SAPIENZA UNIVERSITY OF ROME

DOCTORAL THESIS

Essays on Climate Change Policy Evaluation

Author:
Dr. Chiara CURCIO

Supervisor:
Prof. Maurizio FRANZINI

SAPIENZA
UNIVERSITÀ DI ROMA

A thesis submitted in fulfillment of the requirements for the Ph.D. in Economics

March 11, 2019

SAPIENZA UNIVERSITY OF ROME

Abstract

Faculty of Economics
Department of Economics and Law

Ph.D. in Economics

Essays on Climate Change Policy Evaluation

by Dr. Chiara CURCIO

Climate Change is a global problem that affects several dimensions of human activities. The peculiarity and complexity of the problem let Climate Policies very challenging to design. Moreover, Climate Change has public good characteristics and can lead to free-riding. For these reasons, Economic Literature uses intensively game-theoretic approaches in order to model and assess Climate Change policies. The aim of this Doctoral Thesis is threefold: *i*) to provide a comprehensive review of the economic theory and empirical studies behind International Environmental Agreements (IEAs) and Regional Environmental Policies, with a specific focus on two major examples coming from the European experience: the EU Emissions Trading Scheme and Renewable Energy Sources; *ii*) to empirically assess the cooperative nature of the Nationally Determined Contributions of the Paris Agreement (the latest and broadest IEA) and to provide an empirically-based methodology in order to forecast potential cheaters to the Paris Agreement and to identify the socio-economic determinants that could lead a country to defeat from its commitment; *iii*) to study the socio-economic and political drivers of Photovoltaic Panels deployment in Italian cities under the Feed-in Tariff mechanisms, *Conto Energia* by adopting a spatial econometric approach. The structure of this Thesis follows a general-to-specific approach in order to account for different dimensions of Climate Change policy, from the global (International Environmental Agreements) to local perspective (Italian Feed-in Tariff mechanism at the city-livel). The final goal is to provide a longitudinal assessment of different types of Climate Change mitigation policies through the application of econometric tools.

Acknowledgements

I would like to thank Prof. Maurizio Franzini for his help and support during my whole PhD. I am particularly grateful to Prof. Richard S.J. Tol for his precious guidance to my research work. My gratitude is also to Prof. Massimiliano Tancioni and Filippo Celata for their help and suggestions. Thanks to all the PhD students, researchers and faculties of the University of Sussex for their useful comments during the drafting of this thesis. Thanks to all the team and participants of the EcoMod Network and SEAI 2018.

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Chapter 1

Introduction

Climate Change is a global problem that affects several dimensions of human activities. The peculiarity and complexity of the problem let Climate Policies very challenging to design. Moreover, Climate Policy takes place at different levels, from global (International Treaties) to local (city-level emission reduction implementation), therefore the economic theory behind these policies should take into account the involvement of several and differentiated agents and possible conflicts in jurisdiction and responsibility. This implies that Climate Change Policies should reflect this multi-dimensionality in order to be effective.

The present Doctoral Thesis starts in chapter 2 with a review on the economic literature behind Climate Policy, with specific regards on its design, implementation and assessment. Then, I focus on the EU Energy and Environmental protection policy and I analyze two successful policies: EU Emissions Trade Scheme and Renewable Energy Policy.

From a pure economic point of view, Greenhouse Gases (GHGs) abatement is a typical example of what Hardin (1968) called "*tragedy of commons*", therefore Game Theory and Contract Theory can help the assessment of the strategic behaviors of the agents involved. Moreover, contrary to the private sector, International Environmental Agreements (IEAs) are signed by independent countries and there are no international authorities who can guarantee and enforce the agreements.

Therefore, most of the literature focuses on two major problems arising from IEAs: free-riding and self-enforceability. It is possible to identify two branches of the literature, *i*) Non-cooperative-based models, whose pioneer is Barret (1994) and *ii*) Cooperative-based models, born from the contributions by the recent Nobel Prize W. Nordhaus. The conclusions of the two approaches are very different from each other and in the last decade many empirical studies focus on the impact evaluation of the latest IEAs in order to find evidence in support for one of the two theories.

Some examples are papers by Murdoch and Sandler(1997) in which the authors test if the Montreal Protocol is compatible with a Voluntary Provision of a Pure Public Good; Almer and Winkler (2017), who used the synthetic control method by Abadie and Gardeazabal (2003) in order to evaluate the final effect of the Kyoto Protocol based on a Treatment-Effect perspective.

Nevertheless, a big limitation of these theoretical models is the lack of attention on equity-related issues. Since the nature of Climate Change is such that it causes inter- and intra-generational inequalities, it is important to address these issues in all stages of the policy's life-cycle.

chapter 3 is an ex-ante, empirically based assessment of the cooperative nature of the Paris Agreement. Using as reference the paper by Murdoch and Sandler (1997), I test whether the Nationally Determined Contributions (INDCs) of the Paris Agreement are compatible with the model of voluntary provision of a pure public good, by Bergstrom et. al (1986). The model implies that,in non-cooperative Nash equilibrium, GHGs abatement is linearly increasing in income. The evidence leads to reject that the Paris Agreement is compatible with a pure Nash equilibrium outcome but it is not sufficient to exclude the possibility of free-riding among coalition members. Therefore, I developed an empirical methodology in order to forecast the potential cheaters of the treaty and the socio-economic variables that could lead a country to deviate from the emissions target committed. Since the Agreement is still at the beginning of its life, I start the analysis by defining the potential cheating as a projected relative deviation from the GHGs abatement target.

I thus compare the estimated outcomes of the NDCs with the official GHGs projections by the UNFCC for the year 2030, the target year. The potential cheater is therefore identified as the country whose relative target deviation is greater than a certain threshold. Since the analysis is theoretically agnostic, I explore three different scenarios based on three different thresholds. Evidence from an ordered probit model suggests that potential cheaters, even with low/medium target deviation, are those countries who suffered more from natural disaster, did not receive adequate International aid by the Global Environmental Fund and are highly involved in multilateral Environmental agreements. For medium target deviations, countries who are ranked by the Freedom House as partly free and who are located in the Tropics are more likely to be potential cheaters.

The policy implication of this analysis is twofold: first, it gives policy makers a simple methodology in order to forecast potential cheaters of an International Agreement; second, it can be used as a starting point to enrich game theoretic models of coalitions.

Furthermore, in chapter 4, I run an empirical assessment of the widest and most relevant renewable energy incentive mechanism in Italy, *Conto Energia*. I built a detailed cross-section dataset using Italian cities (i.e. "Comuni") as spatial units. The novelty of this dataset is the combination of variables related to the incentive, Italian cadastral data, geographical and spatial data and detailed info on the political composition of the cities' cabinets. I run and compare two spatial econometric models: the Spatial Durbin Model and the SARAR model in order to account for all kind of spatial interactions between PV deployment and the socio-economic and political structures of the Italian cities.

The main results of the study are twofold: from the one hand, I found a significant spatial concentration of PV in the cities characterized by low population density, low urbanization and high income (most of the small cities in the North of Italy). Moreover, households who own more than one dwelling are more likely to install PV in order to take advantage of the house's maintenance reduction cost. In the Spatial Durbin Model, I also find a positive and significant spatial auto-correlation in the dependent variable, suggesting that individual green practices, such as installing a PV on the roof, are subject to imitative behaviours across neighbours.

From the other hand, the study shows that there exists a political nepotism effect: if the local party belongs to the same political wing of the national government, the PV deployment rate is relatively higher. The results of the analysis have relevant policy implications. Most of the concentrations of the PV are in the northern Italy rather than in the south, where solar irradiation is higher. This would suggest a friction in the local administration and, together with the presence of a nepotism effect with the national government, it advocates for an administrative delocalization of the subsidy. Moreover, "Conto Energia" seems to cover only the highest income percentile of the population. Among all possible interventions, this would suggests that involving tenants together with owners could enhance the potentiality of the policy.

Finally, in chapter 5 I will present the conclusive remarks, with a specific focus on the main contributions of my work to the current literature, drawbacks and forthcoming research proposals.

Chapter 2

Climate Change Policy: Design, Implementation and Assessment

2.1 Introduction

Climate Change is a global problem that affects several dimensions of human activities and it has been addressed by a pool of interdisciplinary scientists all over the world.

Economists are interested in the way agents face the risk of Climate Change, the strategic behavior among Countries in order to find and keep an agreement on Climate mitigation, the distributional and equity issues related to the actions taken to face this problem.

The peculiarity and complexity of the problem let proper Climate Policies very challenging to design. Moreover, Climate Policy takes place at different levels, from global (International Treaties) to local (city-level emission reduction implementation), therefore the economic theory behind these policies should take into account the involvement of several and differentiated agents and possible conflicts in jurisdiction and responsibility.

The aim of this chapter is to analyze and summarize how recent economic literature have addressed to these issues.

I proceed with a two-step analysis that follows a vertical reasoning approach (general-to-specific). In section 2.2, I explore the economic theory behind the International Environmental Agreements (IEAs) taking into account three levels of assessment: *i*) the problem of self-enforceable IEAs and the use of Game Theory in order to face this problem (subsection 2.2.1); *ii*) Equity-related issues involved in the design and implementation of the Treaty (subsection 2.2.2); *iii*) The use of econometrics for the impact evaluation of IEAs (subsection 2.2.3).

The second step of the analysis focuses on Regional and Local Climate Policies for emissions abatement with a specific focus on the EU environmental policy framework. This topic will be addressed in section 2.3 and I explore two relevant and successful EU policies: Emission-Trade Scheme (ETS) and renewable energy production, in subsection 2.3.1 and in subsection 2.3.2 respectively.

Finally, in section 2.4 I will provide my final considerations.

2.2 The Economic Theory behind IEAs

2.2.1 Game Theory and The Problem of Self-Enforcement

Ensuring participation, compliance and distributive justice in International Environmental Agreement is very difficult to achieve. Some recent example of withdrawal

FIGURE 2.1: Payoffs Matrix of a simple two-country IEA Game

		European Union	
		Ratify	Not Ratify
United States of America	Ratify	3 **World optimum**	1 **free riding by EU**
	Not Ratify	4 **free riding by USA**	2 **national optimum**

Source: Eyckmans and Tulkens (2005).

and defeating has risen the problem of self-enforceable IEAs from a legal and economic point of view.

Contrary to private agreements, International Agreements are signed by independent countries and there are no international authorities who can guarantee and enforce the Treaties. Moreover, the International coordination of climate policy has public good characteristics:

- The Benefits arising from the coordination (less Climate Change, hence less damage) are non-excludable;
- Countries that did not contribute to the emissions reduction can still benefit from the actions taken by others (Free-riding);
- Public good (Climate Change mitigation) is under-provided in an unregulated free market economy;

For instance, the GHGs effects is a typical example of what Hardin (1968) called "tragedy of commons".

From an economic point of view, the context of IEAs has been often addressed by the literature using tools and models coming from the Game Theory. As an example, Figure 2.1 shows that it is possible to model a two-country IEA in a simple Game. In the Figure are reported the payoffs that an individual country, such as the United States, can get from the ratification of the IEA, given the ratification decision made by the other country, for example European Union.

From Figure 2.1, we can see that "not ratify" is the dominant strategy and, by assuming the Game symmetric, the Nash equilibrium ends up to the absence of the agreement.

Coordination failure, the presence of free-riding and the need for stabilization are confirmed also in this simple scenario.

According to Finus (2008), Game Theory can model each stage of the negotiation process of IEAs. Figure 2.2 summarize the stages of coalition formation under a game theoretical perspective.

The Pioneer who first tried to model self-enforceable IEAs is Scott Barrett in 1994. In his paper, Barrett studies the characteristics of international commitments in a non-cooperative scenario and he founds that self-enforceable IEAs may not be able to improve the non-cooperative outcome. Beside of Barrett (1994), many economists tried to exploit the concept of "self-enforcing" agreement in order to identify the types and the characteristics of stability that a coalition should have.

In particular, the definition given by D'Aspremont et al. (1983) , has been widely applied in the literature of IEAs by many scholars such as Barrett (1994), Carraro & Siniscalco (1993), Hoel (1992), Carraro, Eyckman and Finus (2006) and many others afterwards. Specifically, D'Aspremont et al. (1983) says that, under a non-cooperative framework, a self-enforceable coalition should respect both internal and external stability.

In order to better explain these concepts, let consider a World composed by N countries, and suppose that a group of $S \subseteq N$ join the coalition. Let $v_i(S)$ be the individual payoff of a country $i \in S$. It is possible to distinguish between *Internal Stability* (equation (2.1)) and *External Stability* (equation (2.2)):

$$v_i(S) \geq v_i(S \setminus i), \forall i \in S \tag{2.1}$$

$$v_i(S) \geq v_i(S \cup i), \forall i \notin S \tag{2.2}$$

That is, in equilibrium, no signatory belonging to coalition S has an incentive to leave its coalition in order to become a non-signatory, given the participation decisions of all other countries. By the same token, no non-signatory has an incentive to join coalition S, given the decisions of all other countries. Note that by definition coalition $S = i$ is internally stable and coalition $S = N$ externally stable by definition.

Models on IEAs stability in non-cooperative scenario can be found also in Diamantoudi & Sartzetakis (2006). The basic assumption arising from economic models of Climate Change in a non-cooperative framework is that if a country deviates from IEA, the remaining members continue to cooperate but re-optimizing their strategy. Therefore, deviating from an IEA has only a small cost for the defeater: important decrease in emission reduction costs combined with a small increase in climate change damages.

Given the assumptions made within this framework, the predictions about the size and effectiveness of IEAs are very pessimistic. Indeed, in all models mentioned above the conclusion is always that international coalitions can do very little or none improvement –in terms of individual country's worth and emissions abatement-with respect to the business-as-usual scenario, i.e. no agreement.

On the other hand, if we consider a cooperative Game, the approach focuses first on strategies chosen jointly by the members of the grand coalition, that is, the set N of all countries. If the scenario is such that:

- no individual player can reach a higher payoff by choosing the best individual strategy he could find rather than adopting the strategy assigned to him in the efficient scenario;
- no subset of players, smaller than N, can similarly do better for its members, that is, by rejecting the strategies assigned to them by the efficient scenario and adopting a strategy of their own.

Then, this scenario and the grand coalition that generates it, are said to be stable in the *core sense*[1].

[1]The concept is expressed in Eyckman and Tulkens (2003); Bréchet, Gerard and Tulkens (2007).

Formally, let i refers to player $(i = 1, \ldots, n)$, $S \subseteq N$ be a coalition and let the vector $W = (W_1, \ldots, W_i, \ldots, W_n)$ denotes an imputation, that is a vector of individual payoffs W such that their sum is equal to the worth of the grand coalition, formally:

$$\sum_{i \in N} W_i = W(N) \tag{2.3}$$

The imputation W belongs to the core if the individual payoffs W_i satisfies the following two properties:

- Individual Rationality:
$$\forall i \in N, W_i \geq W(i) \tag{2.4}$$

- Coalition Rationality:
$$\forall S \subset N, \sum_{i \in S} W_i \geq W(S) \tag{2.5}$$

Where $W(i)$ refers to the strategy and ensuing payoff of player i that corresponds to the Nash equilibrium scenario; while $W(S)$ states that the worth of coalition S is the sum of the payoffs obtained by the members of S as they result from enacting the joint strategy that maximize this sum.

The basic assumption here is that if one country deviates from the IEA, the remaining group falls apart and we end up without IEA. This implies that individual deviations are more costly than in non-cooperative framework. Indeed, by defecting, the cost of emissions reduction goes down but the damages increase substantially. According to this idea, the predictions about the size and the effectiveness of IEAs given by Chander & Tulkens (1995, 1997) and Eyckmans & Tulkens (2003) are more optimistic than the non-cooperative approach, but only in the case where transfers of welfare can be used.

When a coalition and its strategies are not stable, transfers of resources between countries may induce stability. Many scholars in the literature have analyzed this property. Remarkable contribution to the literature is given by the recent Nobel Prize Nordhaus & Yang (1996).

Regardless most analysis, which treat global warming as a single-agent problem, Nordhaus & Yang (1996) adopt a regional-level approach by presenting the Regional Integrated model of Climate and Economy (RICE). By disaggregating into countries, the model analyzes different national strategies in Climate Change policy such as pure market solutions, efficient cooperative outcomes, and non-cooperative equilibria. The authors find that cooperative policies show much higher levels of emissions reductions than do non-cooperative strategies and they show that high-income countries may be the major losers from cooperation and this could lead to possible defection by Developed Countries (as it has been confirmed by the behavior of USA and Canada in the Kyoto Protocol framework and USA in Paris).

More recently, Hagen and Eisenack (2015) investigate whether global cooperation could be improved among asymmetric countries with different parallel Environmental Agreements. They find that for constant marginal benefits of emission reduction, the possibility of multiple agreements signed by clusters of countries can increase the number of cooperating countries and the total abatement. The problem has been addressed by Vassiliki Manoussi, Anastasios Xepapadeas (2014), too, who analyze the cooperation and competition in Climate Change policies when Countries are asymmetric.

These results are very important for the political debate of today because they give support for regional coalitions instead of the big global coalition, as it is in the

FIGURE 2.2: Structure of Coalition formation in membership models

1. Stage: participation			
Sequence	Simultaneous	Sequential	
		No revision of members	revision of members
Agreements	Single	*Multiple*	
Membership	Open	*Exclusive*	
		Majority	*Unanimity*
2. Stage: abatement and transfers			
Sequence	Simultaneous (Cournot)	Sequential (Stackelberg)	
Abatement	Joint welfare maximization (Efficient)	*Bargaining*	
		Majority	*Unanimity*
Transfers	No	*Yes*	
Payoffs	Objective	Subjective	
	Social planner	Politician	
	Material	Non-material	
	Certain	Uncertain	

Source: Finus (2008).

purposes of the latest IEA, the Paris Agreement. Anyway, as widely discussed in Barret *et al.* (2003) the problems of IEAs still remain participation and compliance and it is economists'duty help policy makers to overcome this issue.

Nevertheless, a big limitation of the game theoretical models used by the literature is that the payoff matrix is based only on cost-efficiency issues and ignored equity and justice considerations. In the next section, I will discuss how equity and justice play an important role in the stability of IEAs.

2.2.2 Equity issues in Environmental Agreements

Environmental Pollution rises relevant problems in terms of equity. The nature of GHGs is characterized by a long residence time in the atmosphere, up to hundreds of years, and the public-good nature of Global Warming has severe impacts in terms of inter-generational and intra-generational justice.

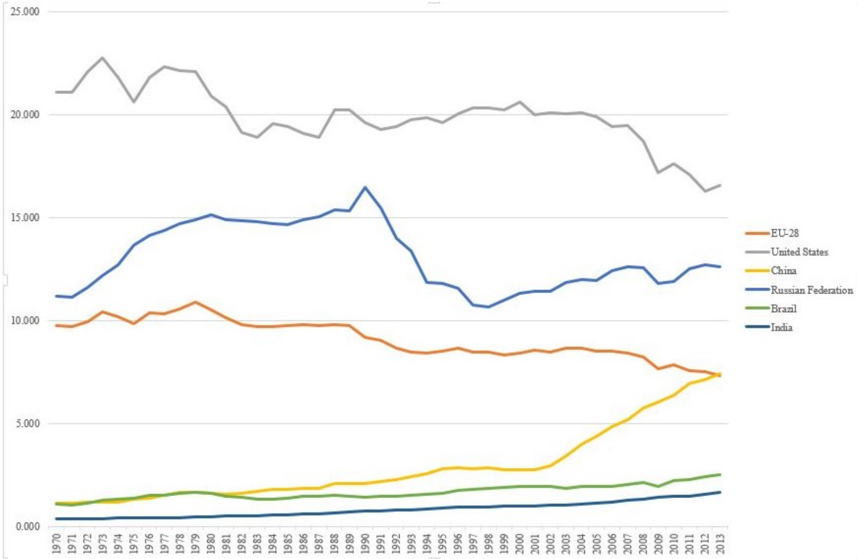
Figure 2.3 clearly shows that some countries contribute to environmental pollution more than others. The discrepancy among current national-level emissions and the historical responsibility paved the way to negotiation conflicts and several difficulties in the formation of an international coalition.

We can identify three "big polluters", such as United States, Russian Federation and European Union. In the recent years, China has been reaching EU-28 emissions level, and it is now an important player for IEAs[2].

Furthermore, Figure 2.3 implicitly shows the presence of huge asymmetries not only in the responsibilities but also in the possible worth coming from emission abatement policies. Hence, commitments in abating GHGs can have unequal effects in the distribution of wealth, giving rise to inequality issues.

[2]Z. Liu *et al.*(2015) affirm that China's carbon emissions maybe are significantly lower than previously thought –about 14% less with respect to the previous estimations. This mistake is due to the ambiguous definition of "coal" used by the Chinese government. According to the authors of the above-mentioned article, the coal used in China is mostly low-quality coal, very dusty, which produces less energy and less heat-trapping CO_2. The Zhu Liu-team's findings do not unseat China from its position as the world largest emitter of carbon dioxide, even when lower estimate is taken into account. The principal contribution of this study is that it underscores long-lasting uncertainties in the methods with which scientists compute individual nations' emissions and could help in the responsibility identification of CO_2 emissions.

