et al. (2015) makes an ex-ante evaluation of the EU ETS in order to estimate the impact of the policy in 2013-2030 period. They predict that the EU ETS will lead 5560 $MtCO_2$ of emissions abatement between 2013 and 2030 and 1465 $MtCO_2$ of total abatement will come from aviation sector. Moreover, approved and proposed measures by the European Commission would lead to 524 $MtCO_2$ additional abatement. However, these measures will not be sufficient to compensate surplus allowances coming from previous periods until the beginning of Phase IV. The study advices to policy makers to construct more flexible policy structure which can answer unexpected changes such as economic crisis. In addition to the aviation sector, they suggest to broaden the EU ETS to other sectors which potentially may demand high level of CO_2 emissions right such as transportation sector. Finally, the study suggests to increase the emissions reduction target for 2030 from 40% below 1990 level to 53%.

In addition to quantitative evaluation studies, there are also some qualitative methods in order to measure the impact of the EU ETS as noted in the previous section. According to the survey study conducted by Löschel et al. (2010) only 6% of 120 German firms state that the main factor behind the reduction in the emissions was the explicit target for abatement and 90% of the surveyed firms view the emissions abatement as side benefit of investments in order to increase energy efficiency (Martin et al., 2012).

Both quantitative and qualitative studies compiled above show that although high amount of emissions reduction is observed in post-financial crisis period, only small amount of this abatement is caused by the EU ETS. The excess emissions allowances carried from Phase II to next phase is one of the biggest problem in current situation. Although inclusion of the aviation sector is a step in order to solve this problem, further measures are essential for the continuity of the scheme.

CHAPTER 4

METHODOLOGY

Social scientists are interested in the impact of the policy interventions, infrequent events that influence large area at an aggregate level. They often prefer to use comparative case studies in order to estimate the impact of these changes. In comparative case studies scholars compare the evolution of the aggregate outcomes, which is directly related to the intervention between the unit exposed to the intervention and the control group that consist of units unexposed to the intervention. The main problem about the comparative case studies is the ambiguity about the selection of control units. At the comparison unit selection stage, researchers make their choices based on subjective measures. Moreover, the representativeness and the predictive effectiveness of the aggregate data are other problems. Even if researchers use complete aggregate data, traditional inference techniques may remain incapable to reproduce counterfactual outcome for the unit affected by the intervention in the absence of this intervention. To eliminate the ambiguity in comparative case studies Abadie and Gardeazabal (2003) suggest a data-driven procedure. This procedure decreases the subjectivity of the control unit selection process motivating researchers to use quantifiable measures. In most cases, finding single comparison control unit which resembles the unit exposed to the intervention is difficult. Abadie and Gardeazabal (2003) claims that instead of a single unit, using a combination of control units (synthetic control unit) reproduces a better comparison unit for treated unit. The synthetic control method is an extended form of difference-in-difference technique. While difference-in-difference method only looks at the change in outcome variable, synthetic control method considers the impact of unobserved confounding variables (Abadie et al., 2012).

This chapter explains the major characteristics of comparative case studies, counterfactuals and difference-in-difference estimation technique in order to present a background for synthetic control method. After short background information, it represents the key characteristics and requirements for the implementation of synthetic control method. In final section, the implementation of the synthetic control method for two empirical example from political science and climate science literature are summarized.

4.1.Comparative Case Studies

Kaarbo and Beasley (1999) define the comparative case studies as "systematic comparison of two or more data points (cases) obtained through use of the case study method" (p. 372). A case study is a detailed analysis of a single case such as policy intervention, systematic crisis or political change. However, in comparative case studies researchers compare more than one unit in order to understand the influence of the intervention. The selection of the units is crucial at research design phase for the feasibility of the conducted study. While one or more units have to be exposed to the intervention, one or more comparative units have to be unexposed (Abadie et al., 2012).

In order to establish a sound framework, the characteristics of the intervention, similarities and differences of the units exposed to this intervention have to be taken into consideration (Goodrick, 2014). Prezeworski and Teune (1970) advice researchers to select units as similar as possible in order to decrease the number of explanatory variables (Kaarbo and Beasley, 1999). In this sense key evaluation questions (KEQs) are significant. KEQs will guide researchers to decide whether the design is appropriate or not for the analysis of the intervention. Comparative case study method is more appropriate for the analysis of cases which have clear objectives. Mix methods that combine both qualitative and quantitative data are used in comparative case studies. These qualitative and quantitative data is gathered using some data collection technics such as surveys, performance measures, project documentations, interviews and observations (Goodrick, 2014).

4.2.Counterfactuals

Counterfactuals make statement about the cases that did not occur in reality. A quotation of Barrington Moore from Fearon (1991) illustrates counterfactual conditionality perfectly. Barrington Moore states that:

> "Without the prior democratic modernization of England, the reactionary methods adopted in Germany and Japan would scarcely have been possible.

> Without both the capitalist and reactionary experiences, the communist method would have been something entirely different, if it had come into existence at all."

In counterfactual analysis, "what if" is the key question. Researchers look for the answer of what would have been the targeted outcome in the absence of an intervention, change or any other treatment.

4.2.1. Counterfactuals in Evaluation of Environmental Policy

Impact evaluation studies analyze the changes in the outcome caused by an intervention other than the factors independent from the intervention. In order to measure the impact of an intervention on the outcome, analysists need to know what the outcome would be in absence of the intervention. In other words, they ask whether the intervention is better than no intervention or not. These counterfactual results can be estimated indirectly by conducting an evaluation design which controls confounding factors (Ferraro, 2009).

Counterfactual thinking is crucial in order to obtain a result about effectiveness of environmental policies. Since the environmental outcomes are affected by various confounding factors depending on the location of the intervention and the timing such as changes in weather conditions, economic crisis and changes in fuel prices, realistic behavioral methods create unrealistic results about the effect of the environmental interventions (Ferraro, 2009). Even if observed indicators show a positive or negative impact, the reason behind this change may not be the intervention of interest. Comparing the outcome of interest for treated unit with control units helps to eliminate the impact of confounding factors.

4.3.Difference-in-Difference

Difference-in-difference (DD) estimation generally used to estimate the impact of a treatment or an intervention. One who makes DD estimation, compares the outcomes of two groups in two time periods. While one group is exposed to the treatment in second period, other group is not exposed to any treatment in both first and second periods. First group is called as treatment group and the second group as control group. The impact of the intervention can be estimated subtracting the average gain in the control group from the average gain in the treatment group. Although DD estimation has some limitations, it is preferred due to the simplicity of the method.

	Before Change	After Change	Difference
Treatment Group	Y_{t1}	Y_{t2}	$\Delta Y_t = Y_{t2}-Y_{t1}$
Control Group	Y_{c1}	Y_{c2}	$\Delta Y_c=Y_{c2}-Y_{c1}$
Difference			$\Delta\Delta Y = \Delta Y_t - \Delta Y_c$

Table 3 Representation of the difference-in-difference

Table 3 illustrates the DD estimation in a simple way. We can write the model that gives the impact of the treatment on the outcome ($\Delta\Delta Y$) as:

$$\Delta\Delta Y = (Y_{t2}-Y_{t1}) - (Y_{c2}-Y_{c1}) \qquad (1)$$

Where Y_{t1} and Y_{t2} are the outcome of treatment groups in before and after treatment periods; Y_{c1} and Y_{c2} are the outcome of control groups.

The linchpin assumption of the DD method is that changes in the means of the outcomes of both treatment and control groups have to be the same in the absence of the intervention. However, the means of the outcomes for two group do not have to be the same (Bertrant et al., 2003).

4.4.Synthetic Control Method

Synthetic control method is a technique that aims to measure the impact of interventions that are exposed to small number of units. As opposed to the synthetic control method, large sample sets and numerous examples of the intervention of interest are essential for traditional regression techniques. These essential requirements make the use of classical regression techniques impractical for the evaluation of unfrequently observed but large scale events or interventions. Scholars often use time-series data or comparative case studies in order to analyze the effect of infrequent events or interventions. Although single unit time-series data would be sufficient for short term evaluations, it would not be efficient in middle and long term evaluations because of the various events that would affect the outcome of interest after the intervention in the long run (Abadie, 2011). Even though traditional comparative case studies are used often in order to measure the impact of the large scale policies, the most important drawback is the ambiguity in selection of control units. Besides, a single comparison unit cannot provide a good counterfactual for the unit which is exposed to the intervention. However, synthetic control method provides more accurate technique for reproducing a counterfactual comparison for treatment unit on the basis of data driven unit selection procedure. The synthetic control unit consist of weighted average of multiple comparison units. The combination which best resemble the characteristics (predictors of the outcome of interest) of the treated unit is chosen as a synthetic control.

The following part explains the formal details and the use of the method. Suppose that there are J+1 unit. The first unit (J=1) is the unit that is influenced by the policy intervention of interest and called as "treated unit". The remaining J (J=2, …, J+1) units are potential control units which are not affected by the policy intervention of interest and called as "donor pool". Let T is the number of total time period that we analyze. T_0 denotes the number of pre-intervention period and $1 < T_0 < T$. The outcome of the intervention of interest is denoted as Y_{jt} for unit j in time t. There are also k number of predictors for each unit which are symbolized as $X_{1j}, \ldots, X_{kj}$. The pre-intervention outcomes, Y_{jt}, may be included to the set of predictors. The post-intervention outcomes of the treated unit are represented as Y_{1t}^I and Y_{1t}^N, in case of both with and without intervention, respectively. The effect of the intervention of interest for treated unit at time t is:

$$\alpha_{1t} = Y_{1t}^I - Y_{1t}^N \quad (2)$$

Since the intervention is exposed to the first unit at time T_0, the post-intervention outcome value Y_{1t}^I is observed. However, in order to estimate the impact of the policy intervention (α_{1t}) at time $t > T_0$, we need to estimate what the outcome value of interest would be in the absence of the policy intervention (Y_{1t}^N). The main object of the synthetic control method is reproducing a synthetic control for treated unit. A synthetic control is a weighted average of comparison units in the donor pool. The weights of each unit in the donor pool are denoted as W= {w_2, …, w_{j+1}}. Given W values, the estimator for the synthetic control ($\widehat{Y}_{1t}{}^N$) and the change of outcome in treated unit at time t are formulized below as:

$$\widehat{Y}_{1t}{}^N = w_2Y_{2t} + \ldots + w_{j+1}Y_{j+1t} \quad \text{and} \quad \hat{\alpha}_{1t} = Y_{1t} - \hat{Y}_{1t}{}^N \qquad (3)$$

To eliminate the extrapolation, the values of the weights have to be positive and sum of all weights have to be equal to one (Abadie et al., 2012).

