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Effectiveness of the European Union Emission Trading System in reducing carbon dioxide emissions

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1. Introduction

The freedom of an enterprise to emit greenhouse gases is an example of market failure known as negative externalities. According to theory, the solution to this problem is to ensure that costs of emissions are taken into account in the decisions of companies emitting greenhouse gases (the so-called internalisation of externalities). In classical terms, it may be done by imposing a tax on entities generating negative externalities at a rate ensuring equalisation of marginal social benefits from emissions with marginal social costs generated by those emissions (see e.g. Pigou 1912, 1932).

Most often, two classes of instruments used to limit carbon dioxide emissions are distinguished in the literature: market instruments (including the so-called carbon tax, cap-and-trade and baseline-and-credit mechanisms)[1] and non-market instruments, based on regulatory restrictions (see e.g. Crocker, 1966; Dales, 1968; Baumol and Oates, 1971; Baumol, 1972; Montgomery, 1972; Duval, 2008; Aldy and Stavins, 2011; Mooij et al., 2012; Goulder and Schein, 2013)[2].

In 2005, the European Union Emission Trading System (hereinafter: EU-ETS), based on the theoretical concept of cap-and-trade mechanism came into force. In theory, cap-and-trade mechanism is characterised by high environmental effectiveness. However, its practical application in a complex socio-economic, institutional and regulatory environment led to its departure from theoretical solution in many areas (Matthes et al., 2005). The most important deviations of the EU-ETS from the theoretical cap-and-trade mechanism are:

- functioning of the EU-ETS in phases, between which significant changes of the rules of its operation may be introduced,

[1] Carbon tax is a tax imposed on energy resources, the combustion of which is associated with the emission of carbon dioxide. It can be imposed at different stages of the life cycle of these resources (e.g. extraction, import, combustion).

In the cap-and-trade mechanism used for controlling of carbon dioxide emission, regulator sets a limited number of special certificates which act as emission allowances. These certificates are then transferred to the entities covered by the mechanism, where they can be freely traded.

In the baseline-and-credit mechanism, regulator sets a base path for emission levels, usually specific for specific entities or projects. Entities whose actual emissions turn out to be lower than this path receive certificates that can be sold to entities that have emitted more than the baseline. Entities with emissions higher than the baseline are obliged to surrender certificates for the excess emissions.

[2] There are also voluntary mechanisms, which do not require intervention by the regulator, but their importance in reducing of carbon dioxide emissions is negligible. Therefore, they were not discussed in detail in the thesis.

- geographically limited scope of the system in pair with the global nature of emissions subject to limitation[3],
- free allocation of emission allowances for many sectors, introduced mainly to reduce the costs of the system for covered installations and to lower the risk of carbon leakage outside the EU-ETS system[4],
- complicated allocation mechanism leading to the increase of administrative and transaction costs of the system,
- lack of transparency of the regulatory process.

Numerous deviations of the EU-ETS from theoretical concept of cap-and-trade mechanism, combined with a strong sensitivity of the EU-ETS to external factors (e.g. current macroeconomic situation), may have distorted price signal of emission allowances and led to significant reduction of environmental performance of the EU-ETS. This issue is the subject of my dissertation.

The dissertation fits into at least three threads of the literature.

The first concerns the broad concept of externalities and theoretical methods of their internalisation, starting from classic solutions (e.g. Sidgwick, 1883; Marshall, 1920; Pigou, 1932) to more contemporary ones (e.g. Coase, 1960; Buchanan, 1969; Barnett, 1980).

The second concerns the complexity of the problem of internalisation of externalities in the area of carbon dioxide emissions and limitations of model-based solutions (see e.g. Baumol and Oates, 1971; Haites, 1991; Goulder and Pizer, 2006; Stern, 2008; Duval, 2008; Jamet and Corfee-Morlot, 2009; Mooij et al., 2012; Nordhaus and Sztorc, 2013).

[3]It is often pointed out that under such conditions the mechanism should not cover installations that produce emissions, but rather the consumption of carbon-intensive products (see e.g. Afionis et al., 2017). In that solution, the mechanism affects domestic installations emitting carbon dioxide to a lesser extent, as it is limited only to that part of their production which is related to products consumed within a geographical boundaries of the system. On the other hand, such mechanism covers imported products as well, and thus also carbon content external to geographical boundaries of the system embodied in these products. Moreover, such mechanism may be calculated for emissions resulting not only from the production process, but also from the transport of products to final consumers. The key drawback of such solution is the need to establish a complex system for monitoring of the carbon content of products covered by the mechanism.

[4]Carbon leakage occurs when regulations limiting emissions lead to a transfer of production from the area covered by those regulations to the area where such regulations do not exist or are less restrictive (Summerton, 2010; Kiuila et al., 2016). This transfer may be direct (a company decides to close a factory in one place and open it in another) or indirect (due to regulation, the competitiveness of companies covered by the system decreases, which leads to their gradual crowding out by external entities not covered by similar regulations). The main cause of the carbon leakage risk in the EU-ETS is the limitation of its geographical coverage. This shows that a single deviation from theoretical concept often creates undesired effects that have to be counteracted which further deviations for the model solution.