FIGURE 2.3: World Big Polluters (CO2 *per capita*)



Source: EDGAR Database

Kverndokk and Rose (2008) identify four levels in which equity issues take place in Environmental Policy:

1. *National*: Given that Climate Change is a public good whose externalities take place globally, mitigation measures require international attention. This level refers specifically to cost-distribution in IEAs and relates to the fact that Developed countries are mainly responsible for the current level of GHGs stock in the atmosphere. Moreover, Developed Countries have the sources and capabilities to engage in consistent emissions reduction policies which are very costly. Principles of fairness of this type have been used as excuses by some countries for not ratifying IEAs. As an example, at the time of the Kyoto Protocol, USA has pointed out that several large emitters, such as China and India, have not committed to GHGs abatement. On the other hand, Developing countries remarked their lack of resources and claim that industrialized countries ignored this problem when they were at a similar stage of economic development. Furthermore, inequality at national level can have other forms, too. Vona and Patriarca (2010), argues that within rich countries, a large dispersion in the capacity of generating environmental innovations appears correlated to the level of inequality. Moreover, the authors show that an excessive inequality harms the development of environmental technologies especially in rich countries.

2. *Regional*: Climate Change concerns rely also below national level. It happened that local governments, such as regions, states and cities, realized cooperative arrangements focused on emissions reduction. One famous case is the Western States Climate Initiative (WCI): some US States agreed to commit on emissions abatement even though the Federal government has not ratified any international agreement about that.

   Anyway, a situation like WCI could raise conflicts of fiscal federalism, such as which jurisdiction should control carbon taxes or emission permit auction revenues, and it could lead to disparities on the distribution of costs and revenues among the States involved.

3. *Inter-sectorial*: Many scholars have pointed out that Climate Change heavily affects only some sectors and determines some gains in others. Clearly, equity issues and justice should be taken into account in this framework. Given the peculiarity of Climate Policies, only energy-related sectors are affected and, in particular, oil and gas energy sectors pay the highest price, rather renewable energy production gains market share and prosperity.

   The problem become even more serious when job losses in these sectors are taken into account. Notoriously, mine workers, especially if they do not belong to any union, would be heavily affected by the introduction of energy-switch policies in favour of renewables. In order to correctly estimate the Welfare net gains coming from climate change policy, it is important to rely on a general equilibrium framework[3].

4. *Interpersonal*: Many scholars argue that mainstream climate policies, such as carbon tax and emission permits, have severe regressive effects because they determine energy prices to rise, thus affecting a basic necessity. This means that poor people are penalized much more than rich people by the introduction of this type of policies. Moreover, some authors (Vona, Marin *et al.* (2015, 2016)) have pointed out that environmental regulation triggers technological and organizational change and it leads to a differentiation in terms of demand for new and high-quality skills between green jobs and non-green jobs, with important implications for the labor market.

The Kyoto Protocol, since its original formulation, recognizes that Developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere because of more than 150 years of industrial activity. Thus, under the principle of "common but differentiated responsibilities”, it places a heavier burden on developed nations.

Anyway, the design of the Kyoto Protocol is mainly focused on cost-efficiency rather than distributional equity. In line with this figure, the Kyoto Protocol outlined a set of “flexibility mechanisms” that capitalize on the mutual gains from trade, such as emissions trading, or forms of bilateral cooperation through the Joint Implementation (JI) and the Clean Development Mechanism (CDM).

Completely different from Kyoto, the solution proposed by the Paris Agreement is to let each nation self-determine the commitment for emissions reduction. The basic idea is that each country can better identify its own contribution compatible with its state of development and its own resources. This process help to overcome problems of asymmetric information but it still could lead to moral hazard and free-riding.

Regarding the possibility of asymmetric responsibility and capability, the Kyoto Protocol try to take into account these asymmetries, and signatories have been split into two categories: Annex A and Annex B countries. The former refers to the “Developing Countries” who did not bind themselves in emissions reduction, while the latter is the list of the Developed and most responsible countries who commit in GHGs abatement policies proposed in the Treaty.

Moreover, equity consideration relates to the time horizon of the Climate Change problem. Since GHGs could persist in the atmosphere for thousands of years, the actions taken by the current generation have important implications for those in the future. Arrow et al. (1996), Stern (2007), Dasgupta (2006) and Weitzman (2007) refer in more details about the inter and intra-generational equity issue touched on above.

[3] In subsection 2.3.2 I will deeply explore this item.

For what concerns the intra-generational justice, the inter-sectorial dimension proposed by Kverndokk & Rose (2008) needs to be better addressed for future Climate Policies.

In particular, the energy industry is a powerful lobby in many countries or regions, and the uneven impacts deriving by energy-switch policies have already stopped many important Climate Change Policies.

Following this line, many scholars like Dinan and Rogers (2002), Repetto and Austin (1997) and Parry et al. (2006), study the income distribution impacts of carbon taxes or carbon emission permits (since they are the most used tools for climate policy). They find that although the initial focus was only in sectors which emit carbon (Oil / Coal / Gas extraction, transportation and refining), the principal role of these products means, however, that carbon reduction policies will eventually spread throughout the economy, with possibly negative outcomes.

For these reasons, most of the general equilibrium models are integrated with carbon-cycle models in order to capture the effects of carbon accumulation in the economy (as in Barrett(1994) and many other scholars afterwards). Moreover, fossil energy products and most energy-intensive processed goods like housing, food and cars, are necessities and difficult to substitute. As Economic theory says, spending on necessities is inversely related to income, hence, *ceteris paribus*, carbon taxes would be regressive in partial equilibrium terms.

2.2.3 Empirical Assessment of Recent IEAs

To assess empirically IEAs is very controversial because of the specific nature of these agreements. In particular, according to Ringquist *et al.*(2005) three problems arise when assessing IEA:

- scarcity of good time series data on environmental quality (especially for former agreements);
- a complex mix of non-policy factors that affect environmental quality;
- participation in IEAs is voluntary and this lead to self-selection sample.

Anyway, the quality of an IEA can be measured by different points of view. It can be assessed in terms of its impact, i.e. in its capacity to "force" the participants in implementing emission reduction policies that they would not have implemented in a Business-as-usual- scenario. It can also be assessed in terms of its cooperative nature and its stability.

One of the most cited work on the IEA's assessment in terms of its cooperative nature is Murdoch and Sandler (1997) on the Montreal Protocol. In their work, they examine whether the outcome of the Montreal Protocol were compatible to the game theoretical model of voluntary contribution to a pure public good by Bergstrom *et al.*(1986).

The theory of the voluntary provision of a pure public good states that contributors reduce their emissions linearly according to their income. A test for linearity in the case of the Montreal Protocol, leads the authors to conclude that the Protocol is compatible with this formulation. This implies that emission reduction of the Montreal Protocol signatories would have been the same even in the absence of the agreement.

This important results have been confirmed by other quantitative studies and similar conclusions apply to other IEAs, as well.

Ringquist *et al.*(2005) apply impact evaluation techniques to the Helsinki Protocol, controlling for selection bias and non-random assignment. Their results confirms the study by Murdoch and Sandler (1997) and they conclude that the Helsinki Protocol has made no difference in nations' success in reducing sulfur dioxide emissions. Moreover, a comparison between ratifiers and non ratifiers shows that emission reduction rates were almost equivalent before and after the ratification.

For what concerns quantitative studies on the impact of IEA, many scholars focused mainly on the Impact Evaluation of the Kyoto Protocol because of the availability of good data and because it represents the first attempt in which some countries had binding and quantitatively determined commitments.

Despite the widespread criticism coming from the theoretical literature and quantitative studies on previous agreements, Aichele and Felbermayr(2012,2013) and Grunewald and Martinez-Zarzoso(2016) find that countries with binding emission targets under the Kyoto Protocol have lower CO2 emissions than they would have had in the absence of these targets. Indeed, they estimate the CO2 reduction effect to be 7-10% and this result is highly significant.

Nevertheless, these results are criticized and completely reversed by Almer and Winkler (2017). In their paper, the authors point out that in order to estimate the treatment effect of the Kyoto Protocol the researcher faces four major obstacles:

- Selection bias with respect to the treatment (as already pointed out in previous studies) and the violation of the common trend assumption between treated and non-treated units;

- the timing of the treatment is not obvious. Several dates could be taken into account: the date of ratification, the date of entry into force, the date of US withdrawal etc. …

- Violation of the SUTVA do the fact that Annex B countries could achieve their emission targets either via domestic policies or through the use of the "flexibility mechanisms" (Emission Trading -EM-, Joint Implementation -JI-, Clean Development Mechanism -CDM-);

- Possible presence of carbon leakage: policies enacted by Annex B countries to comply with binding targets may cause GHG emission increases in countries without emission targets.

To overcome these four challenges, they adopt the Synthetic Control Method (SCM) developed by Abadie and Gardeazable (2003) and Abadie *et al.*(2010, 2015). The SCM consists in the artificial construction of counterfactuals for each treated unit by a weighted average of non-treated units in order to balance all relevant characteristics.

Almer and Winkler (2017) try different time specification and different counterfactuals but they always lead to the result that there is "no statistically significant and persistent treatment effect for any of the Annex B countries under investigation".

2.3 Regional Climate Policies for Emission Abatement: a focus on the EU

In Figure 2.3, it is clearly shown that European Union is one of the world biggest polluters. Anyway, EU has implemented several successful emissions reduction policies and its experience has become a virtuous model for other regions.

In this section I will explore two important implementations, the EU ETS and the Renewable Energy Policy.

2.3.1 EU Emissions Trade Scheme- EU ETS

In 2005 the European Union's Emissions Trade Scheme (EU ETS)[4] became operating and it is considered the world's large-scale CO_2 emissions trading program.

Undoubtedly, thanks to its key aspects, it is the most significant attempt by a set of nations to impose an effective limit on GHGs.

Anyway, even though the EU ETS was born in order to achieve the commitments under the Kyoto Protocol framework, it is not the first attempt in the history.

Within the EU, some favorable mention of market-based instruments in order to achieve emission reduction has been made before the publication of the *Green Paper on the GHG Emissions Trading* (European Commission, 2000), where EU started considering CO_2 emissions trading as an integral part of its climate policy.

TABLE 2.1: Main Differences between EU ETS and US SO_2 Program

	EU ETS	US SO_2 Programme
Sources	11,500	3,000
Prepolicy emissions	2 billions $MtCO_2$	16 million of tons SO_2
Value of Allowances	$41 billions	$5 billions
Emission Reduction	low to mid single digits	50%
Implementation	Decentralized	Centralized
Gas under control	CO_2	SO_2

Note: Exchange rate USA/EU = 1.25

Some EU countries was already familiar with this mechanism, such as UK (UK Emissions Trading Scheme), Denmark (Danish CO_2 program) and Netherlands with very promising results even though the programs were very different from each others.

Anyway, the first world's big experiment in Emissions Trading comes from USA. Table 2.1 summarizes the main differences between the two programs.

The economic idea behind Emissions trading refers to the Coase's Theorem on externalities and was originally formulated by Dales (1968) and Montgomery (1972). Since environmental externalities arise because of the absence of a specific market (and thus a price) of pollution, one possible solution is to create a virtual market where pollution rights are traded among agents.

In theory, there are two different forms for Emissions Trading: Cap-and-Trade system (like the one adopted by EU) and Tradable Performance Standards.

For what concerns the Cap-and-Trade system, it is realized in four steps:

1. **Market creation**: CO_2 emissions are allowed as far the agent has the permits to pollute. The authority, in this case the European Commission, sets the total level of emission allowed (CAP);

2. **Initial Allocation**: the authority allocates the emission permits among the polluters. There are two options in which the allocation can take place. The most

[4]For an extensive overview on the structure and evolution of the EU ETS network, refer to the paper by Borghesi and Flori (2018)

favorable in economic terms is by auctioning but, given to some initial challenges, emissions permits were distributed by "grandfathering". More precisely, in the beginning formulation, only four EU members chose to exercise the auctioning options [5] The others distributed the permits "for free" to the firms according to their market share. This decision resulted in the formation of "windfall profits", especially from energy-intensive industrial firms, when electricity prices increased as a result of both higher energy prices and the new carbon price.

3. **Trading phase**: once permits are allocated among firms, they are free to sell and buy the permits according to their position, either short (firms who emit more than what is covered by the permits -buyers) or long (firms who emit less than what is covered by the permits- sellers). Illustrations can be found in Figures 2.4, 2.5, 2.6 and 2.7.

4. **Verification**: Once the trading phase is completed, actual emissions are verified and firms use their permits in order to cover surplus of emissions. Fees are provided in case of defeating.

As the figures show, many countries were in a long position and many scholars argued that this was due to an "overallocation" of permits.

As pointed out by Ellerman and Buchner (2007), "in a cap-and-trade system like the EU ETS, differing abatement possibilities and economic circumstances would cause installations to be both long and short and for the net balance to be a relatively small percentage of the total allocation".

However, several member states were unbalanced since all installations were long and the net long position is large. Such large and unbalanced long position could determine overallocation and this phenomenon was mainly recorded in East Europe and in the non-power sectors. Moreover, the persistence of overallocation determined the carbon price to fall, as it is shown in Figure 2.8.

Under the first formulations of the EU ETS, the sectors covered accounted for 45% of total EU CO_2 emissions. More precisely the sectors involved in the scheme were energy (combustion installations $> 20MW$), refineries, steel and nonferrous, paper, cement, bricks and chemistry.

EU member states were responsible for the initial allocation to their domestic installations through the, so-called, “National Allocation Plans” (NAPs).[6] Member states were free to chose allocation as long as their national allocation was compatible with their longer term Kyoto commitment, “path to Kyoto commitment” and NAPs were to be verified by the EU Commission.

One limitation of this scheme is that NAPs covered somewhat less than 50% of CO2 emissions and smaller emission installations (for instance cars, lorries, domestic heating systems, ...) were not covered. In Phase III (2012-2020) the NAPs are replaced by a harmonized allocation rule.

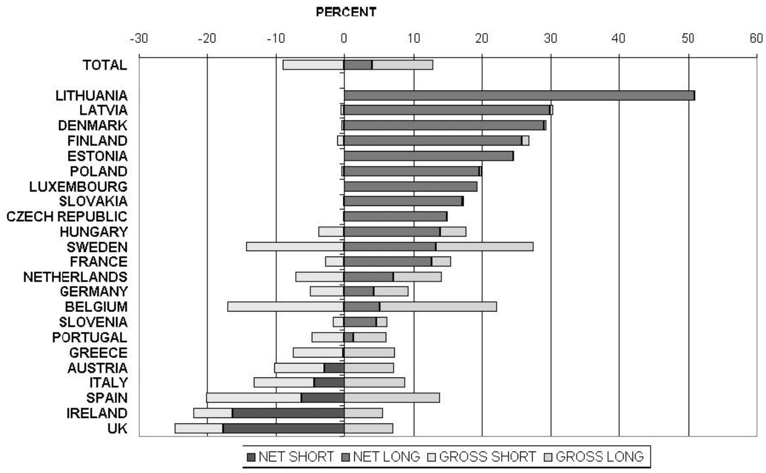
Regardless of all the criticisms, the EU ETS has been a successful experiment of local climate policy. In Figure 2.9 it is evident that EU emissions under ETS are much lower than the estimated counterfactuals and, for these reasons, it is considered as a cornerstone for global climate policy. Anyway, as discussed in Nehuoff *et al.*(2006), ETS requires policy makers attention for what concerns possible negative spillover effects in terms of influence on energy market prices and other economic distortions.

Recently, the ETS has been revised and some new feature have been added:

[5] Denmark, Hungary, Lithuania and Ireland.

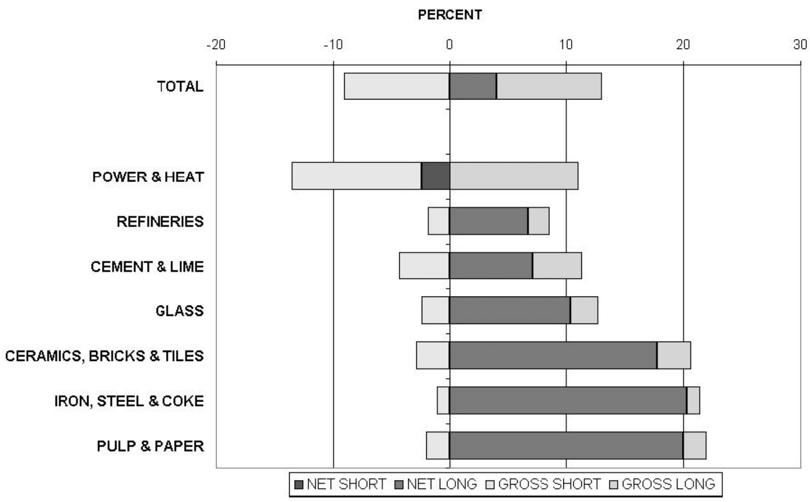
[6] More details on the legal structure of the ETS can be found in Borghesi, Montini and Barreca (2016)

FIGURE 2.4: Long and Short positions of EU member states (% 2005 allocation)



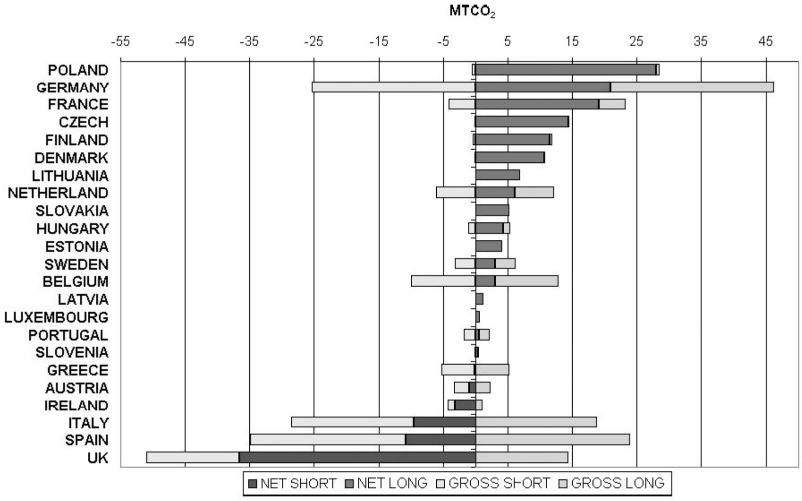
Source: Community Independent Transaction Log (2006) and Kettner et al. (2006).

FIGURE 2.5: Long and Short positions at the sector level (% 2005 allocation)



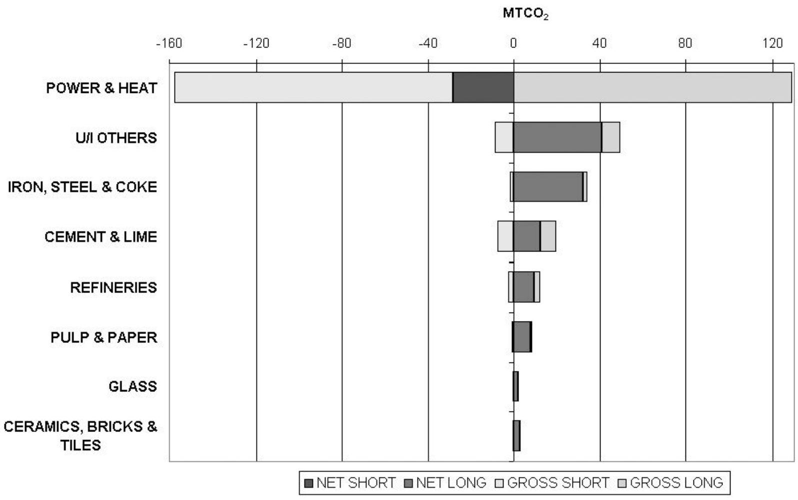
Source: Community Independent Transaction Log (2006) and Kettner et al. (2006).

FIGURE 2.6: Long and Short positions of EU member states (Absolute values)



Source: Community Independent Transaction Log (2006) and Kettner et al. (2006).

FIGURE 2.7: Long and Short positions among EU sectors (absolute values)



Source: Community Independent Transaction Log (2006) and Kettner et al. (2006).

FIGURE 2.8: EU ETS carbon price

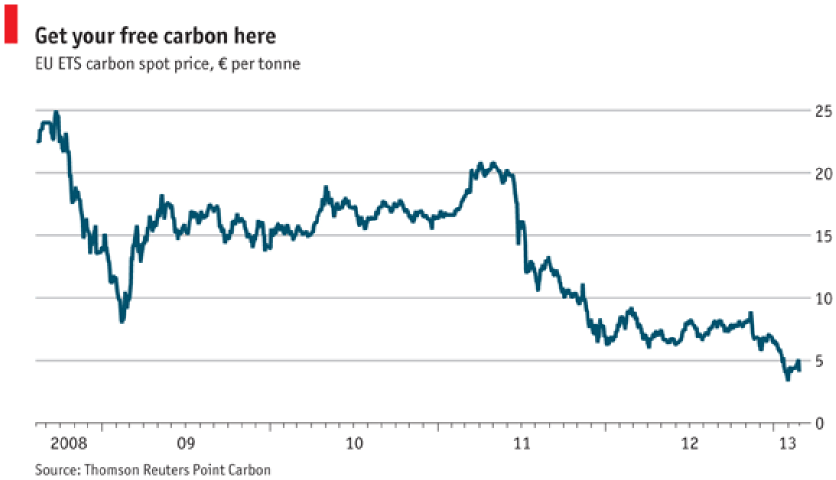
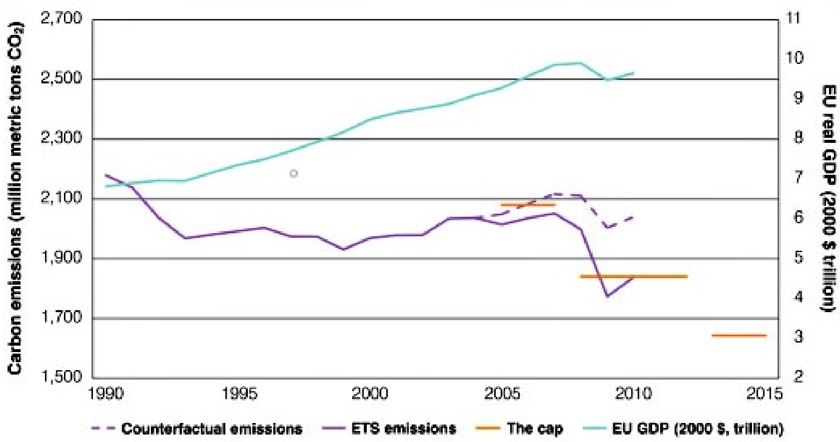


FIGURE 2.9: EU ETS sector emissions (million metric tons CO_2), emissions cap and EU GDP, 1990-2015



Source: European Environmental Agency -EEA (2016).