The next step is the determination of the values of the weights for all units in the donor pool. Abadie et al. (2012) and Abadie and Gardeazabal (2003) suggest to choose weights that reproduces the synthetic control best resemble the pre-intervention predictors of the treated unit. In practice, they propose to minimize the distance between X_{k1} and $X_{kj+1}W_{j+1.}$ If the coefficients v_1, …, v_k represent the importance of the pre-intervention period predictors, the values of W are the ones that minimize the following equation (Abadie, 2011).

$$v_1(X_{11} – w_2X_{12} - \ldots - w_jX_{1j})^2 + \ldots + v_k(X_{k1} – w_2X_{k2} - \ldots - w_{j+1}X_{kj+1})^2 \qquad (4)$$

According to Equation (4), which estimates w values, the coefficients v, which denotes the importance of the predictors, have to be chosen. Abadie (2011) suggests four methods in to choose v_1, …, v_k.

- The first method proposes to choose v_1, …, v_k based on subjective assessment of importance of the predictors, X_{k1}, …, $X_{kj=1}$.
- The weights, v_1, …, v_k, can be calculated using regression in a first step exploratory data analysis.
- Third method selects v_1, …, v_k that minimize the mean squared prediction error (MSPE) of the outcome variable in pre-intervention time period. However, this can be applied by solving bilevel (nested) optimization problem, where v_1, …, v_k are given in order that W minimizes the MSPE in pre-intervention period.
- The final method proposed by Abadie et al. (2012) is maximizing out-of-sample fit for selection of v_1, …, v_k via cross-validation. If pre-intervention time period is long enough, it is divided by two as an initial training period t = 1, …, t_0 and a validation period t = t_0+1, …, T_0. Based on the data from training period, potential choice of v_1, …, v_k reproduces a synthetic control, which is selected by minimizing equation 4. The mean square prediction error of the synthetic control regarding $Y_{1t}{}^N$ in validation period is:

$$(Y_{1t_0+1} - w_2(V)Y_{2t_0+1} - \dots - w_j(V)Y_{jt_0+1})^2 + \dots + (Y_{1T_0} - w_2(V)Y_{2T_0} - \dots - w_j(V)Y_{jT_0})^2 \quad (5)$$

Equation 5 is minimized with respect to v and the resulting $v_1, \dots, v_k$ from previous estimation, and data of the predictors for the time period $t = T_0 - t_0 + 1, \dots, T_0$ are used in order to calculate W.

Abadie (2011) states that to be able to implement synthetic control methods, there are some requirements. First of all, the units in donor pool do not have to be exposed to the intervention of interest. Not only the same intervention but also other events or similar interventions that affect the outcome of interest in comparison units may create problem in terms of the accuracy of the results. Second problem that may cause a bias in results is the actions of the forward looking actors within the system of interest. These actors may act different from their routine in order to make advantage of upcoming intervention. In order to eliminate this factor, the intervention time may be backdated. In this way, the overall influence of the intervention can be observed explicitly. The other potential problem is the possibility of spillover effect. A policy implemented in treated unit may influence the outcome of interest in other units indirectly. For example, setting a barrier for CO_2 emissions may motivate producers to shift their production to the countries which do not have any emissions restriction policy. If a spillover effect is observed in comparison units, these units have to be excluded from donor pool. Moreover, the units in donor pool have to be selected from the similar region with treated unit in order to eliminate the impact of regional events on the outcome of interest. Another important issue is the difference between the values of pre-intervention predictors of treated unit and control units. If this difference is extremely high, synthetic control method may not be appropriate for the case. Also, the outcome of interest for the unit affected by the intervention may be at an extreme point. In this case, transforming the outcome data to different forms may be useful. For example, instead of using the outcome value at time t, the difference in outcomes between t and t-1 can be used in order to estimate counterfactual outcome data.

As a final step in order to measure the credibility of the results Abadie et al. (2015) conduct two types of placebo studies. The first one is “in-time placebo” study which looks into what the outcome of interest would have been if the intervention time is backdated. If new counterfactual outcomes of interest in time period between the new and actual intervention resembles the actual outcome data at the same period, it proves the credibility of the model and the results. The second way is to reassign the intervention to a comparison country. By this way, the synthetic control outcome data for unit which is not exposed to the intervention, is estimated. Similar to the in-time placebo study, the similarity between outcome data of synthetic control and new treated unit is an evidence for the credibility of the study.

4.5. Examples from Literature

Abadie et al. (2015) uses the synthetic control method in order to understand the impact of the 1990 German reunification on the economics of West Germany. The "treated unit" is West Germany and "donor pool" is consists of OECD countries which have similar economic characteristics with West Germany such as Austria, USA, Japan, Switzerland and Netherlands. In order to measure the economic growth, they use GDP per capita as outcome variable, and the predictors are trade openness, inflation rate, industry share, schooling and investment rate. The 1960-1990 country level panel data is used for pre-treatment period and the 1990-2003 for post-treatment period. They make placebo tests for evaluating the credibility of the estimates and run the robustness checks in order to check the sensitivity of the estimates. They conclude that the 1990 German reunification affects West Germany negatively. In the first two years they estimate slight decrease in per capita GDP. After 1992, while per capita GDP growth slows down in West Germany, the growth in synthetic West Germany continuous to increase at the same level similar to that of just before the reunification.

Almer &Winkle (2012) evaluate the effect of Kyoto emissions targets on domestic CO_2 emissions. They look at the effect of an international protocol which influences more than one country. As opposed to other studies treated unit group consists of seven major countries who sign the Protocol, namely Canada, Australia, France, Japan, Italy, Great Britain and Germany. They make the estimates for seven countries separately. The donor pool consists of the other countries who did not sign the Protocol. They use domestic GHG emissions data between 1980 and 2004. They define treatment date as 1997, which is the adoption date of the Protocol. The indicators that they use for projections are GHG emissions targets, value added manufacturing, alternative and nuclear energy, inflation, population, CO_2 intensity, GDP per capita, energy use, energy production and electricity production.

They plot both the actual and the synthetic graphs of these seven countries. The results for Canada, Italy and Australia are unequivocal, and there is not a big difference between the actual and synthetic path. These results do not support the hypothesis that claims the Kyoto Protocol contributes to the GHG emissions reduction in Canada, Italy and Australia until 2004. The GHG emissions results for synthetic Japan is lower than actual data; however, it is not significant according to inference analysis. Although there is considerable gap between the synthetic and real graphs of Germany and France, the results were insignificant for these countries. Great Britain was the only treated unit that there is significant difference between the real and synthetic data. The CO_2 emissions are 30% higher in synthetic Great Britain than it is in the actual Great Britain in 2004. The study shows that there is not any observable impact of the Kyoto Protocol in terms of reducing CO_2 emissions except Great Britain until 2004.

CHAPTER 5

RESEARCH DESIGN

Most of the studies in literature on the evaluation of the EU ETS reproduce business-as-usual baseline in order to estimate emissions reduction. The difference in CO_2 emissions between the verified outcome and estimated amount, which would have been in the absence of the scheme, gives the total abatement. The studies, which estimate the abatement in the literature, mostly use econometric models and focus on the first phase of the scheme. The economic growth, energy and electricity consumption, energy efficiency and energy mix are key indicators in order to establish counterfactual baseline for almost all studies. The inaccurate baseline data create problem in the evaluation of the first phase of the scheme. However, this study use aggregate per capita CO_2 emission data from EDGAR, and the difference in emissions reduction between the EU and a comparative control unit gives the emission reduction caused by the EU ETS. There are a few aggregate level studies which look into the impact of the scheme after Phase I, especially after the 2008 economic crisis. The most important problem about the current literature is high level of uncertainty in the establishment of counterfactual baseline. Besides, the economic recession increases the existing uncertainty and makes conducting a research more difficult. The existing literature is inadequate to estimate confounding factors that have impacts on the CO_2 emissions. One of the most important advantage of synthetic control method is its ability to control these unobserved confounding factors, which vary with time, while traditional econometric methods cannot control. Using synthetic control method for the evaluation of the EU ETS controls the impact of the economic recession, which is the biggest problem for the evaluation of Phase II in the literature. Moreover, as opposed to the complexity of traditional econometric methods, the synthetic control method can provide natural control in a simpler way.

In sum, in order to understand what CO_2 emissions would have been in the absence of the EU ETS, this study reproduces a synthetic EU that is composed of weighted combination of developed and developing countries that do not have any effective policies in force. The difference between this synthetic and real EU gives the actual impact of the EU ETS. The weights of these comparison countries are estimated considering the similarities of the predictor variables for CO_2 emissions in the pre-intervention period.

5.1.Selection of Countries

As stated above selection of comparison units is essential not only for synthetic control method but also for every comparative case study. First of all, the unit levels of both treated and comparison units have to be the same. Because of the sui generis characteristic of the EU, it is not possible to find a comparison unit at the same unit level with the EU. Based on the basic requirement of the method stated above, in order to be able to measure the impact of the EU level climate policy, the unit level is reduced to country from region by estimating average CO_2 emissions per capita level of the EU-15 countries. Although when the first phase of the EU ETS come into force in 2005, the EU compose of 25 member states with the EU-15 and Central and Eastern European (CEE) countries, which join to the EU in 2004; this study excludes CEE countries. The reason behind excluding these countries is the economic transition experienced by CEE countries (Brohé et al., 2012, p. 12). Moreover, political priority of climate change was very low for CEE countries (Yamin, 2012, p. 223). Anderson and Di Maria (2011), Egenhofer (2011) and Ellerman et al. (2010) show that most of the reduction occurred in the EU-15. Although some level of reduction is observed in CEE countries, the major cause of this reduction is the continuing restructuring process in the economies of these new member states (Egenhofer, 2011).