The third includes papers focusing on empirical assessment of the environmental performance of selected methods of carbon dioxide emissions reduction (see e.g. Convery, 2009; Martin et al., 2010; Wrake et al., 2012; Laing et al., 2013; Martin et al., 2016). In this context, it is worth noting that while before the start of the EU-ETS as well as in its first few years of operation, the assessment of environmental effectiveness of the system had been a topic often discussed in the literature, it has not received much attention since then. My dissertation, which analyses the environmental performance of the EU-ETS in the years 2005-2016, fills this gap. In addition, much of the research, especially that carried out in the first three years after the system was launched, was based on very simplified and imperfect research methods. That created a significant risk of drawing wrong conclusions from the results obtained. For example, many studies did not adequately control the impact of current economic situation on emissions. The approach used in my dissertation to a large extent takes these often overlooked or ignored aspects into account.

2. Purpose of the dissertation and research hypotheses

The main objective of the dissertation was to verify the thesis that the EU-ETS had not been an effective mechanism for carbon dioxide emission reduction in the countries and sectors belonging to the system in the years 2005-2016. In order to verify this thesis, four supporting hypotheses were introduced. They were defined in such a way, that their potential rejection supported the validity of the main research thesis:

1. In the years 2005-2016, the EU-ETS generated significant incentives for the emitters to reduce their carbon emissions during periods of severe economic downturn.
2. The EU-ETS is very similar in its design to the theoretical concept of cap-and-trade mechanism.
3. The potential deviations of the EU-ETS from theoretical concept of cap-and-trade mechanism did not have any negative impact on its environmental performance in the years 2005-2016.
4. In the years 2005-2016, the EU-ETS contributed significantly to the reduction of carbon dioxide emission in the covered installations.

3. Structure of the dissertation

The dissertation consists of an introduction, five chapters and a summary.

The first chapter discusses the economic literature on the theory of greenhouse gas emissions reduction. Starting from the classical theory of externalities, this chapter discusses theoretical concepts for the internalisation of externalities in the area of carbon dioxide emissions, i.e. regulatory approach and various solutions within the market approach. Special attention was paid to the theoretical foundations of emission trading schemes.

The second chapter presents the history and the background of EU-ETS introduction. It discusses the first years of the common environmental policy, the concept of carbon tax introduction in the 1990s and the impact of the United Nations Framework Convention on Climate Change and the 1997 Kyoto Protocol for a change in the approach to carbon dioxide emissions reduction in the Community.

The third chapter discusses the characteristics of the EU-ETS and its deviations from the theoretical cap-and-trade model. It also identifies the potential impact of these deviations on the environmental performance of the scheme. The analysis considers, inter alia, the following aspects of the EU-ETS: its time coverage, including phasing, geographical and sectoral coverage, rules for the primary allocation of emission allowances, the link between the EU-ETS and other abatement mechanisms, its regulatory instability, and the role of the price of carbon allowance within the scheme.

Chapter four provides an overview of empirical studies analysing ex-post the environmental effectiveness of the EU-ETS. In the review, empirical literature was grouped based on two dimensions: the research method applied and the phenomenon measured.

In the first dimension, studies based on (i) the results of qualitative interviews and surveys, often carried out on small groups of enterprises covered by the system, and (ii) statistical and econometric studies, in which the assessment of the environmental performance of the EU-ETS system is made on larger samples, most often using secondary data from various sources, were distinguished.

In the second dimension, studies focusing on the impact of the EU-ETS on current emissions and studies assessing the impact of the scheme on investment in clean technologies, which are important for the long-term environmental effectiveness of the scheme, were distinguished.

Chapter five presents the author's own empirical study. It explains in detail and justifies the proposed research method and identifies and describes the data used in the study. Then, the estimation procedure used in the study is presented and the results obtained are discussed.

The conclusions of the conducted analyses are presented in the summary of the dissertation.

4. Research methods and findings

4.1. Research methods

To verify research hypotheses, a set of various research methods was used in the study:

1. Review and detailed analysis of theoretical literature on the internalisation of externalities, including the concept of cap-and-trade mechanism, with particular emphasis on the method of generating incentives to reduce emissions and the assumptions made in the model.

2. Critical assessment of the functioning of the EU-ETS so far, with a particular focus on the system's deviations from the theoretical cap-and-trade mechanism and their potential impact on the environmental performance of the system.

3. Review of empirical studies analysing ex-post the impact of the EU-ETS on current carbon emissions and on investment in clean technologies to reduce long-term emissions.