- Commercial Aviation emissions are now covered by the scheme;
- The coverage has been extended to nitrous oxide (N_2O) from production of nitric, adipic and glyoxylic acids and glyoxal, and to perfluorocarbons (PFCs) from aluminium production;
- The participation to the ETS is mandatory for companies operating in these sectors but, in some sectors only plants above a certain size are included; certain small installations can be excluded if governments put in place fiscal or other measures that will cut their emissions by an equivalent amount and in the aviation sector, until 31 December 2023 the EU ETS will apply only to flights between airports located in the European Economic Area (EEA).

Nowadays, the EU ETS is in its third phase. The main contributions of this new phase are: 1) A single, EU-wide cap on emissions in place of the previous system of national caps; 2) Auctioning is the default method for allocating allowances (instead of free allocation), and harmonized allocation rules apply to the allowances still given away for free.

The European Commission is working on a fourth phase for the period 2021-2030 to enable EU member states to achieve the EU's 2030 emission reduction targets in line with the 2030 climate and energy policy framework and as part of the EU's contribution to the 2015 Paris Agreement.

2.3.2 Energy-Switch and Renewable Energy production

Together with the Emissions Trade Scheme, renewable energy production is among the strategic options chosen by the EU in order to achieve emissions abatement.

EU has shown high interest in energy switch and, since the Directive 2009/28/EC, it sets a binding target of 20% final energy consumption from renewable sources (RES) by 2020.

The Directive obligates each EU Member State to submit a National Renewable Energy Action Plan (NREAP) showing what actions they intend to take to meet their renewable targets.

In a Global perspective, the EU is one of the best player in terms of renewable energy production. In 2016, the EU ranked second after China as regards total installed and grid-connected domestic renewable electricity capacity.

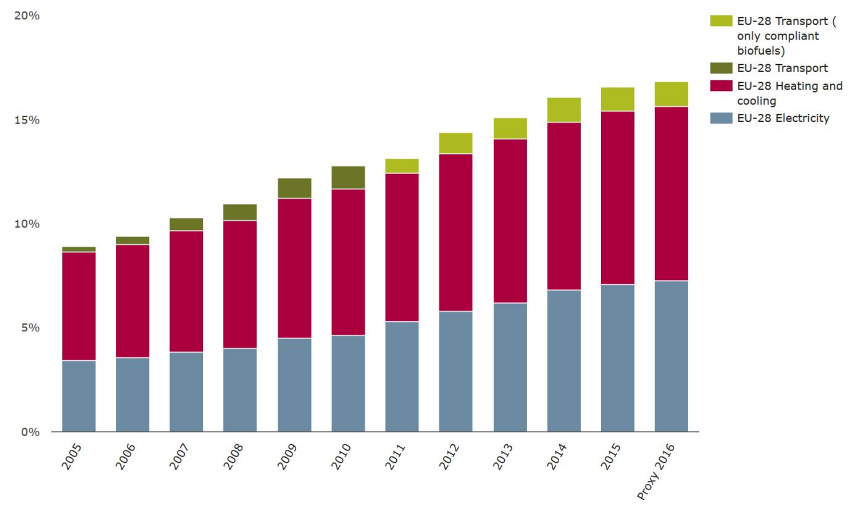
At a global scale, the highest share of investment in RES mainly focus on solar and wind energy for electricity generation. According to the Frankfurt School-UNEP, 2017, these technologies together, account for over 90% of total global RES investments.

In the "Renewable Energy Prospect for the EU" by IRENA, it is possible to notice that the EU is the clear leader in renewable electricity capacity *per capita* and per GDP units and performed well over the period 2005-2016, ahead of the USA, Brazil and China.

However, China has quadrupled its installed capacity since 2005 and is poised to overtake the EU as world leader.

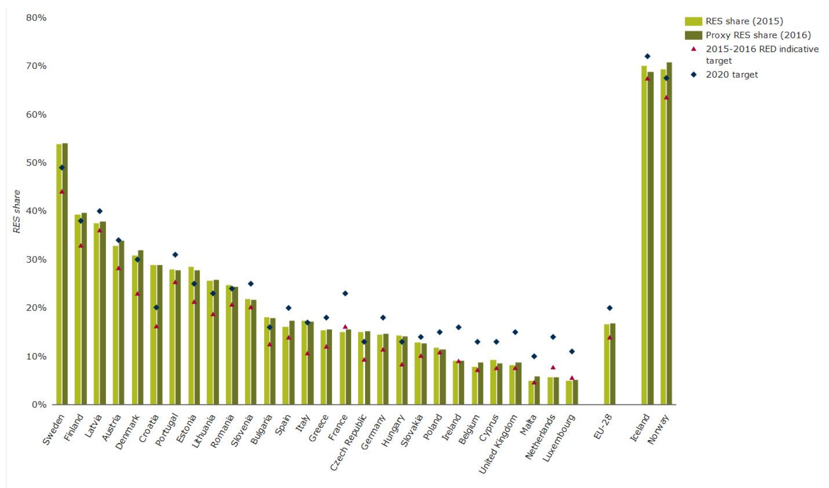
At a more local scale, in 2017, most climate mitigation policies and measures reported by the Member States under EU reporting requirements (the Monitoring Mechanism Regulation -MMR) were aimed at the energy consumption, transport and energy supply sectors. The objective of such policies and measures was often to increase the RES share.

FIGURE 2.10: Share of RES in final energy consumption



Source: European Environmental Agency -EEA, EUROSTAT.

FIGURE 2.11: RES share by country



Source: European Environmental Agency -EEA, EUROSTAT.

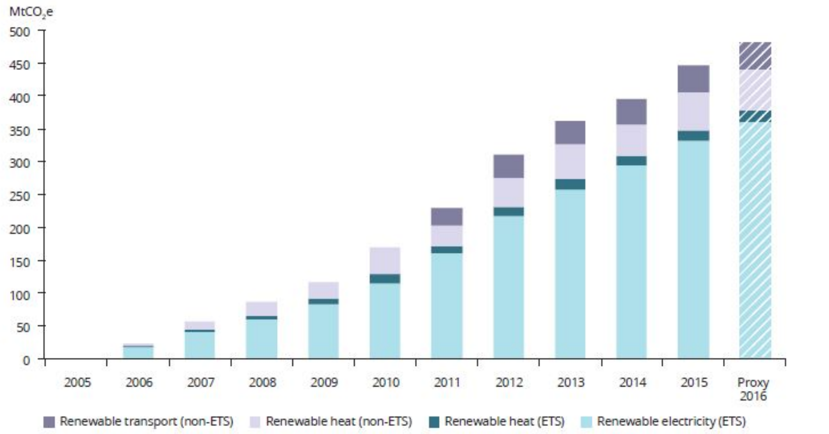
In absolute terms, renewable heating and cooling remains the dominant RES market sector in EU. In the EU transport sector, renewable energy made up around 7% of all energy use[7]. More specifically, the RES use in transport sector comes from biofuels which registered the fastest growth in the last ten years (with a annual growth rate of 16% on average).

Today, RES are a major contributor to the energy transition in Europe. The speed at which renewables have grown since 2005 has determined some economic distortions, too, especially in terms of market prices.

According to Edenhofer *et al.* (2013), from an economic point of view, the RES deployment should be assessed not only in terms of climate change mitigation but also in terms of other public policy objectives. More precisely, the authors suggests other five relevant public objectives:

[7]Estimates by EEA.

FIGURE 2.12: Estimated Gross Reduction in GHG emissions in EU-28, by energy market sectors



Notes: This figure shows the estimated gross reduction in GHG emissions due to the increase in renewable energy consumption since 2005.
Source: EEA.

1. *Energy Security*. Arvizu *et al.* (2011) define "energy security" as the robustness against sudden disruptions of energy supply. The aim should be to reduce global energy interdependence through the increasing in diversity and resilience of the energy supply[8]. For many developed countries, among which the EU members, "the key energy security challenge is the dependence on imported fossil fuels, particularly oil"[9]. Indeed, in case of oil prices shocks, importer countries will be highly affected. RES production could be a valid solution but, where there are large domestic resources, such as in the US, the energy substitution by RES has little impact on energy security. Therefore, policy makers should be aware of the cost-benefits outcome of this type of policies[10].

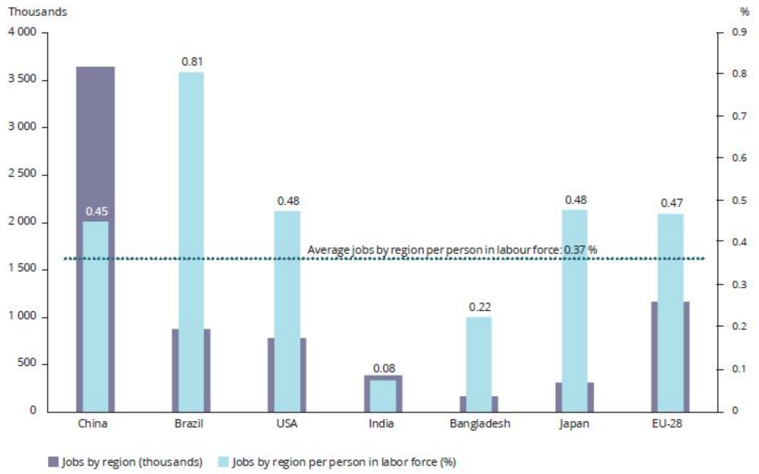
2. *Green jobs*:Borenstein (2012) argues that subsidizing RE deployment could stimulate job creation in RES-related sectors. Anyway, job creation can be achieved by several policy options and these short-term comparison of different policy instruments have not been deeply analyzed in the literature. According to Edenhofer *et al.* (2013), RE should be subsidized only if their social returns on investment are higher than their private returns on investment and lower than investments in other technologies. Moreover, as mentioned in subsection 2.2.2, a branch of literature refers to income inequality deriving from the development of new environmental technologies. Moreove, it has been demonstrated that investing in green technologies generates a gap between "green jobs" and "non-green jobs" in terms of skills and human capital, with severe labor and education policy implications.

   Nevertheless, in terms of employment in renewable energy sector, EU is still a key player even if it is below Brazil, Japan and USA, in terms of the share RES-related jobs *per capita* in the labour force.

   Within the EU, Germany is the greatest employer of RES-related jobs. Figure 2.13 gives an overlook of this item.

[8]GEA, 2012.
[9] Edenhofer *et al.* (2013).
[10]Borenstein (2012).

FIGURE 2.13: Share of RES-related Jobs



Notes: The primary y-axis displays absolute numbers (thousands of jobs) in 2016. The secondary y-axis relates the absolute number of jobs to the total labour force of each region, thus displaying jobs per person in the labour force. The jobs displayed include both direct and indirect jobs along the value chain. All EU data are from 2015, as the 2016 data were not yet available.

Sources: Absolute jobs (IRENA, 2017c); jobs per person in the labour force (World Bank, 2017a).

3. *Green Growth*: Many scholars claim that RE deployment is a driving force behind long-term GDP growth and decreasing emissions. Economic growth is related to other relevant public objectives such as job creation, welfare and tax revenues. It is considered a win-win strategy [11]. Anyway, this strategy could be risky if it is seen as an alternative to carbon pricing (such as ETS) due to political feasibility constraints. Several studies [12] have estimated the costs of RES technology policy as an alternative to carbon pricing. They all agree that the best way to reach not only emission abatement but also green growth, the two policies must be implemented together.

4. *Reducing local environmental damages* from fossil fuel extraction. Extensive mining and fossil extraction have caused several environmental damages in many countries in the world. Increasing the production of RES could help reducing this damage and, given the consequently air pollution abatement, there are other important cobenefits related to public health.

5. *Poverty reduction and other sustainability concerns*: Subsidizing RES could contribute to facilitate access to energy to remote and poor rural areas. This makes them well-suited for remote regions not serviced by large infrastructure.

Edenhofer *et al.* (2013), stress the point that the presence of cobenefits related to RES can only occur in the case of second-best setting. More precisely, they argue that the potential positive spillovers of RES could apply only if local externalities have not been addressed by appropriate policy instruments.

Contrary to the above statement, McCollum *et al.* (2011, 2013), estimate that "the policy objectives listed above result in substantial synergies that lead to proportionally lower policy costs if all policy objectives are tackled holistically" [13].

As a result, a proper policy design and a good assessment of the welfare effects of RE deployment should be done necessarily under a multi-objective framework.

[11] UNEP report, 2011.
[12] Among all, Fischer and Newell, 2008; Palmer and Burtraw, 2005.
[13] Edenhofer *et al.* (2013).

2.4 Conclusions

Climate Change is characterized by a broad multi-dimensionality in terms both of effects and of agents involved. This implies that Climate Change Policies should reflect this multi-dimensionality in order to be effective. This paper analyzes different levels of Climate Change Policy, starting from the more general (Global Climate Policy) to the more local (EU Environmental Policy).

In section 2.2, I discuss the two major economic issues concerning International Environmental Agreements: self-enforcement and equity.

In particular, since Climate Action has public good characteristics (non-excludability and non-rivality), Game Theory has been widely used in the economic literature in order to explore the economics of IEAs. More precisely, most of the literature focuses on two major problem arising from IEAs: free-riding and the problem of self-enforceability.

It is possible to identify two branches of the literature, *i*) Non-cooperative based models, whose pioneer is Barret (1994) and *ii*) Cooperative-based models, born from the contributions by the recent Nobel Prize Nordhaus.

To summarize, non-cooperative models are very pessimistic on the outcome of IEAs and show that they can do very little or none improvement in emissions reduction. On the contrary, cooperative models suggest that big coalition can enforce stability of IEA, especially if transfer mechanisms have been taken into account.

Anyway, a big limitation of this literature is that the payoff matrices are often based only on cost-effectiveness and do not account for equity and justice considerations.

Indeed, given that GHGs have a very long persistence time in the atmosphere, recognition of responsibility and even allocation of mitigation efforts are very difficult to compute and rise to inter- and intra-generational equity issues.

Kverndokk and Rose (2008) identify four levels in which equity issues take place in Environmental Policy: national, regional, intersectorial and interpersonal.

The main result of this analysis is that climate policy has several spillover effects, in some cases are positive (economic growth, energy security, public health), in some other they create economic distortions (distorted energy prices, regressive outcome and possible job losses).

For that reason, economic literature and policy makers should refer to General Equilibrium models in order to account for all the possible effects of climate policy on the economy.

For what concerns the assessment of IEA through econometric models, as discussed in subsection 2.2.3, Ringquist *et al.*(2005) identify three problems that arise when assessing IEAs:

- scarcity of good time series data on environmental quality (especially for former agreements);
- a complex mix of non-policy factors that affect environmental quality;
- participation in IEAs is voluntary and this lead to self-selection sample.

Moreover, IEAs can be assessed either on their cooperative nature or on their effective impact.

For what concerns the former level of assessment, a milestone paper by Murdoch and Sandler (1997) try to assess the cooperative nature of the Montreal Protocol. They find that the Protocol was compatible with a model of voluntary provision of a pure public good, therefore, the Montreal Protocol did not lead countries to engage in emissions reduction policies stronger than their business-as-usual scenario.

Some other quantitative studies related to different IEAs lead to the same results and they give force to the branch of economic literature that supports the non-cooperative nature of IEAs.

Nevertheless, some studies on Kyoto Protocol, the first IEA with binding abatement commitments, evidence was in favour for Cooperation outcome. Anyway, a recent study by Almer and Winkler (2017) apply to the Kyoto Protocol a synthetic control method in other to face the difficulties identified by Ringquist *et al.*(2005). Their results confirm that the participation to the Protocol did not lead Annex B countries to adopt mitigation measures significantly different from their counterfactuals.

In the second step of the analysis, I explore two successful EU environmental policies: the Emissions Trading Scheme (EU ETS) and the Renewable Energy Sources Policy (RES policy).

After a brief discussion on their main features and their implementation, I focus on the point, arised by Edenhofer *et al.* (2013), that from an economic point of view, local environmental policies should be assessed not only in terms of climate change mitigation but also in terms of other public policy objectives. More precisely, the authors suggests five relevant public objectives: energy security, green jobs, green growth, reduction of local environmental damages and poverty reduction and other sustainability concerns.

All these public objectives, together with equity and justice concerns, should be addressed both in the design and in the assessment of Climate Change Policy at all dimensions.

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Chapter 3

Cheating on Paris Agreement: an Empirical Approach

3.1 Introduction

The history of International Environmental Agreements has been pretty controversial in last decades. Even though Climate Change is widely considered as a sensitive topic by the international community, cooperation among countries is still politically and economically fragile. From a game-theoretic perspective, if cooperation fails there is room for free riders and some countries could cheat on the commitments submitted under the Agreement.

In the context of the Kyoto Protocol, many countries have shown non-cooperative behaviours. For example, the United States of America (one of the world biggest polluter) did not ratify, even though it actively participated in the negotiation processes and left Canada as the only nation in the Americas with a binding emissions-reduction obligation. Canada, indeed, ratified the Kyoto Protocol but withdrew in 2011.

At that time, many countries for which the emissions were not covered by the Kyoto Protocol (the US and China, for example) were responsible for 41% of total world emissions. China's emissions increased by over 200% from 1990 to 2009. [1] For what concern the Paris Agreement, it results to be the largest coalition in the history of Environmental Governance and with the greatest number of countries with binding emission-reduction commitments.

Anyway, some issues put criticism on the effective cooperative nature of the agreement. First, the emission-reduction obligations are freely determined by each state; second, in 2017 the US President Donald Trump has announced the withdrawal of his country from the Agreement. Since there is no international jurisdiction that can enforce the agreement among states, it is crucial to economically assess the cooperative nature of the Agreement and the socio-economic drivers that lead a country to either withdraw or miss the target committed.

The aim of this paper is therefore twofold: from one hand, I exploit the game-theoretic nature of the Paris Agreement, from the other hand, I investigate the socio-economic determinants of potential cheaters to the Agreement.

I proceed with a two-steps analysis. First, I assess the cooperative nature of the Paris Agreement by applying the methodology suggested by Murdoch and Sandler (1997) to the Nationally Determined Contributions (NDCs). In the second step, I give a definition of cheating for what concern the Paris Agreement and I run a Probit model on the variable in order to identify the socio-economic drivers of cheating.

[1] IPCC report for Policy makers-2011

In section 3.2, I describe the model of Voluntary provision of a pure public good by Bergstrom et al (1864) and the empirical evaluation methodology proposed by Murdoch and Sandler(1997). In section 3.3, I present and discuss the results referred to the NDCs; in section 3.4 I derive the empirical methodology for the identification of the potential cheaters in the Paris Agreement. Finally, in section 3.5 I discuss the conclusions.

3.2 The Voluntary Provision of GHG abatement

3.2.1 The Model

The empirical methodology developed by Murdoch and Sandler (1997) is based on the model of voluntary provision of a pure public good, as analyzed by Bergstrom (1986), Andreoni *et.al.* (1988), and Cornes and Sandler (1996) who used a subscription model of public good contributions to identify contributors. According to this model, Country i's preferences for a global public good, G, is expressed by a quasi-concave, strictly increasing utility function

$$U_i = U_i(y_i, G) \tag{3.1}$$

, where y_i and $G = \Sigma_j g_j$ denotes consumption of a private and a pure public good (Emission reduction),respectively. The country i's linear income constraint can be written as:

$$w_i = y_i + pg_i \tag{3.2}$$

where w_i denotes income and p is the relative price of a marginal unit of a public good in terms of private consumption. State i's demand for the total amount of the public good derives from the utility maximization subject to the budget constraint and spillovers from other countries' abatement:

$$max_{y_i,G}\{U(y_i, G; \Theta)|w_i + pG_{-i} = y_i + pG; G \geq G_{-i}\} \tag{3.3}$$

Θ is a parameter vector or index measuring country-specific tastes and the inequality constraint indicates that the i-th country is a contributor when $G > G_{-i}$, so that $g_i > 0$. Non-contributors choose $G = G_{-i}$ and contribute nothing. Murdoch and Sandler(1997) show that country i's level of emission reduction in a non-cooperative Nash equilibrium is given by:

$$g_i^* = \begin{cases} w_i/p - w^*(p,\Theta)/p & \text{if } w_i > w^*(p,\Theta) \\ 0 & \text{if } w_i \leq w^*(p,\Theta) \end{cases} \tag{3.4}$$

A Nash equilibrium results when we have a vector of individual contributions, g_i, that maximize utility (3.1) subject to (3.2) and to the best-response level of spillovers G^*_{-i}.

According to Murdoch and Sandler (1997), equation (3.4) indicates that pollution cutbacks are a linear function of income with slope of $1/p$.