Second important issue in unit selection phase is the similarity between the comparison and treated units with regard to the characteristics of interest (Abadie et al., 2015). In order to reproduce a synthetic EU-15, the donor pool has to consist of countries which has similar industrial characteristics, since the EU ETS targets industry and electricity production sectors. Moreover, the countries in donor pool have to be chosen from countries which do not implement any policy that may influence emissions level different than the EU. The primary set of comparison countries consists of non-EU OECD countries, Argentina and Brazil.

In Australia, the National Greenhouse and Energy Reporting Act was initiated in order to collect energy production, consumption and GHG emissions data in 2007. As a following step, the Clean Energy Act, which puts the carbon-pricing scheme into force, has been introduced in July 2012. The starting price of a ton of CO_2 was $23 in 2013, and it reaches $24.25 and $25.40 in 2013 and 2014 respectively (Fahimnia et al., 2013; Villoria-Sáez et al., 2016).

In Canada, although some strategies and framework plans have been developed to control emissions recently, there is no federal level policy regarding emissions reduction yet. However, British Columbia and Quebec regions implement carbon taxes, and Alberta region introduced emissions trading system, which includes all industrial installations in order to decrease emissions level by 12% of their 2003-2005 CO_2 emissions level in 2007 (Sumner et al., 2015; Villoria-Sáez et al., 2016).

Australia
Canada
Chile
Iceland
Israel
Japan
Korea
Mexico
New Zealand
Norway
Switzerland
Turkey
United States

Table 4. Non-EU OECD Member Countries

Although Norway and Iceland are not members of the EU, they are in the European Economic Area and the Commission announced linkage of the EU ETS for the non-EU members of the European Economic Area in 2008 (Ellerman et al., 2016).

Japan initiated a carbon taxation in 2012 and the tax for one ton of CO_2 was about $3.5. Even though there is not a nation level emissions trading system, Tokyo Metropolitan Assembly passed the first mandatory ETS of Japan in 2010.

Korea introduced the first emissions trading scheme of East Asia in January 2015 in order to meet %30 reduction emissions target by 2020 (Song et al., 2015).

There is not any active climate policy in Chile but the carbon tax legislation is enacted in 2014. However, the implementation of the tax on carbon emissions is going to start in 2018 (Mondal et al., 2016).

Mexico initiated a carbon tax law (*Putting a Price on Carbon with a Tax)* which includes just emissions from use of additional fossil fuels instead of natural gas in 2014. The tax is the 3% of the sales price of the fossil fuel. The Ministry of Energy announced the developments of the emissions trading system in energy sector in 2014 (Kossoy et al., 2015).

Even though there are some initiations in Brazil, there is no carbon policy in operation. The National Climate Change Policy which is adopted in 2009, includes attempts for the development of carbon market in Brazil and an emissions trading scheme is in progress (Serre et al., 2015). Similarly, there is no policy in Argentina regarding an abatement in CO_2 emissions.

The New Zealand Emissions Trading Scheme includes industry, forestry, waste and energy sectors. The scheme which covers only emissions from forestry was set up in 2008 and expanded to the other sectors stated above in 2010 (Villoria-Sáez et al., 2016).

The Swiss ETS is adopted with a five-year voluntary period in 2008 and the mandatory scheme for energy intensive large enterprises started in 2013. The negotiations on linkage to the EU ETS is completed in January 2016 (Carbon Pricing Watch 2016).

Although there is no nation-wide carbon policy regarding emissions reduction, some states introduced carbon tax and emissions trading policies in the United States. The Regional Greenhouse Gas Initiative is the first mandatory carbon emissions scheme in the United States, which aims to decrease CO_2 emissions level originating from power sector in Delaware, Maine, Connecticut, Massachusetts, Maryland, New York, New Hampshire, Vermont and Rhode Island. Another carbon emissions trading scheme in the United States is the Californian Cap-and-Trade System which is introduced in 2013. An emissions trading scheme is under consideration in Washington state (Serre et al., 2015).

In Israel and Turkey there is no carbon policy in force. However, Turkey as a candidate country that has started to the accession negotiations with the EU has to complete the environmental acquis of the EU which includes the EU-ETS directive (Serre et al., 2015).

Based on the active carbon policies, the donor pool of the analysis consists of Argentina, Brazil, Canada, Chile, Israel, Japan, Korea, Mexico, Turkey and the United States. Argentina, Brazil, Chile, Israel, Korea, Mexico and Turkey are the countries which do not implement any carbon policy until 2014. Although there is a few regional carbon tax and pricing policies in Canada, Japan and the United States, they are included to the donor pool because of the absence of any nation level policies.

5.2.Outcome Variable

The EU ETS is the main instrument of the EU in order to meet the emissions targets of the Kyoto Protocol. The EU ETS aims to reduce CO_2 emissions in the EU by encouraging enterprises to invest in energy efficiency and to use low-carbon energy resources. Although many studies in the literature look into total emissions level in order to measure the impact of the scheme, this study chooses the CO_2 emissions per capita as outcome variable because of methodological restrictions.

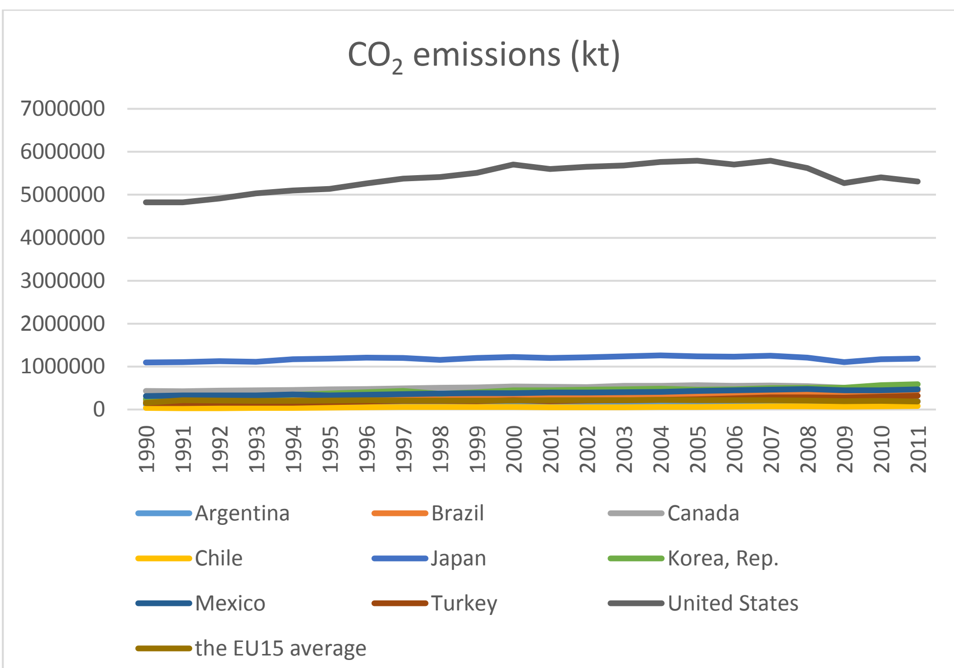

Figure 2. The total carbon emissions in the EU-15 average and the donor pool

The large difference between countries in the values of any variable may create problem for the estimation of synthetic control (Abadie, 2011). Since there are large differences between the total CO_2 emissions of the countries, the outcome variable is chosen as CO_2 emissions per capita. Especially, total CO_2 emissions levels of the United States and Japan are much higher than the other countries in donor pool as illustrated in Figure 2. As presented in Figure 3, there are not large differences between the values of the CO_2 emissions per capita compare to the differences in total CO_2 emissions. The CO_2 emissions per capita gathered from Emissions Database for Global Atmospheric Research (EDGAR).[1] The data includes emissions of fossil fuel use and industrial processes. The emissions from short-cycle and large-scale biomass burning are excluded in the data.

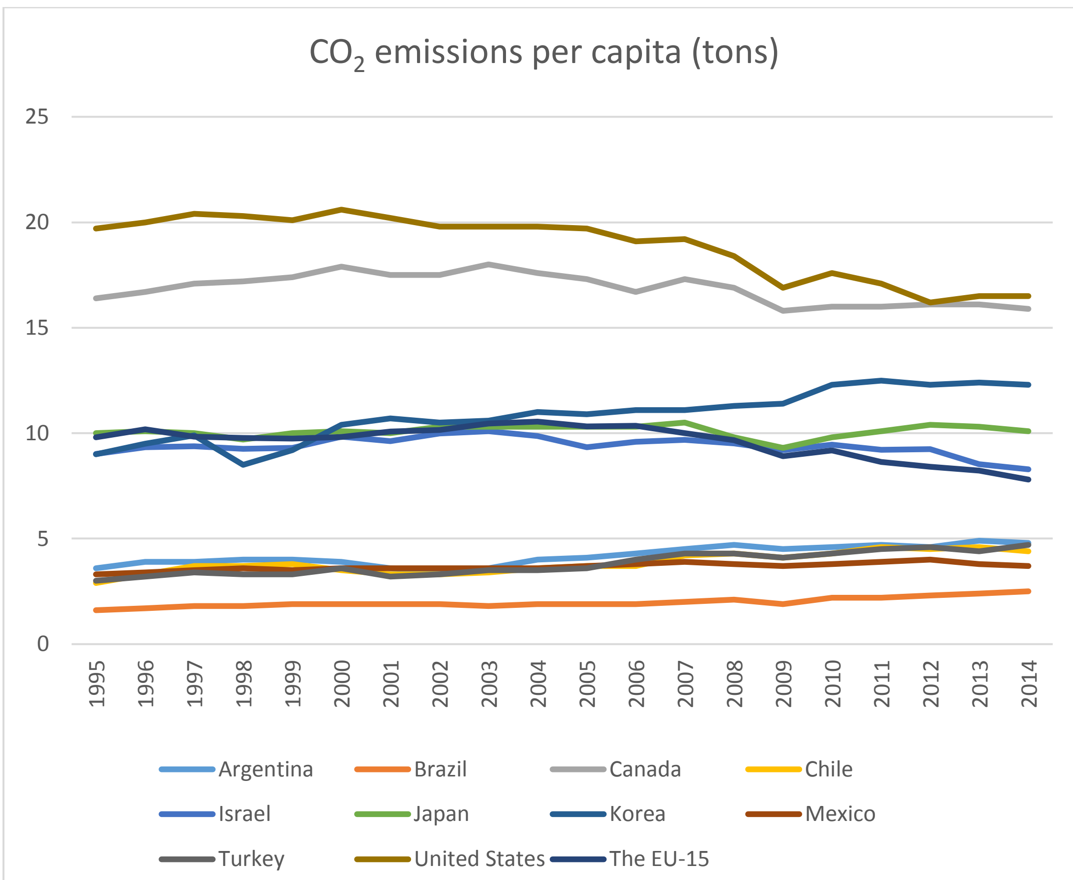

Figure 3.The CO_2 emissions per capita for the EU-15 and comparison countries between 1995-2014.