All contributors within the same taste category Θ, consume the same amount of the private good, which equals $w^*(p,\Theta)/p$, and allocate their remaining income to the public good.[2]

[2] Murdoch and Sandler(1997)

TABLE 3.1: MS(1997) Variable description

Variable	Description
GNP85	Gross National Product in 1985, expressed in hundred billions of dollars.
DEMIT	1989-1986 Differential in CFC emissions, expressed in thousand metric tons.
POP85	Population in 1985, expressed in milions
GASTIL	The sum of the Gastil's indices of civil liberties and political freedom.
FREE	A Dummy variable equal to 1 for $GASTIL \leq 4$, and 0 otherwise
PFREE	A Dummy variable equal to 1 for $4 < GASTIL \leq 9$, and 0 otherwise
NFREE	A Dummy variable equal to 1 for $GASTIL \geq 10$.
L1	A Dummy variable equal to 1 if a country is located above the Tropic of Cancer, and 0 otherwise.
L2	A Dummy variable equal to 1 if a country is located between the Tropics of Cancer and Capricorn, and 0 otherwise.
L3	A Dummy variable equal to 1 if a country is located below the Tropic of Capricorn, and 0 otherwise.

In subsection 3.2.2, first, I will discuss the empirical methodology, the data issues and results of Murdoch and Sandler (1997), second, I will describe the empirical model and the data referred to the Paris Agreement.

3.2.2 Empirical Model by Murdoch and Sandler (1997)

Based on the assumptions shown in subsection 3.2.1, Murdoch and Sandler (MS) estimate the following equation:

$$g_i = \beta_0 + \beta_1 w_i + \Theta' \gamma + \epsilon \tag{3.5}$$

with a simple OLS estimation. They use as the dependent variable ($DEMIT$) the absolute reductions of CFC emissions between 1986 and 1989. They refer to a sample of only 61 countries, dropping all countries who expanded the consumption of CFCs during that time ($g_i > 0$). Murdoch and Sandler suggest that the Θ parameter could relate to geographical position, population size and level of democracy, as suggested by Congleton (1992), too. OLS estimations for the Montreal Protocol can be found in 3.2.

TABLE 3.2: OLS results from Murdoch and Sandler 1997

	Dependent variable:						
	DEMIT						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GNP85	1.649**	1.643**	1.633**	1.612**	1.609**	1.611**	1.608**
	(0.052)	(0.051)	(0.051)	(0.050)	(0.051)	(0.053)	(0.054)
GASTIL		−0.152*		−0.136		−0.138	
		(0.073)		(0.071)		(0.075)	
Free			1.296		1.170		1.179
			(0.674)		(0.677)		(0.708)
PFree			−0.422		−0.080		−0.076
			(0.848)		(0.856)		(0.868)
L2				−1.568*	−1.312	−1.560*	−1.308
				(0.634)	(0.693)	(0.645)	(0.706)
L3				−1.680*	−1.744	−1.675	−1.742
				(1.083)	(1.096)	(1.094)	(1.107)
POP85						0.0002	0.0001
						(0.0023)	(0.0023)
Constant	1.061**	2.050**	0.559	2.712**	1.213*	2.713**	1.203
	(0.323)	(0.568)	(0.526)	(0.602)	(0.598)	(0.608)	(0.642)
Observations	61	61	61	61	61	61	61
R^2	0.94	0.95	0.95	0.95	0.95	0.95	0.95
White	0.000	0.012	0.019	0.142	0.0.182	0.001	0.000

Note: *p<0.1; **p<0.05; ***p<0.01

Based on the results shown above, 1985-level of GNP is positive and explains 94% of the total variation in emission cutbacks $DEMIT$.

Moreover, MS estimate a particular Box-Cox transformation as described in (3.6):

$$g_i = \beta_0 + \beta_1[(w_i^\lambda - 1)/\lambda] + \Theta_i'\gamma + \epsilon_i \tag{3.6}$$

in order to test the linear relationship between $GNP85$ and $DEMIT$ as theoretically predicted in (3.4). In order to do so, MS test for the parameter λ and reject linearity if the estimate of λ is significantly different from 1.

For a sample size of 61 Countries, linearity is rejected. Anyway, MS find that by dropping 3 big outliers (China, USSR and USA) the 95% confident interval for the estimation of λ contains the value $\lambda = 1$.

The authors therefore interpret their findings -positive and nearly linear relationship between emission reduction and GNP- as being more consistent with a non-cooperative model, *i.e.* a Nash equilibrium, than a cooperative model of public good provision.

3.2.3 Data issues

This methodology has been highly criticized by Wagner (2009). The crucial concern that Wagner arises is related to the quality of emission data used in MS 1997. He argues that the positive and strongly linear correlation between GNP and emissions found by MS is spurious and it is due to the imputation procedure used by WRI in building its dataset.

More precisely, for almost 75% of the observations of the MS sample, emissions levels were imputed and based on actual values in "similar countries".

Following this critique, Wagner re-run the analysis by using emission data from the United Nations Environmental Programme (UNEP, 2006), considered by the author appropriate for the voluntary provision model "bacause it adds up emissions of all five CFCs that were regulated under the Montreal Protocol and weights them by the relative ozone-depleting potential (ODP)[3][4].

Since the comparison of descriptive statistics of row data, many huge differences in the two dataset arise. The results obtained by Wagner lead to a completely different interpretation with respect to MS 1997.

In particular, when the dependent variable is based on the new data, the coefficient fall to -0.2 and it is significant at the 5% or even better if more covariates are taken into account. Furthermore, Wagner finds a negative and significant coefficient for population. By running the analysis not only on positive contributors ($g_i > 0$) but on the full sample, the same results are confirmed.

Moreover, the Cox-Box estimation of the parameter λ is 0.3 and it is statistically significant at the 5% level. The coefficient is slightly positively affected when more covariates are added to the model but it always remains below 1.

To further support this interpretation, the likelyhood ratio test rejects the hypothesis of linearity ($\lambda = 1$) for all specifications at the 1% significance level.

To sum up, the replication of the analysis run by Wagner do not provide evidence for the voluntary provision of a pure public good. He finds negative or statistically insignificant in most of the specifications provided and the hypothesis of linear relationship between abatement and GDP is rejected in all specifications at the 1% significance level.

[3] The weights for each of the CFCs are listed in Annex A of the 1987 Treaty and range from 0.6 to 1.0
[4] Wagner(2009)

TABLE 3.3: List of Variables

Variable	Description	Source
DEMIT	Difference in consumption of CO2 in 2016 and in 2030-NDCs proj.	UNFCC, IPCC and World Bank.
GDP	billion USD in 2016(base=2005)	World Bank.
POP	Population in 2016	World Bank and CIA World Factbook.
FREE	Dummy for Free Countries	Freedom House.
PFREE	Dummy for Partly Free Countries	Freedom House.
NFREE	Dummy for Non Free Countries	Freedom House.
*L*1	Northern Hemisphere	World Bank.
*L*2	Tropics	World Bank
*L*3	Southern Hemisphere	World Bank

Nevertheless, Murdoch and Sandler reply[5] to the critique raised by Wagner. They claim that the WRI dataset is appropriate for the game-theoretic-based analysis because it reflects the information set available for the policy makers at that time.

The Reaction functions derived by the model presuppose that each player reacts to the belief on the other players' behavior, given the contemporary information on CFC. Given that the policy makers back then did not have the UNEP data, they could not have based their beliefs on this new data. Therefore, since the final goal of the paper was to test a behavioral model, it makes sense to based the analysis on WRI reports.

3.3 Does the Paris Agreement have a Potential Cooperative Outcome?

The Paris Agreement, with respect to the Montreal Protocol, is characterized by the presence of national commitments on emission abatement (NDCs), that represent common and contemporary knowledge to all the members of the treaty.

Therefore, based on the considerations expressed in subsection 3.2.3, it is possible to test the behavioral model of voluntary contributions by using NDCs as declared strategic actions.

So, even though I am aware that the Wagner's critique could apply to this case, given that available info are based on commitments and projections rather than realized data, I refer to the argument by MS 2009 and I replicate the exercise for the Paris Agreement.

Table 3.3 reports the list of variables and their sources. Most of the covariates have been chosen accordingly to the original analysis by Murdoch and Sandler 1997.

The variable *DEMIT* (the name is intentionally left the same of the original paper, in order to facilitate the comparison) is given by the difference between absolute CO2 consumption in 2016 and CO2 consumption estimated in 2030 (Paris Agreement target year) based on NDCs[6].

I consider a sample of 240 countries but I start the analysis by subsetting for the positive contributors ($g_i > 0$), ending up to 138 countries.

This sample is much greater than both MS's and Wagner's, and I expect some results to differ. Moreover, differently from the original analysis, I run an OLS with robust standard errors, in order to account for heteroskedasticity in the error term.[7]

[5]Murdoch and Sandler (2009)

[6]These data are public and freely provided by the UNFCC

[7]In Appendix A the reader can find the exact replication of Murdoch and Sandler's OLS estimations.

The results in Table 3.4 show that GDP is positive and significant in all specifications but it drops from 1.645 in MS to 0.000176 in our analysis. Moreover, GDP explains only 23% of the total variation in $DEMIT$, rather than the 94% in Murdoch and Sandler.

TABLE 3.4: OLS estimation for Paris Agreement, $g_i > 0$

	Dependent variable:			
	$DEMIT$			
	(1)	(2)	(3)	(4)
GDP	0.000176*	0.000166*	0.000170*	0.000162*
	(0.000104)	(0.00004)	(0.000043)	(0.000039)
Population		0.00229*	0.00226*	0.00229*
		(0.00125)	(0.00124)	(0.00121)
Partly Free			−90.78*	−103.720*
			(55.79)	(62.41)
Free			103	148.3
			(90.19)	(114.9)
Tropics				−122.5**
				(76.81)
Southern Hemisphere				−30.03
				(29.80)
Constant	31.06*	−33.13	43.91	131.9
	(18.03)	(25.11)	(60.05)	(106.7)
Observations	138	138	138	138
R^2	0.236	0.260	0.275	0.276

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Surprisingly, Population is positive and significant at the 1% level. One possible explanation could relate to the fact that highly populated countries are more damaged from air pollution and could benefit more from emission reduction.[8]

The positive sign on $FREE$ indicates that the conditional expected value of $DEMIT_i$ is higher relative to Non-Free countries, while the conditional expected value of $DEMIT_i$ is not statistically different for Partly Free and Non-Free nations.

The negative sign of the geographical position dummies means that the expected value of $DEMIT_i$, conditional on income, population and freedom, is less for countries situated in the tropics and in the southern hemisphere when compared to the northern latitude group.

In order to test the linearity relationship between GDP and the dependent variable, I proceed with the same Box-Cox transformation elaborated by Murdoch and Sandler.

The maximum likelihood estimation for λ is 0.95 and the 95% confidence interval includes the value $\lambda = 1$. Moreover, the LR test for $\lambda = 1$ cannot be rejected at a significance level of 1%.

So far, the evidence coming from the mere replication of the analysis for the Paris Agreement lead to the rejection of the hypothesis that the NDCs are cooperative strategies.

[8]Nevertheless, this result could be bias due to the presence of multicollinearity between GDP and Population (high positive correlation). In order to control for this issue, I run the analysis re-scaling $DEMIT$ and GDP by population. Results are shown later on in this paragraph.

TABLE 3.5: Box-Cox Transformation: Estimation Results

	Dependent variable:
	DEMIT
GDP_{transf}	0.000127***
Population	0.000022***
Partly Free	-103.9*
Free	152.7*
Tropics	-124.1**
Southern Hemisphere	-28.98
Constant	131.972
λ	0.953***
$CI^{\lambda}_{0.95}$	[0.466; 1.441]
Observations	138

*** p<0.01, ** p<0.05, * p<0.1

This implies that the NDCs are compatible with the model of voluntary provision of a poor public good, therefore, they are just the reflections of the Business-as-Usual emission strategies that each country should have done even without the Paris Agreement.

Accordingly to the procedure followed by MS, I drop 3 outliers (China, Russian Federation and USA) and table 3.6 reports the estimation results

TABLE 3.6: OLS results without outliers

	Dependent variable:			
	DEMIT			
	(1)	(2)	(3)	(4)
GDP	0.0000915 * **	0.0000756 * **	0.0000752 * **	0.0000756 * **
	(0.000514)	(0.000444)	(0.000484)	(0.000449)
Population		0.00567***	0.00567***	0.00568***
		(0.00526)	(0.00528)	(0.00538)
Partly Free			−9.882	−11.476
			(15.980)	(16.163)
Free			0.979	2.625
			(14.915)	(15.911)
Tropics				1.547
				(13.697)
Southern Hemisphere				18.725
				(17.355)
Constant	24.038***	9.112	12.726	10.268
	(7.900)	(5.963)	(12.364)	(16.111)
Observations	135	135	135	135
R^2	0.649	0.812	0.813	0.815
Adjusted R^2	0.646	0.809	0.807	0.806
Note:				*p<0.1; **p<0.05; ***p<0.01

Robust Standard Errors in Parenthesis

By dropping the 3 outliers, most of the results are confirmed. The only improvement is that now GDP alone explains almost 65% of the total variation in $DEMIT_i$. Nevertheless, the Box-Cox transformation parameter λ drops to 0.835 and it is not statistically different from $\lambda = 1$ at the 10% significance level.

So, removing the 3 outliers from the analysis does not lead to any conclusive remarks. The linear relationship between emission abatement and income is still confirmed even though with a loss of power.

Anyway, it is relevant to remark that estimation results proposed so far could be affected by collinearity between GDP and $Population$. The two variable have, indeed, a high and positive correlation ($corr = 0.75$).

In the previous exercises, this issue was neglected in order to present results as much comparable as possible to the work by Murdoch and Sandler. Anyway, I cannot ignore this important element and I now show the results after re-scaling GDP and $DEMIT$ by population size.

TABLE 3.7: OLS estimation for Paris Agreement, $g_i > 0$. Re-scaling for population

	Dependent variable:		
	$DEMIT_{pc}$		
	(1)	(2)	(3)
GDP_pc	0.0123***	0.00878***	0.00713***
	(0.00205)	(0.00192)	(0.00235)
Partly Free		−0.000191	−0.000213
		(0.000169)	(0.000164)
FREE		0.000326**	0.000370**
		(0.000157)	(0.000161)
Tropics			−0.0002.86
			(0.000101)
Southern Hemisphere			−0.000257*
			(0.000146)
Constant	0.000560***	0.000735***	0.000692***
	(0.000624)	(0.000149)	(0.000146)
Observations	138	138	138
R^2	0.120	0.163	0.170

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

After weighting for population size, the positive linear correlation between *per capita* GDP and emission reduction is confirmed. Moreover, the sign and the significance of the other variables are robust to the new specification. In particular, countries ranked as "Free" affect positively emission reduction *per capita* with respect to "non-free" countries and countries located in the Southern Hemisphere contribute less with respect to Northern Hemisphere countries.

Anyway, once controlling for a possible size effect, the Box-Cox transformation is robust to the new model specification but it suffers from an overall loss of power, as it is shown in Table 3.8.

More importantly, linearity between GDP_{pc} and $DEMIT_{pc}$ is no longer confirmed. The Maximum Likelihood estimation of λ drops to 0.35, the value $\lambda = 1$ is no longer included in the 95% Confidence Interval and the LR Test for the value $\lambda = 1$ is rejected at the 5% significance level.

To sum up, the *ex-ante* assessment of the Paris Agreement based on the game-theoretic methodology proposed by Mardoch and Sandler leads to very interesting results:

- The empirical strategy proposed by Murdoch and Sandler has been updated in order to account for possible heteroskedasticity in the error terms and for collinearity between GDP and Population.

TABLE 3.8: Box-Cox Transformation: Estimation Results

	Dependent variable:
	$DEMIT_{pc}$
GDP_{pc}^{transf}	0.0001565*
Partly Free	-0.0002336**
Free	0.0002891*
Tropics	-0.0000737
Southern Hemisphere	0.0001909
Constant	-0.0001465
λ	0.35***
$CI_{0.95}^{\lambda}$	$[-0.42; 0.47]$
Observations	138

*** p<0.01, ** p<0.05, * p<0.1

- Results show that when Murdoch and Sandler's strategy is followed, NDCs show strong and persistent linear relationship with GDP. It leads to conclude that the Paris Agreement's NDCs are just a reflection of a Business as Usual emission strategy that all country would have done even without the Agreement. They thus lead to a Nash equilibrium rather than a coalition outcome.

- Anyway, when controlling for population size, this linear relationship is no longer observed. It means that with a more accurate empirical strategy the model of voluntary contribution to a pure public good is no longer confirmed.

The main conclusion is that the NDCs are not fully compatible with the model proposed by Bergstrom (1986) but it is not enough to conclude that they reflect an extra-effort afforded by countries due to the participation to the agreement. It does not automatically lead to a confirmation of the cooperative model.

Moreover, the analysis is based only on the commitments that countries submitted in 2016 for the target year 2030. It means that at least in the early stage of the Agreement, the strategic behaviors of the coalition members seems to be based on cooperative intentions.

Anyway, every 5 years countries should revise their strategies and they are obliged to communicate the new target to the UNFCCC.

Furthermore, in the past some countries deviated from the original commitment at the beginning of the coalition, either by withdrawing from the agreement or by deviating from the target and the absence of an international authority who can enforce the obligations arisen from the agreement, could determine room for free-riding.

Many game-theoretic models applied to International Environmental Agreements refer to past experience as part of the set of information available for the players in order to define their strategy.

Therefore, it could be possible to enlarge the information set by identifying the socio-economic drivers the lead a country to potentially deviate from its commitment and to estimate the probability of being a potential cheaters. I will discuss this issues in the next section.

3.4 Potential Cheaters in Paris Agreement

As mentioned in section 3.3, even though I cannot conclude that the NDCs are compatible with a voluntary contributions model, it makes sense to further analyze the possibility that a country could deviate from its commitment.

My goal is to provide an empirically-based approach in order to estimate the probability that a country could cheat from the Paris Agreement and to identify the socio-economic variables that can affect this probability. In order to do so, I proceed with a theoretically agnostic approach: no game-theoretic assumptions will be made for the following steps.

In general, a country can "cheat"[9] to the Paris Agreement either by missing the target expressed in its NDC or by withdrawing from the Agreement.

Since Article 28 of the Paris Agreement states that the earliest possible effective withdrawal date cannot be before November the 4^{th}, 2020, I will take into consideration only the first case. To go further in the analysis I need to add two more variables:

$$EAI_i = \frac{\Sigma_j t_{i,j}}{N_j} \tag{3.7}$$

The index expressed in (3.7) measures the so-called Environmental Activism of country i, and represents the sum of the treaties(j) ratified by country i over the total number of International Environmental Agreements established from 1986 to present.

I will use this index as a proxy of the political involvement of a country in environmental coalitions and it can be interpreted as a participation rate to the International Environmental Governance.

Equation 3.8 measures the Relative Target Deviation, that is the relative difference between country i total emissions projections[10] for the year 2030 based on the NDCs (g_i^{NDC}) and the total emissions[11] estimated for country i by the EDGAR project of UNFCC in the Business as Usual scenario (g_i^*).

$$RETD_i = \frac{g_i^{NDC} - g_i^*}{g_i*} \tag{3.8}$$

According to the definition of "cheating" given above, the higher is the relative deviation from the target committed, the more country i is a *potential cheater*.

Anyway, the time horizon set in the Paris Agreement is pretty long, and it makes sense that small deviation from the target could be due not only by a bad behavior but it could be just a random error.

In order to clearly identify bad behavior from a random error, I will define country i as a *potential cheater* if $RTD_i \geq \tau$, where τ refers to a generic threshold.

Since I want to keep the procedure theoretically agnostic, I explore different values of τ. This choice is based on descriptive statistics referring to the distribution of the variable RTD_i. In particular, I explore threshold values close to the Mode ($RTD_i = 0.29$), the Mean ($RTD_i = 0.445$) and the Median ($RTD_i = 0.35$).

[9]In this definition, a "cheater" is a player who either has a behavior contrary to the final scope of the coalition, or who affects the final result of the coalition with its actions.

[10]Expressed in Mt CO2 equivalent.

[11]Expressed in Mt CO2 equivalent.

TABLE 3.9: List of Variables-Probit Model

Variable	Description	Source
EA_{index}	Environmental Activism Index	Elaboration of the author from InforMEA
GDP_{pc}	GDP per capita (billion USD) in 2016(base=2005)	World Bank
AID	Climate Change adaptation AID (billion USD, base=2005)	GEF
$FREE$	Dummy for Free Countries	Freedom House
PF	Dummy for Partly Free Countries	Freedom House
$Damage$	Total cost of damage from natural disasters (1986 to present)	EM-DAT

Then, I build an ordered categorical variable called $Cheat_i$ that takes the following form:

$$Cheat_i = \begin{cases} Low(1) & \text{if } RTD_i \leq 0.3 \\ Medium(2) & \text{if } 0.3 < RTD_i \leq 0.5 \\ High(3) & \text{if } RTD_i > 0.5 \end{cases} \tag{3.9}$$

and I estimate the probability of being a *potential cheater* by running an ordered probit model. [12]

Just like the binary choice models, the central idea behind the ordinal outcomes is that there is a latent continuous metric (defined as y^*) underlying the observed responses by the analyst.

Let y^* is an unobserved variable, we only know the realization value of y^* when it crosses the thresholds. For instance, if we are modeling the predictors of a school-test score: once y^* crosses a certain value we report "poor", then "good", then "very good", then "excellent".

Now consider a latent variable model given as:

$$y_i^* = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \ldots + \alpha_k x_k + e \tag{3.10}$$

$$y^* = x_i' \alpha + e \tag{3.11}$$

Where $y_i = j$ if $\delta_1 < y^* \leq \delta_2$ and where $i = 1, \ldots N$.