[1]The emissions data gathered from EDGAR is estimated based on the energy balance statistics of the IEA (2014) and BP Statistical Review of World Energy (2013-2014). The population data is gathered from UNDP Review (2013).

5.3.Predictors

Many studies look into the relationship between CO_2 emissions and economic growth, energy consumption, renewable energy and nuclear energy. The first group makes empirical analyses on the link between economic growth and carbon emissions. The environmental Kuznets curve (EKC) hypothesis claims that although the economic growth causes environmental degradation in the early periods of the economic development, this degradation decreases in the following period. In order to test this hypothesis, many scholars conduct studies that are mostly based on regression analysis, but there is a lack of consensus about the EKC in the literature (Narayan et al.,2015). On the contrary, Nordhaus (1992), Shah and Larsen (1992) assert that attempts to decrease carbon emissions may effect economic growth negatively (as cited in Holtz-Eakin& Selden, 1995). Although there are discussions about how the economic growth and carbon emissions affect each other, it is clear that there is a causal relationship between emissions and economic growth.

In addition to the economic growth, there are also other factors which have to be taken into consideration such as energy consumption and energy mix (Stolyarova, 2009). Apergis and James (2010) find that energy consumption has statistically significant impact on carbon emissions based on their analysis which includes 11 Commonwealth countries (as cited in Farhani&Rejeb, 2012). Similarly, Wang et al. (2011) state that economic growth and energy consumption are the causes of CO_2 emissions in the long-run based on their analysis on 28 provinces of China.

The electricity power plants are the main CO_2 emitters, and the power sector is one of the sectors that is included to the EU ETS since the first phase of the scheme. In addition to the energy intensive industries, the rapid development of the information and communication technologies requires high amount of electricity input, which is mostly met by fossil fuels (Lean&Smyth, 2010). However, environmental concerns and energy supply security problem force countries to find alternative ways to supply for their energy consumption such as nuclear and renewable energy sources.

Although there is a large literature on the causal relationship between the energy consumption, economic growth and CO_2 emissions, there is a lack of empirical study about the causal link between renewable and nuclear energy consumption and carbon emissions (Apergis et al., 2010). Even though the concerns and critics have been increasing on generating energy from nuclear reactors after the 2011 Fukushima accident in Japan, nuclear power plants contribute to reduce CO_2 emissions. While the share of electricity production from nuclear resources is %20.28 in 1995 for the EU-15 average, it falls to %17.47 in 2014.[2] More importantly, developments and investments on renewable energy increase significantly. The share of electricity production from non-hydro renewable resources reaches to %20.49 from %2.25 within two decades from 1995 to 2014.[3] However, Apergis et al. (2010) found that while both the renewable and nuclear energy has statistically significant effect on emissions level, nuclear energy has negative and renewable energy has positive impact on CO_2 emissions in the short-run in their analysis based on the period between 1984 and 2007 for 19 developing and developed countries. Similarly, the results of Bilgili et al. (2016) conclude that renewable energy has positive impact on carbon emissions. Heal (2009) and Forsberg (2009) states the reason behind the positive impact of the renewable energy on carbon emissions is the discontinuity and inability of storage of the renewable energy resources and the requirement for backup fossil fuel power plants (as cited in Apergis et al., 2010).

One of the main targets of the EU ETS is encouraging enterprises to invest in energy efficient technologies. In addition to the use of renewable and nuclear energy resources, Ang et al. (2010) state that increasing energy efficiency is the most effective way of reducing CO_2 emissions, in order for increasing industrial competitiveness and eliminating energy security risk (as cited in Wu et al., 2012). The energy intensity is an indicator of energy efficiency and it is the amount of energy that is required per unit of GDP. The study of Shahbaz et al. (2014) provides empirical evidence for the positive and statistically significant effect of energy intensity on carbon emissions.

Begum et al. (2015) states that the population growth has positive but statistically insignificant impact on CO_2 emissions per capita in Malaysia. However, the EU directives on the EU ETS state that many factors have to be taken into consideration, such as population growth, income, structure of industry and energy intensities, in the determination stage of the CO_2 allowance allocations. Moreover, the results of Shi (2003) and Cole & Neumayer

[2] World Bank Sustainable Energy for All Database
[3] World Bank Sustainable Energy for All Database

(2004) state that the population growth has an impact on CO_2 emissions (as cited in Martínez-Zarzoso et al., 2007).

Based on the literature about predictors of the CO_2 emissions explained above, this study uses natural logarithm of GDP per capita (constant 2010 US$) for economic growth; energy use (kg of oil equivalent per capita) and electric power consumption (kW per capita) for energy consumption; alternative and nuclear energy (% of total energy use) for nuclear and renewable energy; energy intensity of industrial sector (MJ/2011 USD PPP) for energy efficiency and finally population growth (annual %) as predictors of CO_2 emissions per capita.

In addition to these covariates, three years of lagged CO_2 emissions per capita for 1997, 2000 and 2003 are added in order to estimate synthetic control unit. The data for predictors is gathered from World Development Indicator and Sustainable Energy for All Databases of the World Bank. The starting point of pre-intervention period is determined as 1995, because the latest members of the EU-15 joined to the EU in 1995. The pre-intervention period ends with the beginning of the first phase of the EU ETS in 2005. The study looks into the impact of the scheme until 2014.

Variable	*Obs*	*Mean*	*Std. Dev*	*Min*	*Max*
carbonpc	220	8.468909	5.42245	1.6	20.6
GDPpercapita	220	24531.63	15835.7	7009.07	50662.41
anenergy	218	10.97798	5.572429	2.78	24.31
energyuse	218	3490.046	2316.055	989.8	8365.2
elecconsp	209	6394.184	4765.178	1226.57	17235.41
enrgyintind	198	5.196414	1.947224	2.51	10.82
popgrowth	220	1.076	.5533851	-.2	2.67

Table 5. Summary statistics[4]

[4]Notes: carbonpc: CO_2 emissions per capita (tons); GDPpercapita: GDP per capita (constant 2010 US$); anenergy: Alternative and nuclear energy (% of total energy use); energyuse: energy use (kg of oil equivalent per capita); elecconsp: electric power consumption (kW per capita); enrgyintind: energy intensity of industrial sector (MJ/2011 USD PPP); popgrowth: population growth (annual %)

This study constructs a synthetic EU-15 that resembles the values of the predictors of the CO_2 emissions per capita in real EU-15 before the initiation of the EU ETS by using the synthetic control method explained in Chapter 4. The difference of the CO_2 emissions per capita level between real and synthetic EU-15 after 2005 gives the impact of the EU ETS. Finally, placebo test is applied to the biggest contributor country in the donor pool, which is Japan.

5.4.Selection Method of the Coefficients of Predictors

As explained in Chapter 4, there are four methods to determine the coefficients of the predictors. First of all, the weight can be assigned subjectively. Because of the uncertainty of the predictor power of the variables, this method is by-passed. Although the cross-validation method gives the most accurate results, it requires large pre-intervention period. However, the ten-year pre-intervention time period of this study is not enough for cross-validation technique.

The remaining two methods are the regression analysis and choosing coefficients that minimize the prediction error of the outcomes in the pre-intervention period. Since minimizing the mean squared prediction error provides more accurate estimation, this technique is used in order to estimate coefficients.

CHAPTER 6

RESULTS AND DISCUSSIONS

This chapter illustrates the result of the statistical estimations and interprets the difference between the actual CO_2 emissions level of the EU-15 and its counterfactual version.

6.1.Results

Figure 4 illustrates the per capita CO_2 emissions levels in the EU-15 and the non-EU15 OECD average. After a rise and fall in around 1995-1996 period in the EU-15, the emissions per capita growth goes parallel until 2000. Even though both groups show an increase in per capita CO_2 emissions level between 2000 and 2005 period, the reduction in the EU-15 is slightly higher than the average of the non-EU15 OECD countries. The first significant change in per capita emissions level is observed just two years after the initiation of the EU ETS in 2005. Following this period while the emissions level starts to fall sharply in the EU-15, it continues to grow until 2007 in the non-EU15 OECD. With the impact of the economic recession, the decline continues until around 2009 in both groups. After an observable recovery until 2010, the emissions level continues to fall in both groups up until 2014. However, the reduction in the EU-15 is slightly higher than the non-EU15 OECD members. Although, a substantial amount of decrease is observed in per capita CO_2 emissions level in the EU-15 after the start of the EU ETS, many factors may affect this decrease. Furthermore, although the EU-15 per capita emissions line goes parallel with the non-EU15 OECD line in pre-intervention period, including all members of the non-EU15 OECD to the donor pool may not provide reliable synthetic control which mirrors the actual EU-15, mainly because of the different policies which is explained in the previous chapter. However, this similarity makes the non-EU15 OECD members appropriate candidates for the donor pool. To estimate the impact of the EU ETS on CO_2 emissions, the main question is what the CO_2 emissions level would have been in the absence of the EU ETS. As represented in Chapter 4, this study estimates per capita CO_2 emissions of the synthetic EU-15 as weighted average of the comparison countries in the donor pool which most similarly resembles the actual EU-15 with regard to values of predictors of the CO2 emissions per capita in the pre-intervention period.