The probability that observation i will select alternative j is:

$$p_{ij} = p(y_i = j) = p(\delta_1 < y_i^* \leq \delta_2) \tag{3.12}$$

$$= F(\delta_2 - x_i'\alpha) - F(\delta_1 - x_i'\alpha) \tag{3.13}$$

For the Ordered Probit, F is the standard Normal CdF. In Appendix A I provide results for the Ordered Logit, where F is the logistic CdF:

$$F(z) = \frac{e^z}{1 + e^z}$$

The list of variables used for the estimation is described in table 3.9.

[12] In Appendix A the reader can find estimations for robustness check. In particular, estimations for ordered logit, multinomial probit and multinomial logit, and two single probits on the values $\tau = 0.3$ and $\tau = 0.5$

3.4.1 Who are the Potential Cheaters and Why

Table 3.10 summarizes the average marginal effects of the ordered probit model. First of all, I can notice that there is a sign inversion when the outcome goes from "Low Cheating" to "Medium Cheating".

TABLE 3.10: Average Marginal Effects: Ordered Probit Model

Variable	Low Cheating	Medium Cheating.	High Cheating
EA_{index}	0.44**	-0.127**	-0.318*
	(0.386)	(0.122)	(0.135)
GDP_{pc}	0.74***	-0.12	-0.63***
	(2.61)	(0.99)	(0.90)
AID	-0.0039***	0.00968***	0.00243***
	(0.00014)	(0.000055)	(0.000049)
Total Damage	-0.00566***	0.00161***	0.000405***
	(0.00018)	(0.000055)	(0.000064)
Partly Free	0.073	-0.017**	-0.025**
	(0.63)	(0.0065)	(0.0060)
Free	0.073	-0.01*	-0.025**
	(0.68)	(0.78)	(0.66)
Tropics	0.14	-0.045*	-0.099*
	(0.104)	(0.0103)	(0.095)
Southern Hemisphere	-0.06	0.004	0.056
	(0.099)	(0.0117)	(0.091)
Observations	138	138	138

Robust Standard Errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1
All the predictors at their mean value

Moreover, I observe that when EA_{index} increases by one unit the probability of $RTD_i \leq 0.3$ (Low Cheating) increases by 44% and it is significant at 5%, moreover, an instantaneous change in GDP_{PC} increases the same probability by 74% and it is highly significant.

It means that richest countries are more like to defeat from the committed target up to 30%, in relative terms.

Interestingly, for the same category of Cheating, suffering more from natural disaster and receiving financial aid by the Global Environmental Fund, reduces slightly this probability. Rather, changes in location and in the level of freedom do not significantly change the outcome probability.

For what concerns the second and third outcomes of the dependent variable (Medium and High Cheating, respectively), I observe opposite results.

In particular, a unit increase in the Environmental Activism index reduces the probability of cheating by 12% in the medium scenario and by 32% in the extreme scenario. This is a sign of a possible "disillusion effect" experienced by countries who are highly involved in environmental governance.

It is important to remark that both EA_{index} and *Damage* are constructed over the period that goes from 1986 (Year of the First Multilateral Environmental Agreement in the History) to 2016 (year in which Paris Agreement entered into force). Indeed, after the announcement by President Trump to withdraw from the Paris Agreement, some relevant figures of the international community started complaining about the

TABLE 3.11: Predictive Margins with Confidence Intervals

Cheat	Margin	Conf. Int.	
Low (1)	0.40^{***}	0.33	0.487
Medium (2)	0.38^{***}	0.30	0.463
High (3)	0.21^{***}	0.144	0.275

effectiveness of these agreements and about the scarce level of commitment experienced so far by many developed countries.

Going further in the interpretation of the results, I can observe that for medium and high cheating an instantaneous change in both Total Damage and International Aid increases the probability of cheating by a small but highly significant percentage. Moreover, results show that the level of freedom and location play a role in the determination of the probability of cheating in the medium and high scenario. In particular, with respect to non-free countries, partly free and free countries have a reduced probability of cheating.

This result seems to confirm the Theory of Congleton (1992) who argued that autocratic regimes are less risk averse and less interested than democracies in insurance-type actions that protect against Climate Change. Moreover, Congleton claimed that, given the short-term nature of this type of government, autocracies would not be as concerned about the long-run consequences of Climate Change[13]

Summing up, results from the ordered probit model show that:

- For Low Cheating, Environmental Activism and GDP *per capita* have a positive impact on the probability of being a potential cheater. On the contrary, keeping everything constant, countries who suffered more from natural disaster and received financial aid from the Global Environmental Fund, are less likely to defeat from the commitment (in the Low Cheating scenario);
- Going from Low Cheating to Medium Cheating and High Cheating brings a systemic inversion in signs that should be further investigated. In the medium and high scenario, results show that an instantaneous change in GDP *per capita* reduces the probability of being a potential cheater by up to 63% in the extreme scenario. Moreover, average marginal effects of location and level of freedom are negative and significant and confirm previous literature.

Table 3.11 and Figure 3.1 show the predictive probabilities for each outcome keeping all predictors at their mean values.

The figure shows that the predictive margin for both the outcome "Low Cheating" (*i.e.* the probability of $RTD_i \leq 0.30$) and "Medium Cheating" (*i.e.* the probability of $0.30 < RTD_i \leq 0.50$) are around 40% while there is only a 20% probability that a country would deviate from its commitment more than 50%.

Given that location and the level of freedom play a role in determining the probability of being a potential cheater, I show in 3.2[14] the outcome probability for each interaction between Latitude and Freedom.

It is interesting to notice that countries located in the tropics who are ranked as either partly free or free, experience the higher probability for category 1 of my outcome variable (Low Cheating). The probability of being a potential cheater in this case is 52% for partly free countries and 50% for free countries.

[13]In 1992 Congleton refered mainly to Ozon Layer Depletion, but his considerations can be easily applied to the broader sense of "Climate Change" used nowadays.

[14]Freedom =1 is "Non-Free", Freedom =2 is "Partly Free", Freedom =3 is "Free".

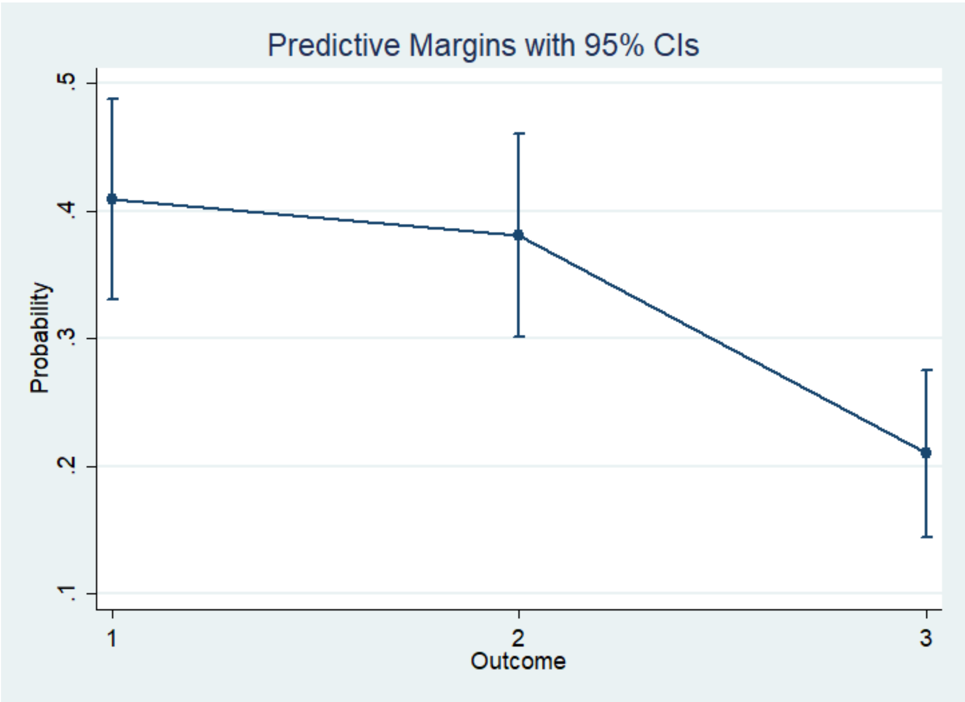

FIGURE 3.1: Predictive Margins with Confidence Intervals

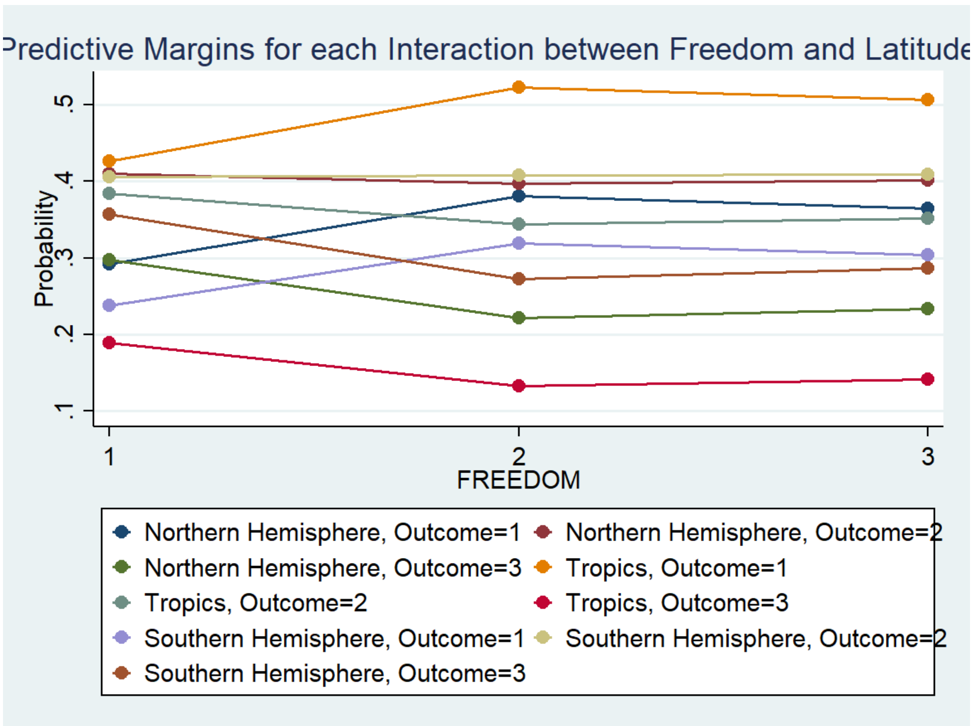

FIGURE 3.2: Predictive Margins for each interaction between Freedom and Latitude.

In general, I can observe that for Low Cheating, the probability experiences a positive jump going from "not free" to "partial Free". The opposite situation is reflected for the High Cheating scenario.

Now, in Table 3.12 I report the Paris-Agreement Member State who has the highest probability of being a potential cheater for each outcome and in Tables 3.13 3.14and 3.15 report the list of the Top 20 potential cheaters.

Let's focus on the first scenario. Surprisingly, the Top 20 potential cheaters in this case are mainly European countries and the one who has the highest probability is Denmark, with a consistent probability of 74%. Two considerations may follow from these results: first, all EU Member States agreed on a common emission target for the Paris Agreement which consists in the reduction of GHG emissions of 40% with respect to 1990 level. Clearly, a one-size-fit-all target is not easy to apply due to many structural characteristics differences among all European Countries.

So, using a game-theoretic perspective, regional groups that do not differentiate national emission targets share a common strategy that could negatively affect the final results of the game.

Second, Greenland is legally territory of the Kingdom of Denmark. Since Greenland has a very low level of emissions, it implies that reducing by 40% GHG emissions when the starting level is too low, is unfeasible. Therefore, it is explained why the probability that Denmark could deviate from the 40%-reduction target in 2030 is almost 74%.

TABLE 3.12: Worst Cheaters

	Low Cheating	Medium Cheating	High Cheating
Country	Denmark	Russian Federation	Russian Federation
Probability	74%	37.5%	37.5%

In the medium-level scenario, the country who has the higher probability of being a potential cheater is Russian Federation ($p = 0.37$), and in the top 20 potential cheaters, many countries ranked as "Partial Free" and/or "Non-Free" appear, accordingly to estimation results of the Ordered Probit Model (table 3.10).

Interestingly, many countries who are members of gas and oil cartels (ex. OPEC) show up in the top 20 list. In order to better investigate the role of OPEC on the probability of being a potential cheater, I re-run the Ordered Probit model by adding a dummy variable for the adhesion to the OPEC. The results are inconclusive. There is no evident correlation between being part of OPEC and the dependent probability for all the outcomes under investigation.

3.5 Conclusions

Paris Agreement represents the largest multilateral coalition for Climate Change mitigation in the history of Environmental Agreements. Previously, many other IEAs failed in their tasks and some countries have shown a non-cooperative behavior that negatively affected the final outcome.

Therefore, it is relevant to assess the quality of the Agreement in terms of its cooperative nature and to find a way to identify on time potential cheaters to the Agreement.

TABLE 3.13: Top 20 potential cheaters for Low Cheating

	Probability	St. Error	ISO2	Name
1	0.74	0.07	DK	Denmark
2	0.72	0.07	DE	Germany
3	0.72	0.07	AU	Australia
4	0.72	0.07	GB	United Kingdom
5	0.71	0.07	CA	Canada
6	0.71	0.07	NZ	New Zealand
7	0.70	0.07	ES	Spain
8	0.70	0.08	JP	Japan
9	0.70	0.07	CH	Switzerland
10	0.69	0.07	AT	Austria
11	0.68	0.07	NL	Netherland
12	0.68	0.07	GR	Greece
13	0.67	0.07	PT	Portugal
14	0.67	0.07	IT	Italy
15	0.67	0.07	BE	Belgium
16	0.66	0.07	CZ	Czech Republic
17	0.66	0.07	PL	Poland
18	0.66	0.07	LT	Lithuania
19	0.66	0.07	FR	France
20	0.66	0.07	LV	Latvia

The analysis proposed in the previous sections demonstrate that the Paris Agreement's NDCs cannot be considered as a mere voluntary contributions to GHG abatement because there is not strong statistical evidence to conclude for a linear relationship between Income and Emission abatement. Anyway, this result is not enough to completely exclude that the Agreement is a pure Nash equilibrium -at least in its early stage- and it is not possible to conclude that there is a full cooperative coalition, either.

Some other game-theoretic models should be tested and analyzed in order to better investigate this issue.

Differently from the paper by Murdoch and Sandler (1997), I update the empirical strategy in order to account for possible heteroskedasticity in the error terms and for collinearity between GDP and Population.

Furthermore, from a game theoretic perspective, each player chooses the best strategy based on the set of current and past information available. Since the Paris Agreement in its early stage has the information about the national emission-reduction commitments and the official emission projections for the target year, in the second part of the paper, I define an empirical and theoretically agnostic approach in order to identify the potential cheaters of the Paris Agreement and the socio-economic variables that affect the probability of being a potential cheater.

For Low Cheating, Environmental Activism and GDP *per capita* have a positive impact on the probability of being a potential cheater and it can be interpreted as a sign for a possible "disillusion effect" due to the several failures in Environmental Governance. On the contrary, keeping everything constant, countries who suffered more from natural disaster and received financial aid from the Global Environmental Fund, are less likely to defeat from the commitment.

TABLE 3.14: Top 20 potential cheaters for Medium Cheating

	p	St. Error	ISO2	Name
1	0.37	0.13	RU	Russian Federation
2	0.36	0.10	IR	Iran (Islamic Republic of)
3	0.35	0.11	CU	Cuba
4	0.34	0.12	OM	Oman
5	0.30	0.09	DZ	Algeria
6	0.30	0.09	JP	Japan
7	0.30	0.13	CN	China
8	0.30	0.08	DE	Germany
9	0.29	0.08	AU	Australia
10	0.29	0.08	DK	Denmark
11	0.29	0.08	GB	United Kingdom
12	0.29	0.09	YE	Yemen
13	0.29	0.11	SA	Saudi Arabia
14	0.28	0.08	CA	Canada
15	0.28	0.08	NZ	New Zealand
16	0.28	0.07	ES	Spain
17	0.27	0.10	VN	Vietnam
18	0.27	0.08	KZ	Kazakhstan
19	0.27	0.07	IT	Italy
20	0.26	0.07	CH	Switzerland

Going from Low Cheating to Medium Cheating and High Cheating brings a systemic inversion in signs that should be further investigated. In the medium and high scenario, results show that an instantaneous change in GDP *per capita* reduces the probability of being a potential cheater by up to 63% in the extreme scenario. It implies that richest countries are less likely to widely defeat from their commitment. Moreover, average marginal effects of location and level of freedom are negative and significant and confirm previous literature.

Indeed, for medium and high scenario, countries with autocratic governments and/or with less freedom, are more likely to be potential cheaters. This result confirms the theory by Congleton (1992) for which autocracies are less concern on environmental protection.

Then, I could predict the probability of being a potential cheater for all the Paris Agreement Member States. It shows up that the Top 20 potential cheaters in the case of Low Cheating are mainly EU members and countries who have very low actual emission levels. The implications are twofold: from one hand, sharing a common emission target in a sub-group of the coalition seems to be unfeasible due to structural differences among the countries involved. On the other hand, high emission-reduction targets committed by countries who enjoy low air pollution and low GHG emissions, look unrealistic and push the probability of cheating very high (up to 74%).

For the last two scenarios, many countries ranked as “Partial Free” and/or “Non-Free” appear in the Top-20 list and many of them belong to OPEC. Nevertheless, no evidence has been found for a significant correlation between being part of the OPEC and the probability of cheating.

Finally, policy implications derive from the analysis: Financial Aid for Climate Change adaptation could be a useful tool in order to compensate damaged countries

TABLE 3.15: Top 20 potential cheaters for High Cheating

	Probability	St. Error	ISO2	Name
1	0.37	0.13	RU	Russian Federation
2	0.36	0.10	IR	Iran (Islamic Republic of)
3	0.35	0.11	CU	Cuba
4	0.34	0.12	OM	Oman
5	0.30	0.09	DZ	Algeria
6	0.30	0.09	JP	Japan
7	0.30	0.13	CN	China
8	0.30	0.08	DE	Germany
9	0.29	0.08	AU	Australia
10	0.29	0.08	DK	Denmark
11	0.29	0.08	GB	United Kingdom
12	0.29	0.09	YE	Yemen
13	0.29	0.11	SA	Saudi Arabia
14	0.28	0.08	CA	Canada
15	0.28	0.08	NZ	New Zealand
16	0.28	0.07	ES	Spain
17	0.27	0.10	VN	Vietnam
18	0.27	0.08	KZ	Kazakhstan
19	0.27	0.07	IT	Italy
20	0.26	0.07	CH	Switzerland

and to bring stability to the coalition. Moreover, common emission-reduction targets could be read by third countries as a clue for potential cheating and could affect the final outcome of the Agreement. Furthermore, this methodology could be implemented in the future in order to help countries to better determined their strategies and emission-reduction commitments.

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Chapter 4

Socio-Economic and Political Determinants of PV deployment: spatial econometric analysis of Italian Cities

4.1 Introduction

Global Climate Change mitigation policy requires national and local governments to implement, together with other measures, energy efficiency and energy-switch mechanisms. A consistent Greenhouse Gases (GHGs) emissions abatement policy can be afforded through several options. Recent history shows that most Developed Countries considered the incremental of national renewable energy production as a valuable strategic channel for emission reduction.

In the EU 2020 goals, de-carbonization of EU area and energy differentiation is declared as an important target. In order to reach this goal, the European Directive 2009/28/EC sets a binding target of 20% final energy consumption from renewable sources by 2020. The Directive obligates each EU Member State to submit a National Renewable Energy Action Plan showing what actions they intend to take to meet their renewable targets.

According to this Directive, Italy must cover 17% of its final energy consumption with renewable sources. The Italian Ministry of Economic Development provides, in the Italian national action plan, a description of the principal support mechanisms in force for electricity production from renewable sources. As an example, the action plan suggests: (*i*) incentive schemes for electricity produced by plants using renewable sources through the green certificate scheme, and (*ii*) incentive schemes for Photovoltaic and solar thermodynamic plants through the feed-in tariff (FiT) mechanism.

The latter option has been successfully implemented by several EU countries and it has been demonstrated[1] that the FiT mechanism played a significant role in promoting domestic application of Photovoltaic Panels (PV).

In this paper, I focus on the Italian renewable energy incentive policy, "*Conto Energia*". I will show that PV deployment in Italy follows a spatial pattern that is not fully consistent with policy expectations. In particular, I find that PV deployment among Italian cities is characterized by spatial spillovers and by some factors that could lead to socio-economic concern and policy interventions.

The aim of this analysis is to find the socio-economic drivers of PV deployment in Italy using a city-level spatial perspective in order to account for possible imitative

[1] Zhang et al. 2011

behaviors in individual green practices. Moreover, I will investigate whether local Political Parties play a role in the bureaucratic barriers to PV deployment.

I start with a brief literature review on PV deployment and its spatial determinants, as discussed in section 4.2. In section 4.3 I describe the context of PV in Italy and "*Conto Energia*"; in section 4.4, I present the dataset and in section 4.5 the spatial econometric strategy adopted. In section 4.6 I show and discuss the results of the analysis. in section 4.7 I propose my final considerations and policy recommendations.

4.2 A brief look at the Literature

The adoption of individual green practices, such as the installation of PV panels on the roof, is affected by several socio-economic variables and, as recent literature shows, spatial determinants play a role as well.

Bollinger and Gillingham (2012) show that a correct specification of the drivers of PV deployment should include in the analysis geographical characteristics and peer effects. Balcombe *et al.* provide a qualitative review of microgeneration technology uptake. They identify five different dimensions that affect motivations and barriers for the uptake of these technologies. The five dimensions are: 1) financial; 2) environmental security of supply; 3) uncertainty and trust; 4) inconvenience (especially related to barriers [2]); 5) Impact on residence.