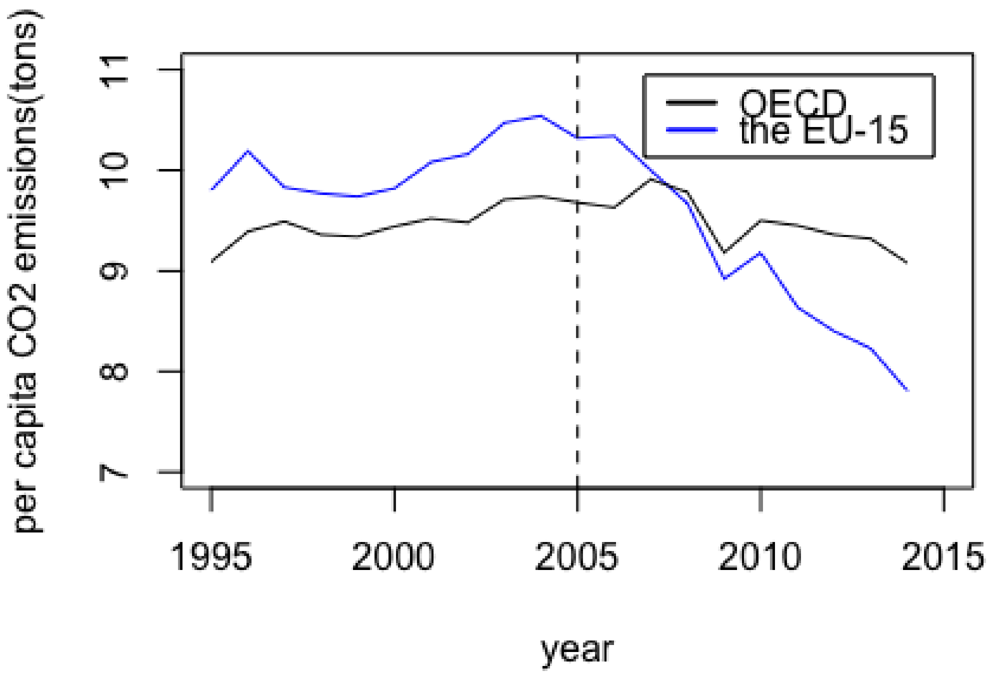

Figure 4.Trends in average CO_2 emissions per capita in the EU-15 and the non-EU15 OECD members[5]

Table 6 illustrates the pre-intervention characteristics of the actual and synthetic EU-15 with the average of ten countries in the donor pool. Although the mean values of some predictors in the average of countries in donor pool are close to the actual EU-15, it does not provide appropriate control for the EU-15. Especially, energy use per capita and energy consumption per capita in the average of the 10 countries are much lower than the actual EU-15. Similarly, synthetic EU-15 average for alternative and nuclear energy share resembles the real EU-15 better than average of the rest. Although, there is not large

[5]European Commission-Emissions Database for Global Atmospheric Research

difference in Ln (GDP per capita) between the real EU-15 and the average of the donor pool, almost 1-unit difference is significant when the scale of the value and the importance of the impact of the economic growth on carbon emissions are taken into consideration. On the other hand, Ln (GDP per capita) value for the synthetic EU-15 mirrors the actual EU-15 perfectly only with 0.073 difference. In addition, the population growth average of 10 comparison countries is more than double of the actual EU-15 during pre-intervention period while the synthetic control estimates much closer growth rate. Last but not least, CO_2 emissions per capita trend of the synthetic version provides much more similar data compare to the average of the countries in the donor pool for 1997, 2000 and 2003. In the same way as explained for Ln (GDP per capita), even small differences have substantial importance for CO_2 emissions per capita. Except energy intensity of industrial sector, the synthetic EU-15 reproduces more similar values for predictors of CO_2 emissions. The synthetic control method motivates the scholars to illustrate the similarity between the treatment unit and the synthetic control unit.

Variables	*Real EU-15*	*Synthetic EU-15*	*Average of 10 control countries*
Alternative & Nuclear energy share	13.378	14.522	10.809
Energy use per capita	4249.987	3789.234	3341.736
Electricity consumption per capita	7866.335	7415.989	5866.243
Energy intensity of industrial sector	5.607	4.183	5.395
Population growth	0.502	0.687	1.228
Ln (GDP per capita)	10.573	10.500	9.689
CO_2 emissions per capita(1997)	9.830	9.936	8.308
CO_2 emissions per capita(2000)	9.820	10.113	8.533
CO_2 emissions per capita(2003)	10.470	10.319	8.469

Table 6. CO_2 emissions per capita means

As explained in Chapter 4, there are four ways to select coefficients of the predictors. This study determines coefficients by minimizing the mean square prediction error (MSPE) of CO_2 emissions per capita value during the pre-intervention period. This MSPE is the mean squared deviations between the CO_2 emissions per capita values of the actual EU-15 and estimated synthetic EU-15 during the 1995-2004 period. “Synth” library in RStudio includes multiple optimization algorithms such as “Nelder-Mead”, “BFGS”, “CG”, “L-BFGS”, “nlm”, “nlminb”, “spg” and “ucminf”. However, if method is specified as “All”, synth runs the optimization for all methods and gives the result of best performing method. Although this option requires more computing time, the loss will be much lower.

Table 7 shows the results estimated by synth. The Ln (GDP per capita) is the most powerful predictor for per capita CO_2 emissions before the initiation of the EU ETS. This result is not surprising when the large literature on the relationship between the GDP per capita and CO_2 emissions is considered. Also, per capita CO_2 emissions for both 1997 and 2000 have substantial predictive powers. While alternative and nuclear energy share has non-negligible predictive power; energy consumption per capita, per capita CO_2 emissions for 2003 and population growth have just small level of impact in predicting the outcome. On the other hand, energy use per capita and energy intensity of industrial sector have almost no predictive power on per capita CO_2 emissions.

Variables	*Weight*
Alternative & Nuclear energy share	0.128
Energy use per capita	0.008
Electricity consumption per capita	0.039
Energy intensity of industrial sector	0.002
Population growth	0.045
Ln (GDP per capita)	0.268
CO_2 emissions per capita(1997)	0.218
CO_2 emissions per capita(2000)	0.232
CO_2 emissions per capita(2003)	0.06

Table 7. Coefficients of predictor variables

Table 8 represents the weights of the control units in the donor pool. According to the estimations, the synthetic EU-15 consists of weighted average of Japan, Israel and the United States. Among these comparison countries Japan is the biggest contributor with the weight value of 0.773. All other countries in the donor pool have no effect in the synthetic EU-15.

Country	*Weight*	*Country*	*Weight*
Argentina	0	**Japan**	0.773
Brazil	0	**Korea**	0
Canada	0	**Mexico**	0
Chile	0	**Turkey**	0
Israel	0.219	**The United States**	0.007

Table 8. Country weights in the synthetic EU-15

As illustrated in Figure 3 in Chapter 5, Israel and Japan are the most similar countries to the EU-15 in terms of per capita CO_2 emissions. This results provides evidence on the power of the data-driven selection procedure. Moreover, similarity in GDP per capita between Japan and the EU-15 is another factor that makes Japan the main contributor of the synthetic EU-15. In addition to being most similar country to the real EU-15 in per capita CO_2 emissions predictors during pre-EU ETS period, Japan resembles the EU in various characteristics. Both of them are highly industrialized, open economies that have significant amount of trade. Also, both Japan and the EU have to develop their production in order to be able to compete with newly emerging economies. Considering all these factors and similarity between Japan and the EU, this result does not come as a surprise.