For what concerns quantitative studies, Sardianou and Genoudi (2013) use a probit model in order to study solar PV installation in Greece. More specifically, they study the effect of gender, marital status, financial background and income and they find that middle-aged and highly educated individuals are much more likely to adopt renewable energy resources in their home.

Zhang *et al.* report a positive impact of housing investments, environmental awareness and government subsidies on PV installations in Japan. They also find that installation costs have negative impacts. A case study of German PV, run by Rode and Weber (2012), suggests that the lower levels of geographical aggregation lead to better estimation results. They also show that imitative behavior is highly localized rather, proximity and neighbourhood effects are drivers of PV deployment. Rode and Weber (2012) also claim that the propensity to install PV increases to the number of previously installed systems in spatial proximity.

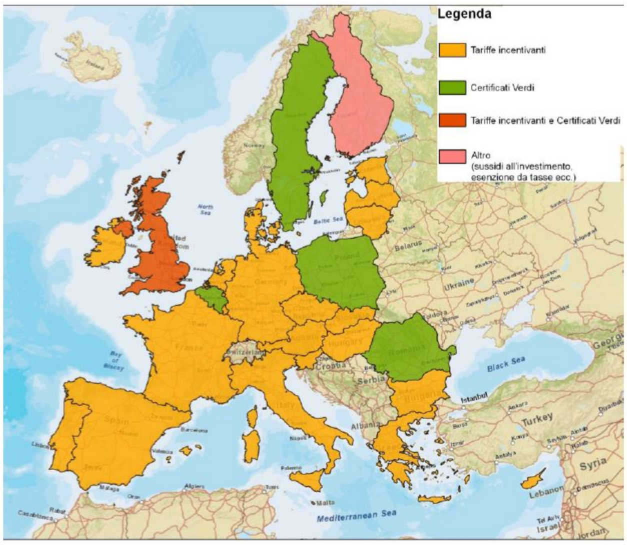
Balta-Ozkan *et al.*(2015), focus on the introduction of the Feed-in Tariff scheme in UK in 2010. They apply a Spatial Durbin Model using cross-sectional data relating to UK. They find that the demand for electricity, population density, education level and pollution are among the drivers of PV uptake in UK. They also find significant regional spillovers effects.

The Italian case is well summarized by Di Dio *et al.* (2015). They stress that the highest number of PV plants in Italy are concentrated in the Northern Regions of Italy, and only in the most industrialized ones there has been a wide and massive spread of installations.

In the South, they claim that speculative behaviors have been taking place due to the lack of attention that Italian politicians gave to the PV market. A report by IEA (2013) says that the Italian PV market has been characterized by very high purchase cost with respect to other EU markets. Anyway, the paper by Di Dio *et al.* (2015) states that Italy did not manage to penetrate the PV market in a massive way.

[2]For example: location not suitable, energy not available, installation issues, neighbour annoyance.

FIGURE 4.1: Incentive Mechanisms across EU countries



Source: GSE- Gestore Servizi Energetici (year 2012)

As a result, once the incentive period expired, Italy registered a diminution of PV installations and a reduction of companies producing solar cells and cables.

4.3 The context of PV in Italy

The objective of this analysis is to evaluate the most important incentive scheme for PV deployment adopted by the Italian Government, "*Conto Energia*", which consists in a FiT mechanisms.

In section 2.1, I state that among EU countries, FiT mechanism is widely used in order to promote renewable energy production[3] (Figure 4.1 provides an idea of the type of mechanisms adopted in EU[4]). The FiT obligates an electricity provider to purchase electricity generated by renewable energy producers in its relevant area, paying a tariff determined by public authorities and guaranteed for a specific period (in general, 20-25 years). A FiT's value thus represents the full price that a producer receives for any kilowatt hour of electricity generated and may include a premium above or in addition to the market price.

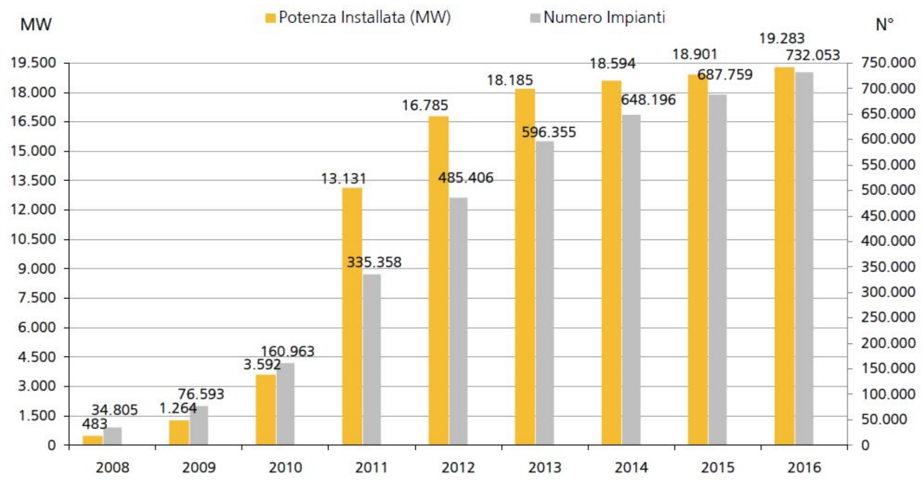
Even though it is commonly used, it differs across countries due to different renewable technologies, natural resource endowments and socio-political conditions.

In Italy, the D.Lgs. 387/2003 sets that PV system must be supported by a FiT mechanism[5]. The first incentive policy for PV system promoted in Italy was the "10,000 PV Roofs" launched in 2001 by the Italian Ministry of Environment with the support of ENEA (Italian Agency for Energy and New Technologies), but only in 2005, with the DM 28/07/2005 the first edition of *Conto Energia* was issued.

In its beginning formulation, FiTs were paid by GSE (*Gestore Servizi Energetici*) which is the Italian Institution for the Energetic System Management. Only grid-connected PV system, with rated power from 1kW to 1MW, could receive FiT and the

[3] 20 EU countries and over 60 worldwide have adopted this measure
[4] Yellow: FiT; Green: Green Certificates; Orange: Both; Pink: Other
[5] Before 2003, only capital subsidies were adopted.

FIGURE 4.2: Number of PV and power installed (MW) in Italy



Source: GSE

duration was set to 20 years with constant remuneration, after, the producer could benefit from the net-metering option or sell the energy to the electricity provider.

Between 2005 and 2012 *Conto Energia* had 5 different editions.

The second formulation was introduced by the DM 19/02/2007, and the new simplified procedure for obtaining the incentives boost the deployment of PV installations all over the country.

DM 06/08/2010 introduced the ”Third *Conto Energia*”. The main differences introduced dealt with the classification of PV plants that allowed a broader class of plants to be included in the mechanism. Furthermore, the values of the related FiTs have been incremented.

In 2011, ”Fourth *Conto Energia*” entered into force with DM 05/05/2011. This version entailed a gradual reduction of FiT incentives in order to gradually align the public incentive with the technology costs. Moreover, it established the creation of the ”Big PV plants register”, that obliged the producer to catalogue the big PV plants in order to get the FiT. In the ”Fourth *Conto Energia*”, the policy maker set the limit to the annual cumulative cost of the incentives to 6 billions of Euros. Anyway, that limit was very close to be achieved and in 2012, with DM 05/07/2012, the last edition was established: ”Fifth Conto Energia”. In this last formulation, all the instructions of the previous editions have been confirmed and the upper-bound for the cumulative cost has been raised to 6.7 billions of Euros. Once reached the limit cost, Conto Energia has no longer been applied but, util 2016 the FiT was guaranteed only for the energy quota pumped into the greed. Figure 4.2[6] show the evolution of PV deployment in Italy across all the version of *Conto Energia*.

4.4 Data

In order to study the socio-economic and political drivers of PV deployment in Italy, many dimensions should be taken into account. For the variable of interest, PV deployment, I use georeferenced information on PV installed in 8094 cities (italian

[6] Yellow: Power installed; Grey: Number of Plants

"*comuni*") under *Conto Energia* until 2011 [7]. Even if a panel structure of the data could enhance to correct the impact effects for the time trend, I refer the analysis only for year 2011. There are several explanations for this choice: first, in 2011- year of the introduction of the fourth edition of *Conto Energia*- the most complete version of the incentive mechanism has been into force and a numerical limit for the cumulative incentive cost has been fixed. Moreover, under the fourth version, all PV installed up to 2011 are covered. Furthermore, in the year 2011, it is possible to refer to the latest cadastral data by the Italian Institute of Statistics (ISTAT). In this way, I can access information about the urban structure, the social composition and the type of buildings present in each cities until that year. Table 4.1 summarizes the variables used for the analysis.

TABLE 4.1: List of Variables

Variable	Description	Source
PV	Number of PV installed under CE	GSE
Population Density	Inhabitants for km^2	ISTAT
Households	number of households resident in the city	ISTAT
Income PH	Income per households	MEF income Tax data
Women share	Share of Women	ISTAT
EDU index	Number of graduates over population over 19 yo	ISTAT
Dwelling PH	Average number of dwellings own by the same household	ISTAT
Dimension	Geographical surface of the city	ISTAT
Dimension	Geographical surface of the city	ISTAT
Altitude	Altitude of the city	ISTAT
City centre	Urban area characterized by contiguous houses/flats and the presence of public services and facilities	ISTAT
Spare House	Urban area in which the distance among each house is greater than 30 meters	ISTAT
WING	Political colour of each city cabinet	MDA-historical archive of elections and administrative registry office

For what concern information on the political composition of each city's cabinet, I refer to the Historical Archive of Elections and the Administrative Registry Office of the Italian Ministry of Domestic Affairs. A brief focus on the differences between the national and local political situation in Italy is described in subsection 4.4.1. Based only on the visualization of PV deployment, reported in Figure 4.3, even though solar irradiation is concentrated in the south and in the islands, most PV are concentrated in the centre, along the Apennines mountain range, and in the northern Adriatic coast. Same results have been found by Di Dio *et al.*. This would suggest that there is spatial clustering of PV deployment. A Moran Test on spatial autocorrelation of PV deployment confirms clustering (results reported in table 4.2); thus there is statistical basis to proceed the analysis with a spatial econometric model.

TABLE 4.2: Global Moran's I summary

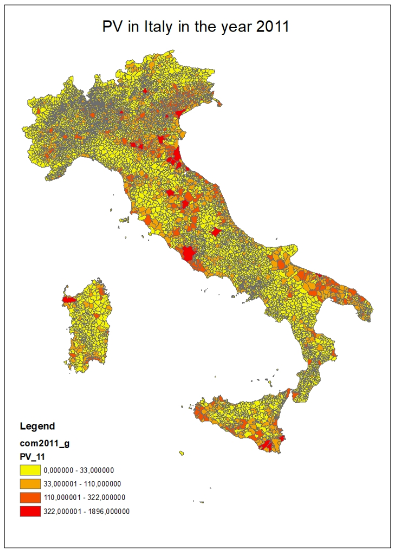
Moran's Index	0.136577
Expected Index	-0.000124
Variance	0.00003774
p-value	0.0000002

4.4.1 The Political Situation in Italy in 2011

From a political point of view, the year 2011 was characterized by critical events that heavily shook the Italian political equilibrium. Since 2008, Silvio Berlusconi (leader of "*Popolo delle libertà*", the major italian Right-wing party at that time) have been the Prime Minister of the National Government but in 2010 the economic crisis, started in 2008 in USA, began to hit Italy. In 2011, the Italian spread on Treasury Bonds rose up to 300 base points and most of the Credit Rating Agencies threatened to declass the Italian solvency rate on its Public Debt.

[7] Data from the GSE database.

(A) Solar Irradiation



(B) Number of PV installed until 2011

FIGURE 4.3: Some visual Issues

Between the 4^{th} and the 5^{th} of August of the same year, Jean Claude Trichet and Mario Draghi, on behalf of the European Central Bank, sent a hard letter to the Italian Government in which they stated a list of austerity policies that Italy should have implemented in order to avoid bankruptcy. Silvio Berlusconi lost the majority in the Parliament and the Italian Government was put under the administration of an external commissioner, Mario Monti.

The delicate and fragile political situation at the national level affected the local administrations' political layout as well. Indeed, the same year administrative elections in several important Italian cities took place and reshaped the political body of the country.

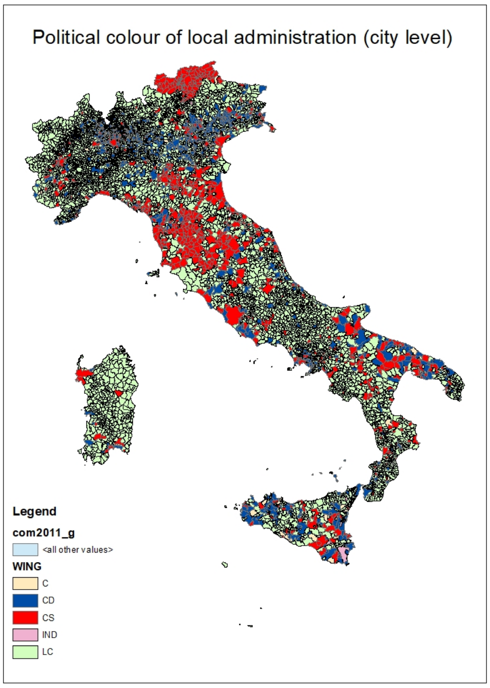
The situation described so far, sees Italy divided into several political forces and none of them was strong enough to be considered as the "first party" of the country.

Moreover, many small political parties that did not take enough votes to get a sit in the Parliament, could run for local administrative elections. To get things even more complicated, it is very common in Italian administrative elections that grassroots movements, group of people coming from the civil society with no belongings to any official political party, run alone for the administrative. Since these -so called- "Civic lists"[8] do not belong to any recognized political party, it could happen that they represent a mix of political ideas but, more often, they are strictly related to territory issues and, somehow, they give voice to green movements and environmentalists that would never get enough votes to be part of the national Parliament.

Since part of the research question of this analysis is to test whether the political color of cities' cabinets plays a role in the formation of barriers to PV deployment, I deal with this complicated situation by grouping all these small parties and civil lists into 5 big coalitions: Center, Center-Right, Center-Left, Civil Lists and indipendentist parties. Table 4.3 reports the summary of the Coalitions, rather Figure 4.4 shows

[8] Even though I am talking about grassroots movements, the peculiar structure of the Italian case leads me to choose the term "Civic Lists" in order to be in line with the Italian name "Liste Civiche"

FIGURE 4.4: Geographical Distributions of Political Coalitions across Italian Cities



the geographical distribution of political coalitions across the 8094 Italian cities under investigation.

As it is shown in Fig. 4.4, the majority of Italian cities are under the administration of Civic Lists. Center-Left is very active in the area of Tuscany and Emilia Romagna (these regions are also called "Red Regions" due to their historical propension to Center-Left coalition). Center-Right is more active in the North of Italy but, at a local scale, it pays the price of the national government crisis.

TABLE 4.3: Political Coalitions in Italian Cities

Name	Coalition	Parties Involved
C	Center	UDC, Alleanza Civica, Alleanza di Centro
CR	Center-Right	FLI, AN, PdL, La Destra, CdL, Lega Nord
CL	Center-Left	PD, IdV, Socialist Party, Rif. Com., SEL, DEM, L'Ulivo, La Margherita
CIVIC	Civic Lists	Fed. Verdi and civil society
INDIP	Indipendentist Parties	

4.5 Empirical Strategy: a Spatial Econometric Approach

When sample data is collected with reference to geographical location, traditional econometrics is no longer the best way to do inference. This is due to two problems that arise with geo-referencing: (*i*) spatial dependence between the observations and (*ii*) spatial heterogeneity in the relationships among variables. When these two issues are ignored, the Gauss-Markov assumptions can be violated and simple linear regressions could lead to biased estimations.

More precisely, in case of spatial dependence, the 2^{nd} Gauss-Markov condition[9] is violated and a problem of endogeneity arises[10].

Balta-Ozkan *et al.* (2015) refer to Elhorst (2010) for the general-to-specific approach for the specification of the most suitable econometric model and lead to the estimation of the Spatial Durbin Model (SDM).

According to this procedure, they start with the general model specification:

$$Y = \rho WY + X\beta + WX\theta + u \tag{4.1}$$

where Y is a (N x 1) vector of observations on a dependent variable and X is an (N x K) matrix of observations on explanatory variables with the associated (K x 1) vector of β.

For what concerns the parameters, ρ is a spatial autoregressive parameter that measures the magnitude of interdependence across spatial units showing the effect of spatial lag in the dependent variable, rather, θ is the spatial lag in the independent variables.

In this model specification, u is independently and identically distributed ($i.i.d$) error term with zero mean and constant variance σ^2.

W is the non-stochastic N x N spatial weights matrix which reflects the structure of spatial interactions among observations. By convention, the generic element of the matrix, $w_{i,j}$, expresses the distance[11] between pairwise combination of observations. In general, $w_{i,j} = 1$ if i and j are neighbours and zero otherwise. There exists several ways to define the W-Matrix but, according to Baltagi and Rokicki(2014) and to the milestone paper by LeSage and Pace (2014) "*The Biggest Myth in Spatial Econometric*" (2014), the choice of the weight matrix may affect the magnitude but not the significance or the sign of the estimated parameters. The model allows to specify two different spatial weight matrices for the lag in the dependent variables and in the covariates. Anyway, if distance is expressed in geographical terms, there is no specific reason to differentiate the two matrices.

Le Sage and Pace (2009), states that among all the spatial model specifications, SDM is preferable because it allows for a distinction between the direct and the indirect impact of the change in an explanatory variable[12]. Another important stand for the SDM, according to LeSage and Pace (2009) is that it leads to unbiased estimations even if the true Data Generated Process (DGP) is the Spatial Lag Model (SAR) or the Spatial Error Model (SEM).

Nevertheless, the SDM cannot account for spatial dependency in the error terms. Indeed, it can happens that the spatial dependence can be affected by other factors in addition to shocks to the spatially lagged dependent variable and the SDM is not capable to capture this type of effects. In order to account for spatial dependency in the error term, Kelejian and Pruha(1999) suggests to start with a cross-sectional (first-order) autoregressive spatial model with (first-order) autoregressive disturbances (SARAR specification).

In order to take into account all sources of spatial dependency, the aim of this paper is to exploit and compare two different model specifications, SDM and the

[9] $E(\mathbf{X'}\epsilon_i) = 0$ and $E(\epsilon_i) = 0$.

[10] The most relevant cause of endogeneity for spatial regression is simultaneity.

[11] The distance could be interpreted either geographically or economically. As an example: Region i and region j can be considered neighbours if they share a common border or the same level of GDP, the level of industrialization or -in terms of flows- if they are great partners in international trade.

[12] More details will be provided later on in subsection 4.5.1

SARAR model, the latter defined in the following equations:

$$y_n = X_n\beta_n + \lambda_n W_n y_n + u_n \tag{4.2}$$

and

$$u_n = \rho_n M_n u_n + \epsilon_n \tag{4.3}$$

Where n is sample size, y_n is a n x 1 vector of observations on the dependent variable, X_n denotes the n x k matrix of exogenous regressors, and W_n and M_n are n x n spatial weight matrices[13]. Scalar spatial-autoregressive parameter are expressed by λ_n and ρ_n which refer to the spatial lag in the errors and in the dependent variable[14], respectively.

Starting with this complete specification is useful because: 1) with respect to the SDM, spatial dependency in the error term is account for; 2) From the most complete specification, I can end up either to the Spatial Autoregressive model (if $\lambda = 0$) or to the Spatial Error Model (if $\rho = 0$). Kelejian and Prucha (1998-1999), demonstrate that the correct and most efficient estimator for the SARAR model, in case of big sample size, is the Generalized Method of Moments. Anyway, a strong assumption of this model is homoskedasticity of the error component.

Since spatial units may differ in important characteristics, homoskedasticity may not hold in many applied spatial problems. Arraiz et al. (2010) provide simulation evidence that when the innovations are heteroskedastic, ML produces inconsistent estimates.

By applying a Cliff-Ord transformation, it is possible to relax this assumption and to account for Heteroskedastic innovations[15]. Generalized 2-stages Least Squared estimator is considered the best estimator for this specification.[16]

Furthermore, in order to provide a more extensive comparison between the two models, in the SARAR specification I explore the Spatial Impact Effects of each covariate distinguishing between Direct and Indirect impact effects[17].

4.5.1 Impact Effects

In the general linear regression, with no spatial interdependence, the effect of the explanatory variable X on the dependent variable Y is given by the first partial derivative and it is expressed by the parameter β. In other words, since the error term in the linear regression has zero mean, the Expected value of Y conditional to X is β:

$$E(y) = X\beta \tag{4.4}$$

For simplicity of explanation, let's consider the SAR Model (equation (4.2)). The reduced form is therefore:

$$Y = (I - \lambda W)^{-1}[X\beta + \epsilon] \tag{4.5}$$

Clearly, in this specification the expected value of the dependent variable is now:

$$E(Y) = (I - \lambda W)^{-1}X\beta \tag{4.6}$$

[13] In most applications $W_n = M_n$
[14] $|\lambda| < 1$ and $|\rho| < 1$
[15] Arraiz I, Drukker DM, Kelejian HH, Prucha IR (2010).
[16] See Kelejian and Prucha(2007, 2010) for the formal derivations.
[17] See La Sage and Pace(2009) and Kelejian(2006)

For simplicity, consider only one regressor. Two situations may arise: 1) there is no spatial effect (in this case $\lambda = 0$ and $E(y_i) = \beta_1 X_i$); 2) $\lambda \neq 0$. Call $G = (I - \lambda W)^{-1}$ and I end up with:

$$\frac{\partial E(y_j)}{\partial X_1} = G_{j1}\beta \tag{4.7}$$

From (4.7), it is possible to notice that a change in the explanatory variable for a given observation, can affect the dependent variable Y in all other observations.

La Sage and Pace (2009) and Kelejian (2006) call $S = (I - \lambda W)^{-1} X\beta$ and distinguish among three types of impacts:

1. Avarage Direct Impact (ADI):
$$N^{-1} tr(S) \tag{4.8}$$

2. Avarage Total Impact (AtI):
$$N^{-1} \Sigma_j \Sigma_i G_{ji} \beta \tag{4.9}$$

3. Avarage Indirect Impact (AII):
$$ATI - ADI \tag{4.10}$$

By using the Variace-Covariance Matrix of the estimated $\hat{\beta}$, it is possible to generate empirical distribution and do inference on the impacts.

In more simple words, the direct impact estimates the effect of changing an explanatory variable in a particular cross-sectional unit on that unit's dependent variable, incorporating feedback effects which pass through neighbouring units and back to the unit which initiated the adjustment process. The indirect impact is an estimate of the effect of changing an explanatory variable in a particular unit on the dependent variables of all the other units.

In section 4.6 I present the results for the SDM and the SARAR model with heteroskedastic innovations, as suggested by Kelejian and Prucha (1998-99), and the spatial impacts. In Appendix B, the reader can find the estimation results for SAR, SEM and SARAR with no heteroskedastic innovations estimated by GMM.

4.6 Results and Discussion

Th empirical strategy exposed in section 4.5 to the PV deployment in Italian cities, starts with the definition of the Spatial Weigh Matrix.

The present analysis is based on an inverse-distance, row-standardized Matrix. For a sensitivity analysis, I tried other specifications such as k-nearest-neighbours, rook and queen contiguity and kernel distance and, as it has been stated in section 4.5, different W-matrix specifications can lead to a change in the magnitude of the estimations but they do not affect either the sign or the significance, as it confirmed by the literature.

In line with the recent literature, we start by running a simple OLS. We take as a base-model the specification by Baltan-Ozkan *et al.* (2015) and we add other covariates according to the recent findings in other empirical applications. Finally, we account for the political color of the cities' cabinet. Estimation results for the OLS can be find in table 4.4.

TABLE 4.4: OLS estimations

	Dependent variable:			
	Number of PV per Household			
	(1)	(2)	(3)	(4)
$Income_{ph}$	0.309***	0.298***	0.260***	0.299***
	(0.037)	(0.038)	(0.041)	(0.037)
Population density	−0.133***	−0.134***	−0.138***	−0.136***
	(0.019)	(0.019)	(0.019)	(0.019)
Altitude	−0.090***	−0.090***	−0.085***	−0.088***
	(0.014)	(0.014)	(0.014)	(0.014)
Av. Dwellings per Household	0.152***	0.149***	0.149***	0.148***
	(0.018)	(0.018)	(0.018)	(0.018)
Education Index	−0.392***	−0.386***	−0.384***	−0.408***
	(0.015)	(0.015)	(0.015)	(0.016)
City Center	0.234**	0.253***	0.277***	0.235**
	(0.094)	(0.095)	(0.095)	(0.094)
Women Share		−0.892*	−0.913*	
		(0.501)	(0.501)	
Foreign Share			0.045**	
			(0.017)	
C-Right				0.215
				(0.149)
C-Left				0.113
				(0.150)
Civic Lists				0.011
				(0.142)
Independentists				−0.058
				(0.486)
Constant	−4.368***	−4.899***	−4.471***	−4.216***
	(0.356)	(0.464)	(0.494)	(0.379)
Observations	8,094	8,094	8,094	8,094
R^2	0.231	0.231	0.232	0.233
Adjusted R^2	0.231	0.231	0.231	0.232
Residual Std. Error	1.396 (df = 8087)	1.396 (df = 8086)	1.396 (df = 8085)	1.395 (df = 8083)
F Statistic	405.166*** (df = 6; 8087)	347.830*** (df = 7; 8086)	305.373*** (df = 8; 8085)	245.103*** (df = 10; 8083)
Note:				*p<0.1; **p<0.05; ***p<0.01

OLS results seem robust to different specifications. Anyway, at the city-level some features change with respect to other countries' findings. More precisely, population density has a strong negative effect on PV deployment. It would suggest that in crowded Italian cities, people hardly engage in green practices such as the installation of a PV panel on the roof. Nevertheless, the sign is positive for City Center. Even though, at a first glance, the two results could seem in contrast to each other, most of the population concentrated in highly density populated cities do not own the house where they live.

Conto Energia, indeed, allowed only landlords to request the incentive and the tenants were excluded.

To further support this interpretation, cities in which households own on average more than one house/flat register higher PV deployment. Surprisingly, women are less attracted than men in the adoption of PV, rather cities with a high share of registered foreigners follow a greener pattern. This last issue could suggest that in Italy, green practices are mainly "imported". Moreover, contrary to other studies, cities with a higher share of highly educated people do not seem engaged in PV system. Finally, from these preliminary results, politics do not have a significant effect on PV deployment.

Anyway, as suggested above, if there exists spatial dependency OLS leads to biased estimators. Table 4.5 reports the Moran's I index on OLS residuals and, in all specifications there is evidence for spatial clustering. There is thus reason to proceed with the spatial models. I start with the SDM model and estimation results are summarized in Tables 4.7 and 4.8.

TABLE 4.5: Moran Test on OLS residuals

	(1)	(2)	(3)	(4)
Moran's Index	0.00715	0.00716	0.00718	0.00715
Expected Index	-0.000373	-0.000388	-0.000424	-0.000405
Variance	0.00003767	0.00003767	0.00003766	0.00003766
p-value	0.0000002	0.0000002	0.0000002	0.0000002

TABLE 4.6: LM tests

	Statistics	df	p-value
LMerr	135.804	1	0.00000
LMlag	110.841	1	0.00000
RLMerr	25.251	1	0.00000
RLMlag	0.288	1	0.591
SARMA	136.092	2	0.00000

In the SDM the spatial dependence expressed by the W-matrix is accounted both for the lag in the dependent variable and in the independent variables. Estimation results are shown in Table 4.7 and Table 4.8, in Table 4.9 the reader can find the impact measures. For what concerns the direct impacts, SDM confirms the OLS results. Income has a direct impact effect, showing that richest cities have a greater number of PV installed with respect to poor ones. This could rise an inequality problem since a government incentive has been used mainly by richest people.

This result is confirmed by the strong positive impact of Av. Dwellings per Household. Households who own more than one house or flat, are more encouraged in adopting PV. This could rely to the fact that when a household manages different dwellings, energy incentives can help reducing ordinary management costs.

Altitude, inverse proxy for solar irradiation, has negative direct impact effect, showing that once controlling for income and other variables, PV are more concentrated in area close to the sea-level and characterized by higher solar irradiation.

Political coalitions do not have significant direct impact effects but they all have positive sign. Interestingly, Center-Right coalition has the highest value in magnitude. Since Right Wing is not historically characterized by specific concerns on environmental protection and ecology, this issue could be interpreted as a sort of "nepotism effect" with the national government.

To further support this thesis, if I look at the indirect impact effects, the indirect impact of C-Right is positive and significant. It means that if the neighbour cities are held by the Center-Right coalition, the deployment of PV is more stimulated.

Owing on average more than one house or flat has a positive and significant indirect effect, too. That is clearly explained by the fact that many rich households own more than one dwellings located in different cities (for example the holiday houses on the sea and on the mountains).

Finally, according to the SDM specification, the spatial autoregressive parameter ρ is positive and significant, showing that there exists spatial spillover effects coming from imitative behaviors among neighbour cities in installing PV panels.

Nevertheless, it is possible that some spatial dependency is not captured by the parameter ρ. This leads to the idea to exploit another model specification, the SARAR, in order to account for spatial dependency in the error component, too.

Statistical base in order to proceed in this direction, is provided by the LM tests, shown in table 4.6. Even though it is not considered by the literature a rigorous procedure for model specification since the tests are not robust, it gives a hint for the possible presence of spatial dependency in the error term.

I therefore proceed with the estimation of the Cliff-Ord type SARAR model with heteroskedastic innovations, as described in section 4.5. Results are summarized in Table 4.10 and impacts are shown in Table 4.11.

Estimation results are robust to change in model specifications, since SARAR model's coefficients estimation confirm the SDM ones.

Anyway, once accounting for spatial dependency in the error component with heteroskedstatic innovation, the spatial lag parameter ρ looses significance, rather the spatial error parameter λ is positive and highly significant. This implies that positive spatial spillovers are driven by other unobserved spatial variables not included in the specification.

Direct and Indirect Impacts confirms the result of SDM but, since the SARAR model is more "conservative" in the estimation process, there is a slightly lost in the power and in the magnitude.

Interestingly, a possible "nepotism effect" for Center-Right coalition is suggested also by the SARAR specification.

It relevant to remark that both SARAR and SDM models are global spillover specifications, that is they refer to situations where an impact on neighbouring units also reverberates on neighbours to the neighbouring units, neighbours to the neighbours, and so on, thus generating endogenous interaction and feedback effects.

Anyway, given the specific phenomenon under investigation, it make sense to explore also the situation in which the spatial dependence produce local rather than

TABLE 4.7: Spatial Durbin Model estimation Results-Part 1

	Dependent variable:			
	Number of PV per Household			
	(1)	(2)	(3)	(4)
$Income_{ph}$	0.259***	0.248***	0.222***	0.252***
	(0.034)	(0.005)	(0.043)	(0.035)
Population Density	−0.144	−0.146***	−0.147***	−0.146***
	(0.030)	(0.032)	(0.021)	(0.017)
Altitude	−0.093***	−0.093***	−0.085***	−0.091***
	(0.013)	(0.014)	(0.014)	(0.014)
Av. Dwellings per Household	0.114***	0.112***	0.112***	0.111***
	(0.019)	(0.021)	(0.020)	(0.019)
Education Index	−0.389***	−0.383***	−0.383***	−0.403***
	(0.015)	(0.024)	(0.017)	(0.016)
City Center	0.102	0.126	0.138	0.104*
	(0.048)	(0.099)	(0.133)	(0.055)
Women share		−0.953	−0.966	
		(0.853)	(0.590)	
Foreign share			0.052***	
			(0.016)	
C-Right				0.192
				(0.843)
C-Left				0.132
				(0.789)
Civic Lists				0.032
				(0.776)
Independentists				0.010
				(0.982)
ρ	0.191***	0.192***	0.192***	0.188***
Note:				*p<0.1; **p<0.05; ***p<0.01

(Continues to the Next Page)

TABLE 4.8: Spatial Durbin Model estimation Results-Part 2

	Dependent variable:			
	Number of PV per household			
	(1)	(2)	(3)	(4)
lag.$Income_{ph}$	0.073	0.087	0.092	0.055
	(0.088)	(0.090)	(0.095)	(0.093)
lag.Population Density	0.043	0.046	0.045	0.028
	(0.080)	(0.076)	(0.030)	(0.054)
lag.Altitude	0.008	0.009	0.002	0.011
	(0.009)	(0.010)	(0.005)	(0.007)
lag.Av. Dwellings per Hous.	0.103^{***}	0.106^{***}	0.107^{***}	0.096^{***}
	(0.037)	(0.040)	(0.036)	(0.024)
lag.Education Index	0.087	0.078	0.080^{***}	0.080
	(0.066)	(0.056)	(0.030)	(0.033)
lag.City Center	0.377	0.343	0.351^{**}	0.341^{**}
	(0.278)	(0.225)	(0.163)	(0.160)
lag.Women share		1.367	1.366	
		(2.407)	(0.952)	
lag.Foreign share			−0.037	
			(0.922)	
lag.C-Right				0.281^{***}
				(0.099)
lag.C-Left				0.038
				(0.056)
lag.Civic Lists				0.043
				(0.050)
lag.Indipendentists				−0.455
				(1.031)
Constant	−4.703	-4.436^{***}	-4.233^{***}	-4.415^{***}
	(1.420)	(1.386)	(1.032)	(0.218)
Observations	8,094	8,094	8,094	8,094
Log Likelihood	-14,113.530	-14,111.390	-14,108.030	-14,104.550
σ^2	1.904	1.903	1.902	1.900
Akaike Inf. Crit.	28,257.060	28,256.790	28,254.060	28,255.100
Wald Test (df = 1)	117.102^{***}	112.003^{***}	110.660^{***}	113.952^{***}
LR Test (df = 1)	111.093^{***}	111.619^{***}	111.688^{***}	105.483^{***}
Note:			*p<0.1; **p<0.05; ***p<0.01	

TABLE 4.9: Spatial Durbin Model: Impacts

	Direct	Indirect	Total
$Income_{ph}$	0.253***	0.073	0.3**
Population Density	-0.146***	0.045	-0.14***
Altitude	-0.090***	0.011	-0.09***
Av. Dwellings per Household	0.113***	0.096***	0.2***
Education Index	-0.38***	-0.08**	-0.46***
City Center	0.104*	0.340**	0.440**
Women share	-0.95	1.366	0.416
Foreign share	0.05*	0.037	0.08*
C-Right	0.192	0.281***	0.474**
C-Left	0.132	0.038	0.170
Civic Lists	0.032	0.043	0.075
Independentists	0.010	-0.455	-0.035

TABLE 4.10: GS2SLS estimation of a Cliff-Ord type SARAR model with Heteroskedastic Innovations

	Dependent variable:			
	Number of PV per household			
	(1)	(2)	(3)	(4)
$Income_{ph}$	0.289***	0.275***	0.240***	0.279***
	(0.057)	(0.057)	(0.061)	(0.056)
Population density	−0.1329***	−0.134***	−0.139***	−0.134***
	(0.020)	(0.020)	(0.020)	(0.020)
Altitude	−0.091***	−0.091***	−0.085***	−0.090***
	(0.012)	(0.012)	(0.012)	(0.012)
Av. Dwellings per Household	0.137***	0.134***	0.134***	0.135***
	(0.025)	(0.025)	(0.025)	(0.025)
Education Index	−0.389***	−0.383***	−0.381***	−0.404***
	(0.015)	(0.016)	(0.016)	(0.016)
City center	0.177	0.200*	0.221*	0.183
	(0.112)	(0.116)	(0.115)	(0.112)
Women share		−0.980	−1.00*	
		(0.504)	(0.0.785)	
foreign share			0.047**	
			(0.021)	
C-Right				0.193
				(0.132)
C-Left				0.116
				(0.133)
Civic Lists				0.014
				(0.130)
Independentists				−0.010
				(0.358)
Constant	−3.948***	−4.513***	−4.134***	−3.751***
	(0.421)	(0.514)	(0.535)	(0.617)
ρ	0.042	0.041	0.032*	0.057
λ	0.189***	0.190***	0.202***	0.167***
Observations	8,094	8,094	8,094	8,094
Wald test spatial parameters				99.202***
Note:	*p<0.1; **p<0.05; ***p<0.01			

TABLE 4.11: Impact measures with Heteroskedastic Innovation

	Direct	Indirect	Total
Income	0.24	0.01	0.25
Population Density	-0.14***	-0.00	-0.14***
Altitude	-0.09***	-0.00	-0.09***
Av. Dwellings per Household	0.13***	0.00	0.14***
Education Index	-0.38***	-0.01	-0.39***
City Center	0.22	0.01	0.23
Women share	-1.00	-0.03	-1.04
Foreign share	0.05*	0.00	0.05*
C-Right	0.193*	0.0116	0.204*
C-Left	0.116	0.007	0.123
Civic Lists	0.0144	0.0008	0.0153
Independentists	-0.010	-0.0006	-0.0115

global spillover effects. This idea is also supported by the the fact, when accounting for spatial dependence in the error terms, the λ parameter is positive and significant.

It could be that a *local* spillover specification, which regards situation where an impact on neighbouring units does not generate endogenous interaction and feedback effects, is more proper in this case.

For the reasons discussed above, I try with the Spatial Durbin Error Model, which is defined in Equation 4.11.

$$y = X\beta + WX\theta + u \tag{4.11}$$

where

$$u = \lambda Wu + \epsilon \tag{4.12}$$

Where θ expresses the indirect effect and hence the local spatial spillover.

Estimation results and impact measures are summarized in Table 4.12, Table 4.13 and in Table 4.14.

Even with this new specification, the main results are confirmed.

I can thus conclude that these results are robust to change in model specifications and in the W-Matrix. Replicating the analysis at the Italian provinces-level lead to the same results with just a lost of power due to the reduction in the sample size.

4.7 Conclusions

The geographical visualization of the number of PV installed under the *Conto Energia* until 2011 confirms that the Italian FiT mechanism managed to boost PV deployment among Italian cities.

Anyway, the city-level spatial pattern of PV shows a significant clustering, especially in the Northern cities, characterized by higher income and better institutions. This leads to the need to better investigate the socio-economic determinants of PV deployment by keeping a spatial perspective.

Recent literature, claims that the best model specification for applied spatial econometric analysis is the Spatial Durbin Model (SDM). The SDM is, indeed, very appealing since it accounts for spatial lag both in the dependent and in the independent variables and this allows the researcher to distinguish between the Direct and

TABLE 4.12: SDEM Estimation Results -Part 1-

	Dependent variable:	
	Number of PV per household	
	(1)	(2)
$Income_{ph}$	0.265***	0.257***
	(0.041)	(0.041)
Population Density	−0.143***	−0.146***
	(0.022)	(0.022)
Altitude	−0.093***	−0.091***
	(0.017)	(0.017)
Av. Dwelling per Household	0.118***	0.115***
	(0.019)	(0.019)
Education Index	−0.389***	−0.403***
	(0.016)	(0.017)
City Centre	0.117	0.118
	(0.103)	(0.103)
Center-Right		0.201
		(0.148)
Center-Left		0.132
		(0.150)
Civic Lists		0.031
		(0.142)
Indipendentists		−0.001
		(0.484)
λ	0.1911***	0.18659***
Observations	8,094	8,094
Log Likelihood	−14,114.060	−14,105.200
σ^2	1.905	1.901
Akaike Inf. Crit.	28,258.120	28,256.400
Wald Test (df = 1)	114.331***	109.339***
LR Test (df = 1)	110.030***	104.182***
Note:	*p<0.1; **p<0.05; ***p<0.01	

TABLE 4.13: SDEM Estimation Results -Part 2-

	Dependent variable:	
	Number of PV per household	
	(1)	(2)
lag.$Income_{ph}$	0.134*	0.114
	(0.073)	(0.074)
lag.Population density	0.019	0.003
	(0.036)	(0.037)
lag.Altitude	−0.010	−0.006
	(0.026)	(0.026)
lag.$Av.Dwelling_{ph}$	0.139***	0.130***
	(0.038)	(0.038)
lag.Education Index	0.012	0.003
	(0.030)	(0.032)
lag.City Center	0.449**	0.412**
	(0.184)	(0.184)
lag.C-Right		0.297
		(0.375)
lag.C-Left		0.026
		(0.371)
lag.Civic Lists		0.014
		(0.353)
lag.Indipendentists		−0.452
		(1.296)
Constant	−5.669***	−5.301***
	(0.682)	(0.760)
λ	0.1911***	0.18659***
Observations	8,094	8,094
Log Likelihood	−14,114.060	−14,105.200
σ^2	1.905	1.901
Akaike Inf. Crit.	28,258.120	28,256.400
Wald Test (df = 1)	114.331***	109.339***
LR Test (df = 1)	110.030***	104.182***
Note:	*p<0.1; **p<0.05; ***p<0.01	

TABLE 4.14: SDEM: Impact Measures

	Direct	Indirect	Total
$Income_{ph}$	0.256***	0.113***	0.37***
Population Density	-0.14***	0.003	-0.14***
Altitude	-0.091***	-0.005	-0.096***
Av. Dwellings per Household	0.115***	0.13***	0.24***
Education Index	-0.40***	0.0034	-0.399***
City Center	0.11	0.412*	0.53***
C-Right	0.20	0.29*	0.49*
C-Left	0.132	0.026	0.158
Civic Lists	0.03	0.014	0.045
Independentists	-0.0014	-0.451	-0.453

the Indirect impact of a change of an independent variable on the dependent one. Moreover, the SDM leads to consistent and efficient estimators even if the true DGP is modeled as a SAR or a SEM.

Anyway, SDM is based on the strong assumption of homoskedasticity of the error terms, that it is very hard to find in an applied spatial analysis. Therefore, in order to account for a possible spatial dependency in the error component and the possibility of heteroskedastic innovation, I compare the results from the SDM with the SARAR model.

Results, from both the SDM and the SARAR, show that income has a strong and positive impact on PV deployment. Indeed, the richest cities in Italy are located in the North and, since solar irradiation is mainly concentrated in the South, this is a signal of a possible economic distortion, more precisely, this incentive scheme shows a regressive outcome.

This claim is further supported by the fact that cities with several households who own on average more than one flat/ house, register a higher number of PV installations.

Being the owner of more than one dwelling is, of course, a proxy for the level of wealth.

Important policy implications derive from this result. It is possible that design of this incentive mechanism leads to economic distortions and income inequalities.

Moreover, *Conto Energia* provides the incentives only for the owners of the roofs where the PV should be installed. Tenants are not included in the mechanism and this determines: 1) a disempowerment of the final impact of the policy; 2) an incentive taken by the richest percentile of the population.

Surprisingly, having a large share of foreign residents determines higher diffusion of PV. It would suggest that "green behaviors" are somehow imported by foreign culture. This is also confirmed by the fact that education and women share have not a positive and significant impact.