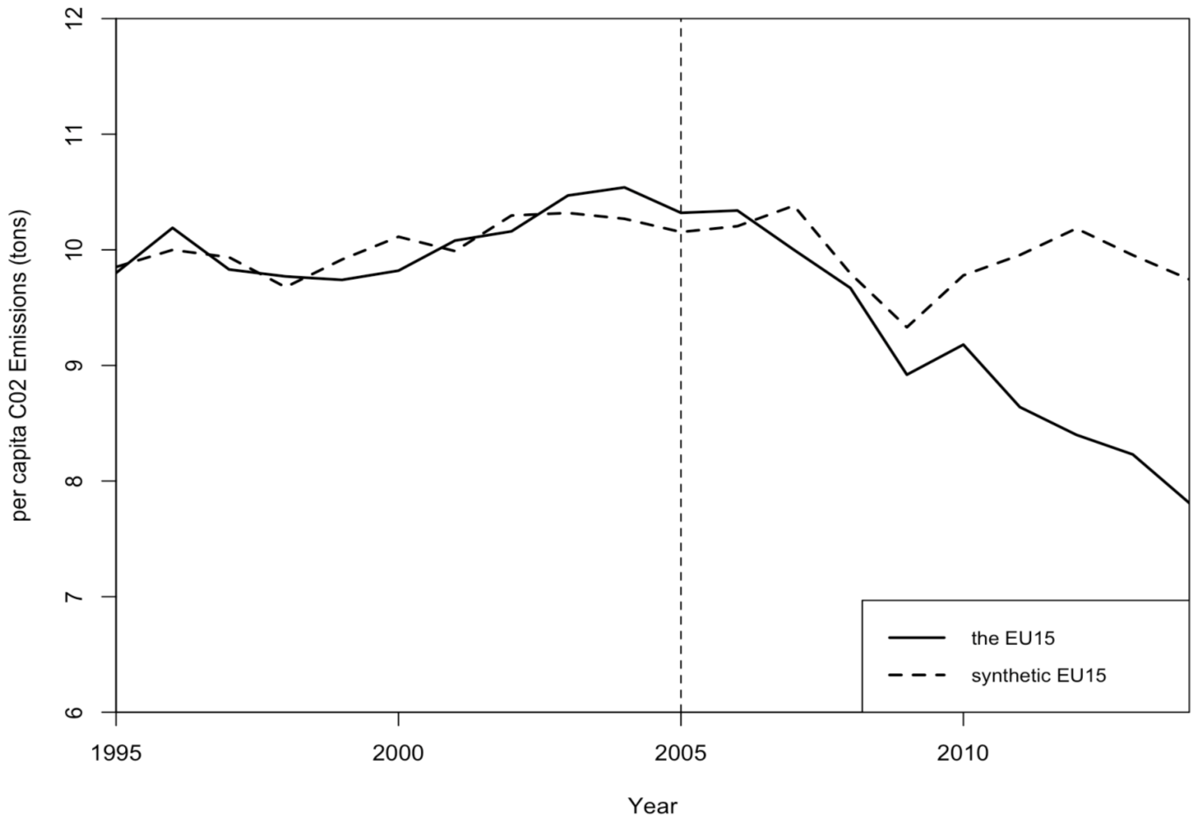

Figure 5. Trends in per capita CO_2 emissions: the EU-15 vs. the synthetic EU-15

Figure 5 illustrates per capita CO_2 emissions for the EU-15 and its synthetic version between 1995 and 2014. In contrast to the difference in per capita CO_2 emissions between the average of the non-EU15 OECD and the EU-15 displayed in Figure 1, per capita CO_2 emissions line of the synthetic EU-15 follows the actual EU-15 line very closely during the pre-EU ETS period. However, just before the intervention there is a positive gap between the real EU-15 and its synthetic version which means per capita CO_2 emissions would have been less than the observed value in the absence of the EU ETS. The most possible reason behind the difference between the synthetic and the real line before the intervention is the use of "grandfathering" as method of allocation. As explained in Chapter 2, grandfathering is a CO_2 allowance allocation method which considers the historical emissions data in order to determine the CO_2 allocations of the following periods. Although it is practical to implement grandfathering method for allocation, disadvantages of the method are explained under methods of allocation section. One of these disadvantages explains the difference between the synthetic and real EU-15 line. Since the historical data matters for future allocations, using grandfathering encourages companies to increase their CO_2 emissions in order to be able to obtain more CO_2 allowances for the following years (De Larragán, 2008). The enterprises tend to increase their emissions because of grandfathering method just before the initiation of the EU ETS in the absence of any binding limit for their emissions.

Although many quantitative analyses (Ellerman & Buchner, 2008; Anderson & Di Maria, 2011) in the literature state that there is small amount of abatement in CO_2 emissions in the 2005-2006 period, qualitative studies (Fazekas, 2009; Ikkatai et al., 2008; Engels, 2009; Carbon Point, 2009) cannot find any evidence for emissions abatement in the first phase. However, Ellerman and Buchner (2008) notes that reproducing entirely accurate counterfactual is not possible because of the lack of baseline data for the sectors covered by the EU ETS. The data collection process during the design of the National Allocation Plan (NAP) in 2004 suffers from potential bias. The data collection in the pre-EU ETS period is based on the voluntary submissions of the industries covered by the EU ETS, and this baseline data cannot be verified by the states because of time pressure. Considering the disadvantage of the grandfathering method, the baseline data used by studies in the literature may be higher than the actual emissions amount (Ellerman et al., 2007). This biased data may result over estimation of the emissions abatement for the studies that use this baseline data. As illustrated in both Figure 2 and Figure 3, this study finds that per capita CO_2 emissions in the actual EU-15 is slightly higher than the emissions amount in its synthetic counterpart during 2005 and 2006. Over-allocations caused by the use of grandfathering in the first phase of the EU ETS and the absence of any signal about the allocation method for the following phase may cause an increase in emissions.

As illustrated in Figure 5, in 2007 verified CO_2 emissions per capita declines to 10 tons/capita from 10.34 tons/capita in 2006, while emissions are rising in its synthetic version. Although real decrease from 2006 to 2007 was 0.34; as displayed in Figure 6, the gap between the synthetic and real values is 0.37 tons/capita at the same period. Based on the results discussed above during the trial phase of the EU ETS, 2007 is the only time period when a significant amount of emissions reduction is observed.

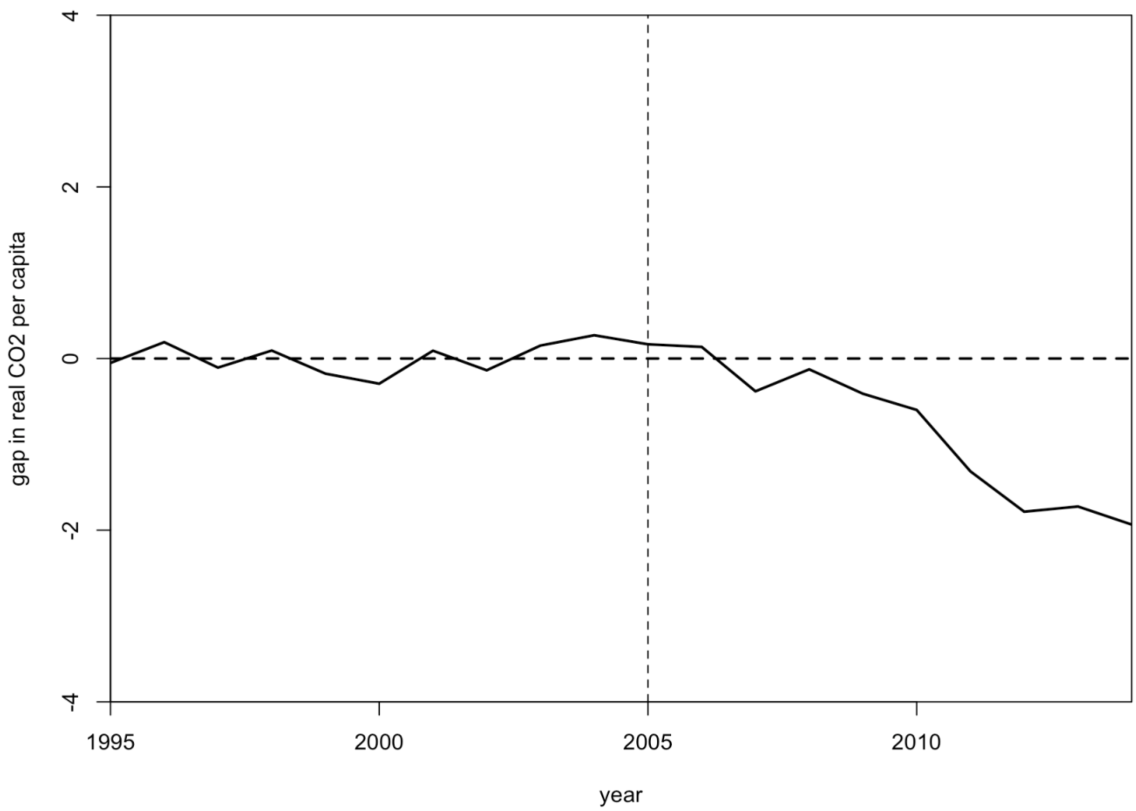

Figure 6. Per capita CO_2 emissions gap between the EU-15 and the synthetic EU-15

Considering the over-allocation problem as a result of biased historical data in Phase I, the emission allowances are cut by the European Commission for Phase II. Another change for Phase II is the introduction of the "banking of allowances". While installations cannot transfer their emissions allowances to the next phase in Phase I, they can carry their excess allowances to the next period as of the beginning of Phase II. The aim of this change was encouraging enterprises to cut their emissions to collect for the next period. 2008-2009 is the most problematic period for researchers to measure the abatement led by the EU ETS because of the large amount of reduction caused by the 2008 economic recession. Although there is a few study for this period, many of them states that the EU ETS lead to small amount of reduction during this period (Egenhofer et al., 2011; Grubb et al., 2012). The use of synthetic control method for evaluating the emission reduction caused by the EU ETS for this time period provides more accurate results with a less complex method, since the countries in donor pool are exposed to the negative impact of the economic recession. The observed emissions decline to 9.67 tons/capita in 2008 which is 0.33 tons/capita less than the emission level in 2007. However, the same trend is observed in the synthetic EU-15. As shown in Figure 6, the emission abatement led by the EU ETS is only around 0.1 tons/capita in 2008 which is the smallest reduction led by the EU ETS after Phase I. Similar to 2008, the emissions reduction keeps continue for both real EU-15 and its synthetic counterpart; however, the abatement in real EU-15 is larger than the counterfactual scenario in 2009. The emissions reduction caused by the scheme is 0.4 tons/capita in 2009. In 2010, a quick recovery is observed in both the real and synthetic emissions values but the gap between them keep growing. While the total per capita CO_2 emissions change in the real EU-15 is 1.36 tons/capita from 2004 to 2010, the same change is almost 0.5 tons/capita in the synthetic EU-15. In sum, per capita CO_2 level reduction caused by the EU ETS is 0.86 tons/capita from 2004 to 2010. The 2011-2014 period is the most interesting part of the results of this study. Although the emissions in the real EU-15 starts to decrease again after the post-crisis recovery, the emissions in the synthetic EU-15 keep rising sharply until 2012 and slightly fall in the 2013-2014 period. Considering the large amount of surplus emissions allowances in the market after the 2008 economic crisis, such amount of gap between the real and synthetic emissions may be caused by another event or intervention.

In order to test the significance of the results of the study, a placebo study is performed by applying the same estimation process to another country in the donor pool. The idea is to analyze per capita CO_2 emissions trend of a country similar to the EU-15 average, but without any effective policy in force that targets reduction in CO_2 emissions. The aim of this placebo study is to test whether the per capita CO_2 emissions reduction observed for the EU-15 may have been caused by any reason other than the EU ETS. Since Japan is the biggest contributor of the synthetic EU-15, the placebo test is applied to Japan by excluding the EU-15 from donor pool.

Figure 7 illustrates the per capita CO_2 line for actual Japan, and synthetic Japan which is a weighted combination of countries in the donor pool. The synthetic Japan mirrors the actual Japan per capita CO_2 trend good enough until 2010. This means that the results of this study provides significant evidence of negative impact of the EU ETS on per capita CO_2 until 2010. However, the large gap after 2010 is an indicator of special event or intervention which impact the CO_2 emissions in Japan. The results of the placebo test also explain the unexpected large gap between the real EU-15 and synthetic EU-15.

The key event for Japan is nuclear accident in Fukushima on March 2011. According to World Bank Sustainable Energy for All Database, after the Fukushima disaster nuclear energy share in electricity production falls about 16% from 26% in 2010 to 9.8% in 2011 and it reaches 0 in 2014. Consequently, the share of fossil fuels in power sector reaches to 88% from 62% within four years just after the Tohoku Earthquake. Cho et al. (2014) estimates that CO_2 emissions increase at least 10% in some regions. In total, the CO_2 emissions level increases by 15% from 1990 level and %2 from 2011 level (Wakiyama et al., 2014). Japan is the second biggest coal importing country of the world since 2012 and oil consumption rises 6.6% after 2012. Although, Japan is back on track by investing on renewable energy, it starts to reopen some of nuclear plants with stricter regulations by 2015 (Trends in Global CO_2 Emissions, 2015).

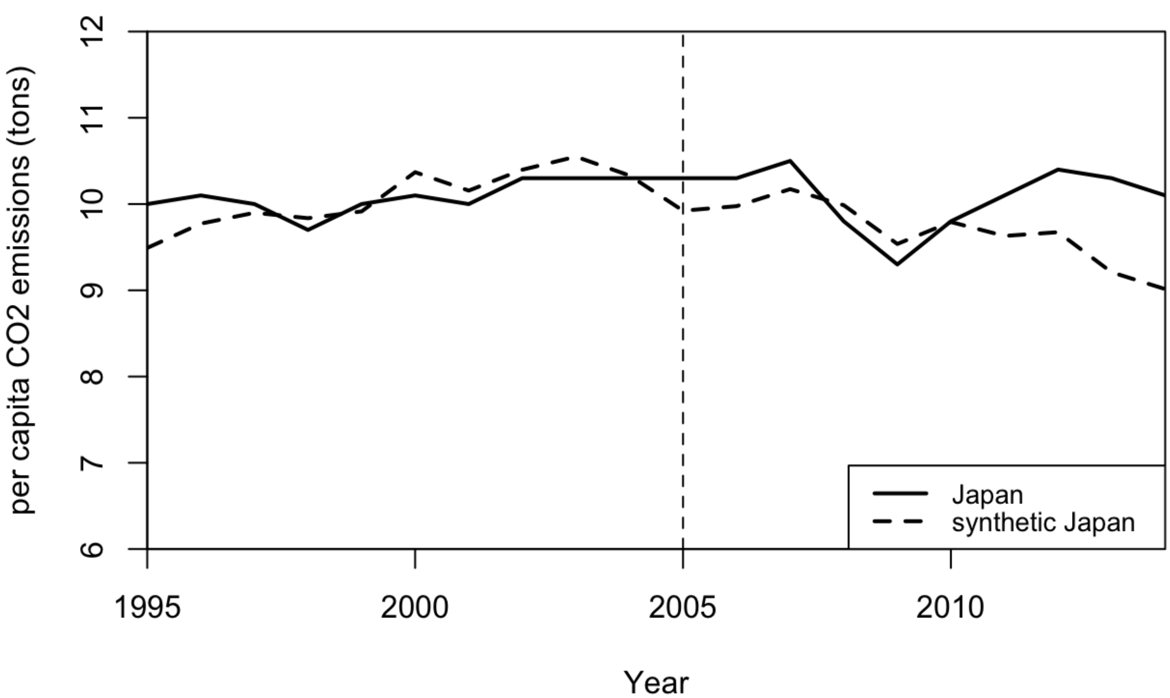

Figure 7. A "Placebo Study", per capita CO_2 emissions for Japan

To obtain more accurate results for the 2011-2014 period, the same analysis is made by excluding Japan from donor pool. However, the loss in mean squared prediction error estimated higher than the previous estimation. According to the new results Israel is the main contributor of the new synthetic control. Figure 5 shows per capita CO_2 emissions for the new actual and synthetic EU-15. As illustrated in Figure 5 and Figure 8, although the emissions trend is almost identical in both of them until 2010, the gap between the real EU-15 and its synthetic counterpart is much lower after 2010 in Figure 8. Although the gap between the real and synthetic EU-15 getting smaller in 2013 and 2014, the highest gap between the synthetic and real emissions is observed after 2010. Considering the high amount of surplus allowances and low carbon prices, this results are unexpected and other factors that just impact the EU-15 countries cannot be controlled due to the restrictions of the methodology.

While a slight decrease is observed in the synthetic EU-15 in 2011 and 2012, this fall is sharper in the real emissions amount. Despite the GDP keep increasing in the EU-15 in 2011, per capita CO_2 emissions start to decrease in both the synthetic and real EU-15. The higher winter temperatures and high fossil energy prices in Europe are the other reasons of the emissions reduction. (European Environment Agency Analysis, 2013). While the emissions start to increase in the synthetic EU-15, it keeps declining in the real EU-15 in 2012. The GDP decrease as a result of economic crisis across the EU is one of the important reasons of abatement in emissions. Moreover, the contribution of the renewable energy resources increases substantially in 2012 (European Environment Agency Analysis, 2014).

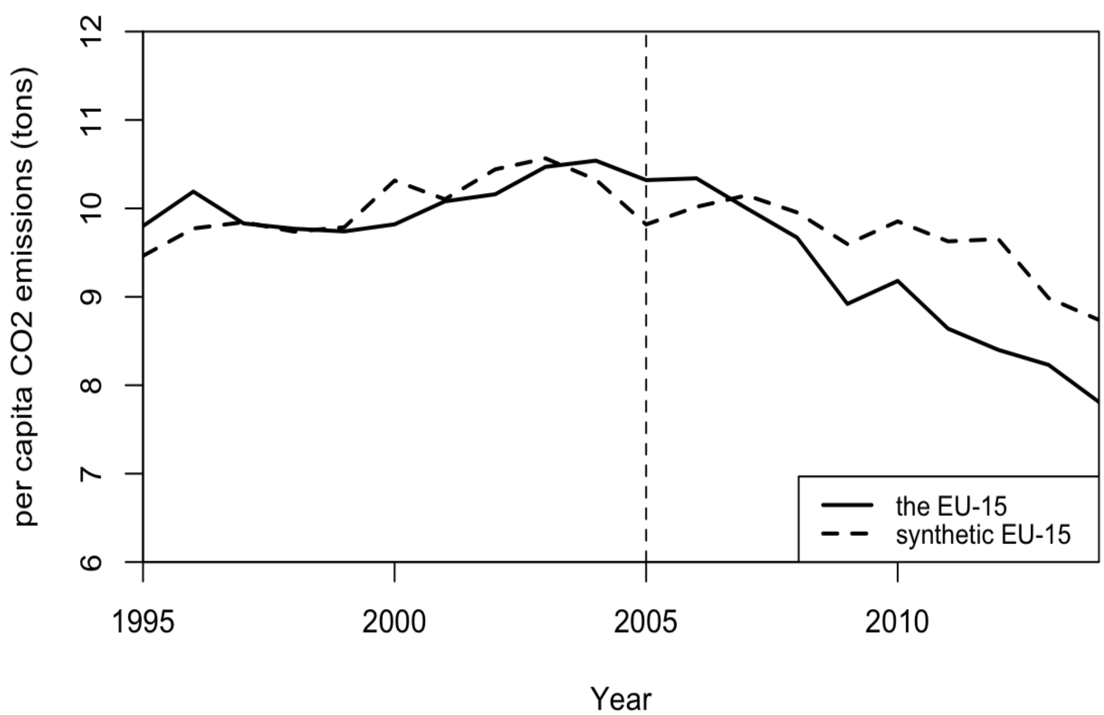

Figure 8. Trends in per capita CO_2 emissions: the EU-15 vs. the synthetic EU-15(Japan is excluded)

Phase III comes with important change in the method of allocation. While new allocation method for power sector is auctioning, main allocation method is benchmarking for other industrial sector covered by the EU ETS. The decreasing trend in emission reductions keeps going in 2013. The "back-loading" decision is put into force in 2014. According to this decision the auctioning of 900 million tones allowances are postponed from 2014-2016 to 2019-2020 period (Morris, 2014). The reduction in emissions is sharper than the previous period in 2014.