The two models also show that there exists positive and significant spatial spillover effects. It means that neighbour cities engage imitative behaviors among each others. This issue could be very useful for future policy interventions.

Furthermore, the analysis suggests that policy do not really matter in the pattern of PV deployment. Anyway, a slightly positive impact is associated to cities whose administration is held by the center-right coalition. Since the bureaucratic procedure to obtaining the incentives passes through the national Agency ENEA, a possible interpretation for this positive effect could rely on a "nepotism effect" of the national government on local authorities that somehow facilitate PV deployment at the city-level.

This interpretation is further supported by the fact that, at that time, center-right coalition did not have particular concerns on environmental sustainability and ecology.

To summarize, future design of renewable incentive mechanisms should take into account:

- Possible economic distortions related to income inequality;
- The possibility to extend the incentives to tenants;
- Positive spatial spillovers that could be further enhanced;
- The role of the national government in the local diffusion of PV. Delocalizing the incentive providers could help PV deployment at a local level.

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Chapter 5

Conclusive Remarks

Climate Change is characterized by a broad multi-dimensionality in terms of both effects and agents involved. This implies that Climate Change Policies reflect this multi-dimensionality, thus the aim of this Doctoral Thesis is to assess Climate Change mitigation policy both at the national and regional level, with a specific focus on empirical evaluation.

In chapter 2, I provide a comprehensive review of the economic literature behind Climate Change policy by adopting a general-to-specific approach, covering policies at the international (IEAs) and Regional (EU) level. The main contribution of this work relies on the fact that it is a comprehensive review of the economic and empirical literature on Climate Change Policy in almost all its dimensions.

Starting from the more general case, I discuss two major economic issues concerning International Environmental Agreements: self-enforcement and equity.

In particular, since Climate Action has public good characteristics (non-excludability and non-rivality), Game Theory has been widely used in the economic literature in order to explore the economics of IEAs. More precisely, most of the literature focuses on two major problem arising from IEAs: free-riding and the problem of self-enforceability.

It is possible to identify two branches of the literature, *i*) Non-cooperative based models, whose pioneer is Barret (1994) and *ii*) Cooperative-based models, born from the contributions by the recent Nobel Prize Nordhaus.

To summarize, non-cooperative models are very pessimistic on the outcome of IEAs and show that they can do very little or none improvement in emissions reduction. On the contrary, cooperative models suggest that big coalition can enforce stability of IEA, especially if transfer mechanisms have been taken into account.

Anyway, a big limitation of this literature is that the payoff matrices are often based only on cost-effectiveness and do not account for equity and justice considerations.

Indeed, given that GHGs have a very long persistence time in the atmosphere, recognition of responsibility and even allocation of mitigation efforts are very difficult to compute and rise to inter- and intra-generational equity issues.

Kverndokk and Rose (2008) identify four levels in which equity issues take place in Environmental Policy: national, regional, intersectorial and interpersonal.

The main result of this analysis is that climate policy has several spillover effects, in some cases are positive (economic growth, energy security, public health), in some other they create economic distortions (distorted energy prices, regressive outcome and possible job losses).

For that reason, economic literature and policy makers should refer to General Equilibrium models in order to account for all the possible effects of climate policy on the economy.

For what concerns the assessment of IEA through econometric models, as discussed in subsection 2.2.3, Ringquist *et al.*(2005) identify three problems that arise when assessing IEAs:

- scarcity of good time series data on environmental quality (especially for former agreements);
- a complex mix of non-policy factors that affect environmental quality;
- participation in IEAs is voluntary and this lead to self-selection sample.

Moreover, IEAs can be assessed either on their cooperative nature or on their effective impact.

For what concerns the former level of assessment, a milestone paper by Murdoch and Sandler (1997) try to assess the cooperative nature of the Montreal Protocol. They find that the Protocol was compatible with a model of voluntary provision of a pure public good, therefore, the Montreal Protocol did not lead countries to engage in emissions reduction policies stronger than their business-as-usual scenario.

Some other quantitative studies related to different IEAs lead to the same results and they give force to the branch of economic literature that supports the non-cooperative nature of IEAs.

Nevertheless, some studies on Kyoto Protocol, the first IEA with binding abatement commitments, evidence was in favour for Cooperation outcome. Anyway, a recent study by Almer and Winkler (2017) apply to the Kyoto Protocol a synthetic control method in other to face the difficulties identified by Ringquist *et al.*(2005). Their results confirm that the participation to the Protocol did not lead Annex B countries to adopt mitigation measures significantly different from their counterfactuals.

I therefore focus on the Paris Agreement, which represents the largest multilateral coalition for Climate Change mitigation in the history of Environmental Agreements. The analysis proposed in chapter 3 demonstrates that the Paris Agreement's NDCs cannot be considered as a mere voluntary contributions to GHG abatement because there is not conclusive statistical evidence to confirm a linear relationship between Income and Emission abatement. Anyway, even if we can exclude that the Agreement is a pure Nash equilibrium -at least in its early stage- it is not possible to conclude that there is a full cooperative coalition.

Differently from the paper by Murdoch and Sandler (1997), the empirical strategy has been updated in order to take into account possible heteroskedasticity in the error terms and collinearity between Income and population size.

Furthermore, from a game theoretic perspective, each player chooses the best strategy based on the set of current and past information available. Since the Paris Agreement in its early stage has the information about the national emission-reduction commitments and the official emission projections for the target year, in the second part of the paper, I define an empirical and theoretically agnostic approach in order to identify the potential cheaters of the Paris Agreement and the socio-economic variables that affect the probability of being a potential cheater.

For Low Cheating, Environmental Activism and GDP *per capita* have a positive impact on the probability of being a potential cheater and it can be interpreted as a sign for a possible "disillusion effect" due to the several failures in Environmental Governance. On the contrary, keeping everything constant, countries who suffered more from natural disaster and received financial aid from the Global Environmental Fund, are less likely to defeat from the commitment.

Going from Low Cheating to Medium Cheating and High Cheating brings a systemic inversion in signs that should be further investigated. In the medium and high scenario, results show that an instantaneous change in GDP *per capita* reduces the probability of being a potential cheater by up to 63% in the extreme scenario. It implies that richest countries are less likely to widely defeat from their commitment. Moreover, average marginal effects of location and level of freedom are negative and significant and confirm previous literature.

When the relative target deviation rate is above 50%, countries with autocratic governments and/or with less freedom, are more likely to be potential cheaters. This result confirms the theory by Congleton (1992) for which autocracies are less concern on environmental protection.

Then, I could predict the probability of being a potential cheater for all the Paris Agreement Member States. It shows up that the Top 20 potential cheaters in the case of "Low Cheating" are mainly EU members and countries who have very low actual emission levels. The implications are twofold: from one hand, sharing a common emission target in a sub-group of the coalition seems to be unfeasible due to structural differences among the countries involved. On the other hand, high emission-reduction targets committed by countries who enjoy low air pollution and low GHG emissions, look unrealistic and push the probability of cheating very high (up to 74%).

For the last two scenarios, many countries ranked as "Partial Free" and/or "Non-Free" appear in the Top-20 list and many of them belong to OPEC. Nevertheless, no evidence has been found for a significant correlation between being part of the OPEC and the probability of cheating.

Finally, policy implications derive from the analysis: Financial Aid for Climate Change adaptation could be a useful tool in order to compensate damaged countries and to bring stability to the coalition. Moreover, common emission-reduction targets could be read by third countries as a clue for potential cheating and could affect the final outcome of the Agreement. Furthermore, this methodology could be implemented in the future in order to help countries to better determined their strategies and emission-reduction commitments.

The most important contribution of this analysis is that, to the best of my knowledge, this is the first empirical assessment of the cooperative nature of the NDCs. Moreover, I provide an empirically-based and theoretically-agnostic methodology in order to forecast potential defeaters in IEAs. This methodology could be used to enhance current economic theory of International Agreements and help the design of future treaties.

Clearly, the study presents some drawbacks that are summarized as follows:

- The analysis is based only on national commitments and current projections for the target year. It is important to replicate the study once the Paris Agreement expires in order to confirm or reject the results I obtained.

- Evidence shows that NDCs are not compatible with the model of Voluntary Provision of a pure public good but I cannot exclude that other game-theoretical models could fit the Paris Agreement.

- For future research, given the limited number of observations, it could be very interesting to investigate this phenomenon by using other econometric techniques, in particular, it would be useful to assess the probability of being a potential cheater using semi-parametric techniques.

- The definition of "cheating" can be addressed in several ways. I chose the one that could better fit the present situation of the Paris Agreement without making any theoretical assumptions. For this reason, in my future research projects I will test for different specification of "cheating" and I am currently working on possible spatial-dependency among the probabilities of being a potential cheaters[1].

In chapter 4, I proceed with the assessment the socio-economic and political drivers of PV deployment in Italy under its most important RES incentive mechanisms, *Conto Energia*, using a spatial econometric approach.

The geographical visualization of the number of PV installed under the *Conto Energia* until 2011 confirms that the Italian FiT mechanism managed to boost PV deployment among Italian cities.

Anyway, the city-level spatial pattern of PV shows a significant clustering, especially in the Northern cities, characterized by higher income and better institutions. This leads to the need to better investigate the socio-economic determinants of PV deployment by keeping a spatial perspective.

Results, from both the SDM and the SARAR, show that income has a strong and positive impact on PV deployment. Indeed, the richest cities in Italy are located in the North and, since solar irradiation is mainly concentrated in the South, this is a signal of a possible economic distortion, more precisely, this incentive scheme shows a regressive outcome.

This claim is further supported by the fact that cities with several households who own on average more than one flat/ house, register a higher number of PV installations.

Being the owner of more than one dwelling is, of course, a proxy for the level of wealth.

Important policy implications derive from this result. First, it is possible that the design of this incentive mechanism leads to economic distortions and income inequalities.

Moreover, *Conto Energia* provides the incentives only for the owners of the roofs where the PV should be installed. Tenants are not included in the mechanism and this determines: 1) a disempowerment of the final impact of the policy; 2) an incentive taken by the richest percentile of the population.

Surprisingly, having a large share of foreign residents determines higher diffusion of PV. It would suggest that "green behaviors" are somehow imported by foreign culture. This is also confirmed by the fact that education and women share have not a positive and significant impact.

The two models also show that there exists positive and significant spatial spillover effects. It means that neighbour cities engage imitative behaviors among each others. This issue could be very useful for future policy interventions.

Furthermore, the analysis suggests that political parties do not really matter in the pattern of PV deployment. Anyway, a slightly positive impact is associated to cities whose administration is held by the center-right coalition. Since the bureaucratic procedure to obtaining the incentives passes through the national Agency ENEA, a possible interpretation for this positive effect could rely on a "nepotism effect" of the national government on local authorities that somehow facilitate PV deployment at the city-level.

[1] The research question is the following: Does the probability of being a potential cheater of country i change if its neighbour j has a high probability?

This interpretation is further supported by the fact that, at that time, center-right coalition did not have particular concerns on environmental sustainability and ecology.

The main contribution of this study is the inclusion of the role of the political parties in the spatial analysis of Italian PV deployment at the city level[2]. The adoption of Italian cities as spatial units determines more accurate and consistent results.

To summarize, future design of renewable incentive mechanisms should take into account:

- Possible economic distortions related to income inequality;
- The possibility to extend the incentives to tenants;
- Positive spatial spillovers that could be further enhanced;
- The role of the national government in the local diffusion of PV. Delocalizing the incentive providers could help PV deployment at a local level.

[2]Similar studies in the literature use different and larger spatial units like provinces or regions and do not account for political parties together with other socio-economic variables, at least for the case of Italy

Appendix A

Appendix Chapter 3

TABLE A.1: OLS estimation for Paris Agreement, $g_i > 0$

	Dependent variable:			
	DEMIT			
	(1)	(2)	(3)	(4)
GDP	0.00175***	0.0066***	0.0070***	0.0062***
	(0.0273)	(0.01936)	(0.01965)	(0.01986)
Population		0.00229***	0.00226***	0.00229***
		(0.00164)	(0.00167)	(0.00166)
Partly Free			−90.776	−103.720
			(67.759)	(67.481)
Free			−102.975	−148.348**
			(62.949)	(65.633)
Tropics				−122.545**
				(56.527)
Southern Hemisphere				−30.030
				(72.874)
Constant	31.062	−33.133	43.911	131.874*
	(38.610)	(25.373)	(52.649)	(66.883)
Observations	138	138	138	138
R^2	0.233	0.682	0.689	0.700
Adjusted R^2	0.227	0.677	0.679	0.686
Breusch-Pagan test	14.449***	130.63***	130.98***	131.02***
Note:				*p<0.1; **p<0.05; ***p<0.01

TABLE A.2: Box-Cox Transformation: HDI

	Dependent variable:
	DEMIT
GDP_{transf}	0.000105***
Population	0.000022***
Partly Free	-103.3*
Free	159.3*
Tropics	-114.8**
Southern Hemisphere	-23.6
Constant	89.344
λ	0.965***
$CI^{\lambda}_{0.95}$	[0.460; 1.470]
Observations	138

*** p<0.01, ** p<0.05, * p<0.1

TABLE A.3: Average Marginal Effects: Ordered Logit Model

Variable	Low Cheating	Medium Cheating.	High Cheating
EA_{index}	0.52**	-0.19**	-0.33*
	(0.398)	(0.165)	(0.249)
GDP_{pc}	0.72***	-0.17	-0.59***
	(2.841)	(1.32)	(1.68)
AID	-0.0036***	0.73***	0.299***
	(0.0017)	(0.00692)	(0.000689)
Total Damage	-0.00531***	0.00194***	0.000337***
	(0.000348)	(0.0000145)	(0.0000223)
Partly Free	0.083	-0.027**	-0.055**
	(0.128)	(0.038)	(0.0935)
Free	0.063	-0.019*	-0.044**
	(0.12)	(0.34)	(0.93)
Tropics	0.14	-0.057*	-0.087*
	(0.103)	(0.019)	(0.088)
Southern Hemisphere	-0.069	0.008	0.061
	(0.103)	(0.019)	(0.088)
Observations	138	138	138

Robust Standard Errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1
All the predictors at their mean value

TABLE A.4: Ordered Logit: Predictive Margins with Confidence Intervals

Cheat	Margin	Conf. Int.	
Low (1)	0.41***	0.33	0.49
Medium (2)	0.38***	0.30	0.460
High (3)	0.20***	0.136	0.273

TABLE A.5: Average Marginal Effects: Multinomial Probit Model

Variable	Low Cheating	Medium Cheating.	High Cheating
EA_{index}	0.46**	-0.36**	-0.097*
	(0.478)	(0.470)	(0.403)
GDP_{pc}	0.80***	-0.75***	-0.76***
	(3.586)	(3.540)	(3.295)
AID	-0.00535*	0.025***	0.028***
	(0.0030)	(0.00225)	(0.000145)
Total Damage	-0.00342**	0.00204***	0.000546**
	(0.000348)	(0.0000145)	(0.0000223)
Partly Free	0.014	-0.18	-0.020**
	(0.124)	(0.120)	(0.121)
Free	0.0025	-0.18	-0.18**
	(0.125)	(0.121)	(0.119)
Tropics	0.043	-0.13*	-0.18*
	(0.115)	(0.109)	(0.095)
Southern Hemisphere	-0.26***	0.427**	0.165
	(0.114)	(0.128)	(0.115)
Observations	138	138	138

Robust Standard Errors in parenthesis
*** $p<0.01$, ** $p<0.05$, * $p<0.1$
All the predictors at their mean value

TABLE A.6: Multinomial Probit: Predictive Margins with Confidence Intervals

Cheat	Margin	Conf. Int.	
Low (1)	0.40***	0.32	0.48
Medium (2)	0.38***	0.31	0.458
High (3)	0.21***	0.146	0.275

TABLE A.7: Average Marginal Effects: Multinomial Logit Model

Variable	Low Cheating	Medium Cheating.	High Cheating
EA_{index}	0.47**	-0.39**	-0.078*
	(0.48)	(0.48)	(0.421)
GDP_{pc}	0.75***	-0.19	-0.56***
	(3.77)	(3.586)	(3.45)
AID	-0.0053***	0.265***	0.265***
	(0.00302)	(0.00225)	(0.000124)
Total Damage	-0.00356***	0.00133***	0.000489***
	(0.00061)	(0.0000581)	(0.000028)
Partly Free	0.085	-0.19**	-0.205**
	(0.127)	(0.125)	(0.129)
Free	0.0047	-0.189*	-0.185**
	(0.128)	(0.123)	(0.125)
Tropics	0.37	-0.13*	-0.17*
	(0.118)	(0.111)	(0.096)
Southern Hemisphere	-0.257*	0.41**	0.15
	(0.116)	(0.129)	(0.117)
Observations	138	138	138

Robust Standard Errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1
All the predictors at their mean value

TABLE A.8: Multinomial Logit: Predictive Margins with Confidence Intervals

Cheat	Margin	Conf. Int.	
Low (1)	0.40***	0.32	0.48
Medium (2)	0.38***	0.30	0.458
High (3)	0.21***	0.144	0.275

TABLE A.9: Results from Probit Model

	Dependent variable: $Cheat_i$		
	$\tau = 0.3$	$\tau = 0.5$	$\tau = 0.7$
	(1)	(2)	(3)
EAindex	2.039^{***}	1.359^{**}	1.147
	(0.469)	(0.656)	(0.913)
GDP_{pc}	0.056	0.022	-0.001
	(0.059)	(0.074)	(0.097)
AID2010	-0.021^{*}	-0.018^{*}	0.005
	(0.025)	(0.030)	(0.037)
Damage	0.048^{***}	0.054^{**}	0.041
	(0.018)	(0.025)	(0.033)
PF	0.018	-0.544^{*}	-0.117
	(0.262)	(0.320)	(0.393)
FREE	0.164	-0.388	-0.108
	(0.260)	(0.313)	(0.408)
Constant	-2.136^{***}	-2.296^{***}	-2.955^{***}
	(0.508)	(0.733)	(1.052)
Observations	236	236	236
Log Likelihood	-127.704	-80.217	-46.920
Akaike Inf. Crit.	269.408	174.434	107.840

Note: *p<0.1; **p<0.05; ***p<0.01

Appendix B

Appendix Chapter 4

TABLE B.1: SAR ML estimation

	Dependent variable:		
	Number of PV		
	(1)	(2)	(3)
Income	0.283***	0.270***	0.238***
	(0.037)	(0.038)	(0.040)
Population density	−0.117***	−0.119***	−0.123***
	(0.018)	(0.019)	(0.019)
Altitude	−0.091***	−0.091***	−0.087***
	(0.013)	(0.013)	(0.014)
Av. Dwellings per Household	0.139***	0.135***	0.135***
	(0.018)	(0.018)	(0.018)
Education Index	−0.378***	−0.372***	−0.370***
	(0.015)	(0.015)	(0.015)
City center	0.187**	0.207**	0.229**
	(0.093)	(0.100)	(0.094)
Women share		−0.959*	−0.976**
		(0.507)	(0.473)
Foreign share			0.038**
			(0.018)
Constant	−3.509***	−4.076***	−3.716***
	(0.364)	(0.469)	(0.496)
ρ	0.162***	0.163***	0.161***
Observations	8,094	8,094	8,094
σ^2	1.918	1.917	1.916
Akaike Inf. Crit.	28,289.310	28,287.370	28,284.550
Wald Test (df = 1)	101.066***	99.639***	99.999***
LR Test (df = 1)	97.579***	98.345***	96.646***
Note:			*p<0.1; **p<0.05; ***p<0.01

TABLE B.2: SARAR Estimation Results- GMM estimation

	Dependent variable:			
	Number of PV			
	(1)	(2)	(3)	(4)
Income	0.289***	0.277***	0.242***	0.283***
	(0.039)	(0.039)	(0.041)	(0.039)
Population density	−0.1324***	−0.134***	−0.138***	−0.140***
	(0.019)	(0.019)	(0.019)	(0.020)
Altitude	−0.091***	−0.091***	−0.085***	−0.089***
	(0.014)	(0.014)	(0.014)	(0.014)
Av. Dwellings per Household	0.138***	0.135***	0.135***	0.136***
	(0.018)	(0.018)	(0.018)	(0.018)
Education Index	−0.389***	−0.383***	−0.381***	−0.407***
	(0.015)	(0.015)	(0.015)	(0.015)
City center	0.182	0.204*	0.226**	0.188
	(0.097)	(0.098)	(0.099)	(0.127)
Women share		−0.972*	−0.913*	
		(0.504)	(0.501)	
foreign share			0.046**	
			(0.018)	
Constant	−3.948***	−4.532***	−4.154***	−4.079***
	(0.421)	(0.514)	(0.535)	(0.450)
C-Right				0.187***
				(0.049)
C-Left				0.110**
				(0.051)
Civic Lists				0.011
				(0.978)
Independentists				−0.172
				(0.988)
ρ	0.043***	0.042***	0.032*	−0.020
λ	0.162***	0.161***	0.170	0.213***
Observations	8,094	8,094	8,094	8,094
Note:	*p<0.1; **p<0.05; ***p<0.01			

TABLE B.3: Impact measures for SARAR model -GMM estimation

	Direct	Indirect	Total
Income	0.29***	0.01	0.30***
Population density	-0.13***	-0.01	-0.14***
Altitude	-0.09***	-0.00	-0.10***
Dwelling per household	0.14***	0.01	0.15***
Education Index	-0.39***	-0.02	-0.41***
CITY CENTRE	0.18	0.01	0.19
C-Right	3.183395***	2.990141***	3.183961***
C-Left	1.283780	1.264304	1.283571
Civic Lists	3.277434	3.076926	3.275348
Independentists	-1.0258	-0.0932	-1.119