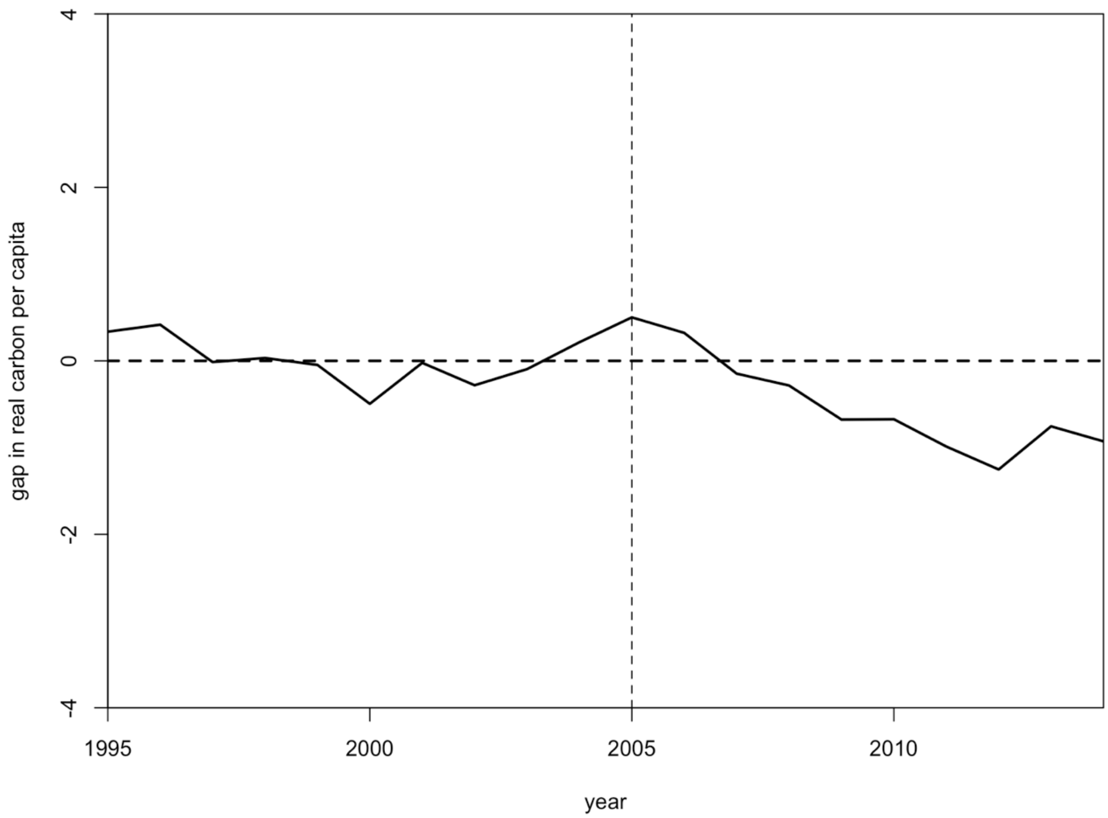

Figure 9.Per capita CO_2 emissions gap between the EU-15 and the synthetic EU-15 (Japan is excluded)

The other possible explanation for the large gap after 2010 is overlapping policies of the member states and the increasing use of renewable energy sources in the EU. The EU members have national RES targets which are legally binding since 2009 (Gawel et al., 2014). The EU member states have introduced many policies such as feed-in tariffs, tender systems and tax incentives encouraging renewable energy investments in order to meet these targets (Koch et al., 2014); Lehmann & Gawel, 2013). The coexistence of this state level incentives and policies and the EU ETS explains the large gap after 2010. On the other hand, these policies that incentivize the use of renewable energy sources create downward pressure on demand for the EU ETS allowances and carbon price (Koch et al., 2014). Furthermore, a number of energy efficiency policy instruments have been introduced during the same period.

As opposed to the literature, this study finds a slight increase in per capita CO_2 emissions during the first two years of the EU ETS. The abatement in emissions starts in 2007. Although the reduction led by the EU ETS is at its minimum level in 2008 due to the 2008 economic crisis, per capita CO_2 emissions caused by the EU ETS keep declining until 2010. Even though the first analysis represents more accurate results until 2010, the placebo study shows that the large gap between the actual and synthetic EU-15 after 2010 is caused by nuclear accident in Japan. As illustrated in Figure 9, the abatement in per capita CO_2 emissions per year are between 0.8-1.5 tons/capita during the 2010-2014 period in the results of the second run, while it reaches to 2 tons/capita especially after 2012 according to the results of the first analysis.

This study finds that although there is an increase in emissions in the first two years of the scheme, the negative impact of the EU ETS on per capita CO_2 emissions is observed in 2007 onward. However, the emissions abatement after 2010 cannot be explained only with the EU ETS. The increasing state level policies and incentives for the use of renewable energy sources explains the significant increase in the emissions reduction. In addition to over-allocation problem and surplus allowances, these state level policies create further downward pressure on CO_2 price and the demand for the EU ETS allowances.

6.2.Discussions

The most problematic part of the synthetic control method is the selection of control unit. In this sense, it is difficult to form a donor pool, which consists of countries similar to the EU-15 average. Although there are some regional carbon taxes and emissions trading systems in Canada, Japan and the United States, they are included to the donor pool. Another issue is the carbon tax implementations in some of the EU-15 countries. The possible impact of the carbon taxes on per capita CO_2 emissions in Ireland, Sweden, Finland and the United Kingdom is not controlled in this study. Also, the impact of flexible mechanisms of Kyoto

Protocol other than emissions trading (Clean Development Mechanism and Joint Implementation) are not considered. Although they started to be implemented in 2008, the methodology controls the impact of these flexible mechanisms since many of the countries in donor pool are parties to the Kyoto Protocol.

The EU ETS covers electricity sector, industrial installations and aviation sector (since 2012) but the outcome variable per capita CO_2 emissions include emissions of industrial processes and fossil fuel use excluding emissions from biomass burning. Although the synthetic control method controls other confounding factors which vary with time, using emissions data of sectors covered by the EU ETS would give more accurate results. However, large historical CO_2 emissions data belongs to the sectors covered by the EU ETS is not available even for the EU-15. The historical emission data for the sectors of interest in the EU is available just after 2004. Moreover, the emissions data of the sectors of interest for the first several years is problematic due to the implication of grandfathering and lack of control.

Since the output data includes all fossil fuel use, the gap between the real and synthetic EU-15 may include emissions from domestic use and transportation. Regarding transportation, this study does not take into consideration the transportation sector because of the absence of any large scale policy that aims to decrease CO_2 emissions in transportation sector within the donor pool. Furthermore, the inclusion of share of CO_2 emissions from transportation as a predictor, makes almost zero change in the weights of control countries.

Similarly, the extreme weather conditions may impact emissions. The heating degree days is a common variable in order to estimate the impact of weather conditions but there is not available large term data. Due to the lack of data, this study cannot include direct predictor for weather conditions. However, energy use and electricity consumption data are indirect controls for the impact of weather conditions. The energy and electricity consumed for heating and air-conditioning are included to the energy use and electricity consumption per capita variables.

In addition to the current predictors, we plan to include value added manufacturing share in GDP as a control for production. Nevertheless, due to the lack of data for Canada and the United States, it has to be excluded from predictor variables.

CHAPTER 7

CONCLUSION

This study attempts to evaluate the impact of the EU Emission Trading System on per capita CO_2 emissions in the EU-15 countries by using synthetic control method which is developed by Abadie, Diamond and Heinmueller.

Although, there is a large literature on the evaluation of the EU ETS in terms of emissions reduction, the inaccurate historical baseline data for the evaluation of Phase I and the difficulty of creating a counterfactual scenario during the 2008 economic recession due to the large emissions reduction caused by the economic crisis are common problem of existing literature. However, the synthetic control method provides more accurate results by creating a synthetic EU-15 which reflects what per capita CO_2 would have been in the absence of the EU ETS by controlling other confounding factors that might impact CO_2 emission in a less complex way, especially, for the first phase and the 2008-2009 economic crisis period. Moreover, this study shows the applicability of the synthetic control method for the evaluation of environmental policy

The biggest contributor of the synthetic EU-15 is Japan with weight of 0.773. Israel is the second with 0.219 and the United States has almost no impact with weight of 0.007 on the formation of the synthetic EU-15. The most powerful predictors are GDP per capita (constant 2010 US$), lagged variables of carbon emissions per capita for 2000 and 1997, and alternative & nuclear energy share in electricity production.

The results of this analysis find that before the initiation of the EU ETS, small amount of increase is observed in emissions. The possible explanation for this increase is the choice of grandfathering for method of allocation. Although some studies (Ellerman & Buchner, 2008; Anderson & Di Maria, 2011) find small amount of decrease during 2005-2006 period, this study observed about 0.1 tons/capita emissions increase for both 2005 and 2006. As stated by Ellerman et al. (2007), the possibility of over-estimation of historical emissions baseline due to the grandfathering may affect the results of these studies. The most possible reason behind the observed increase in this study is continuing use of grandfathering and over-allocations as a result of wrong historical data estimation. The first significant decrease is observed in 2007 at the latest year of Phase I.

Based on the over-allocation problem faced in Phase I, emissions allowances are set more cautiously for Phase II. However, with the impact of the crisis erupted in 2008, both the emissions and carbon prices fall sharply. The observed CO_2 emissions per capita led by the EU ETS for 2008, 2009 and 2010 are about 0.1, 0.4 and 0.6 tons/capita, respectively. Although, the carbon price reaches to almost €30 just before the economic crisis, it falls to €15 at the end of 2010.

Although carbon price decreases further after 2010, the emissions reduction reaches to the largest level during this time period. The results of placebo study indicate that something in Japan causes a bias in the results. The Fukushima accident in Japan is the main result of this unexpected gap between the real and synthetic EU-15. The analysis is repeated by excluding Japan. According to the new results Israel is the main comparison country. Although the results of the first and second analysis are similar until 2010, the emission reduction between 2011 and 2014 is smaller in the second analysis.

Despite the emissions reduction -according to the results of second analysis- is less than the previous one, the observed emissions reaches to the highest value in the 2011-2014 period since the beginning of the EU ETS. However, high amount of surplus in the market and low carbon price cannot explain this difference. The possible explanation for this reduction is increasing incentives for use of renewable energy resources in member states. Rising use of renewable energy sources also create downward pressure on allowance demand in the market and pulls the carbon price back. This method is inadequate to measure the CO_2 emissions caused by the EU ETS after 2010 because it cannot control changing dynamics within the EU. At the 11^{th} year of the policy the carbon price is still around €7-8. New measures and inclusion of the aviation sector in order to decrease surplus emissions cannot contribute in desired level.

The results of this study finds evidences that support the effectiveness of the EU ETS; however, over-allocations as a result of free allocation methods and the 2008 economic crisis are two main reason behind the underachievement of the EU ETS.

For further studies, this analysis can be made for individual countries. When we consider state level policies, the analysis gives more clear results. Similarly, the same method can be applied to specific sectors such as power sector which is the most important sector of the EU ETS. For general literature; instead of ex-post analyses, conducting ex-ante analyses will be more beneficial for the continuation of the EU ETS.

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