4. An econometric model using the *DD* class (difference-in-difference) estimator to assess the environmental performance of the EU-ETS in the years 2005-2016. The use of such estimator is a common practice in evaluation studies. In this method, two groups are distinguished: the experimental group, which is affected by a certain stimulus, and the control group, which is not affected by this stimulus. In addition, the period before the introduction of the stimulus and the period during which the stimulus operates is distinguished. Moreover, it is sometimes possible to extend the approach to other dimensions as well. In this study, it was possible to distinguish three dimensions: geographical (division into countries where the EU-ETS system operates and countries not covered by the system), time ("before" and "during"

the operation of the EU-ETS) and sectoral (division into sectors covered and not covered by the EU-ETS). Such three dimensional estimator is called *the DDD* estimator (difference-in-difference-in-difference). Inclusion of an additional dimension in the study enables better identification of potential differentiating factors for the analysed variable that are independent from the intervention.

The econometric model used in the dissertation took the following form:

$$Y_{itk} = \alpha + \gamma D_i + \delta P_t + \zeta S_k + \sigma D_i P_t + \varsigma D_i S_k + \tau P_t S_k + \rho D_i P_t S_k + X'_{it}\beta + \varepsilon_{it} \quad (1)$$

where:

Y_{itk} — annual dynamics of carbon dioxide emissions in the country i, year t and sector k;

D_i — binary variable that denotes the belonging of a unit (country) i to an experimental ($D = 1$) or control ($D = 0$) group. The variableD_i in the model takes the value of 1 for those countries included in the analysis that were covered by the EU-ETS as of 31.12.2016[5]. For the remaining countries included in the analysis (control group), variable D_i is equal to zero[6];

P_t — Binary variable that identifies the period before ($P_t = 0$) and during the intervention ($P_t = 1$). The variable P_t has a value of 0 for the years 1992-2004, i.e. the period before the introduction of the EU-ETS, and a value of 1 for the years 2005-2016, i.e. the period during which the EU-ETS operated.[7];

S_k — Binary variable identifying the sector not affected ($S_k = 0$) and the sector affected by the intervention ($S_k = 1$). The variable S_k takes a value of 0

[5] Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom. Due to the low quality of data, the following countries were excluded from the experimental group: Cyprus, Liechtenstein, Luxembourg, Iceland, Malta and Luxembourg.

[6] Australia, Belarus, Canada, Japan, Kazakhstan, New Zealand, Russia, Switzerland, Turkey, Ukraine and the United States.

[7] The sensitivity analysis also explored the option of excluding the first, pilot phase of the EU-ETS, i.e. years 2005-2007, from the intervention period.

for the transport sector, which is not covered by the EU-ETS[8] and a value of 1 for the energy sector, which is covered by the EU-ETS[9];

X_{it} control variables matrix[10];

β vector of estimated parameters for control variables;

ε_{it} error term.

α, γ, δ, ρ, ζ, τ , ρ and β are the parameters (vector of parameters in the case of β) estimated in the econometric model. In this model, the parameter ρ constitutes the *DDD* estimator.

4.2. Findings

The analysis of the theoretical cap-and-trade model, as well as of the EU-ETS's deviations from this model conducted in the dissertation, gives grounds to the rejection of the first supporting hypothesis in favour of the alternative, stating that during the slowdown, the EU-ETS did not provide significant incentives to reduce carbon emissions. In the theoretical cap-and-trade mechanism, the regulator specifies quantity of carbon dioxide emissions, and the price of emission allowance is a consequence of the imposed quantity. In the theoretical model, the current economic situation has no impact on the quantity of available allowances. In effect, during a slowdown, the fixed supply of emission allowances, combined with a strongly reduced demand for allowances, leads to a decrease of emission allowance price and thus costs of emission for entities covered by the mechanism. Moreover, due to the possibility of allowance banking described in the dissertation, the weakened incentives to reduce emissions in the EU-ETS may be carried over to the period after the slowdown, only if the oversupply of allowances in the market was high enough. Such effect occurred during the third phase of the EU-ETS until 2017.

The second supporting hypothesis has been reviewed in Chapter 3. It identifies a number of deviations of the EU-ETS from the theoretical solution. These deviations include:

[8]UNFCCC nomenclature group 1.A.3, excluding subgroup 1.AA.3.A - since the EU-ETS covered the civil aviation sub-sector from 2012 onwards, this sub-sector was excluded from the analysis.

[9]UNFCCC nomenclature group 1.A.1. It consists of, inter alia, electricity and heat production, refining of crude oil and production of solid fuels. It should be noted that due to the design specificity of the DDD estimator, this variable also takes a value of 1 for the energy sector in countries not covered by the EU-ETS.

[10]The control variables in the study were: real annual GDP dynamics, level of GDP per capita, level of GDP per capita squared, annual dynamics of average air temperature, annual dynamics of standard deviation of monthly air temperature levels in a given year and real dynamics of crude oil and coal prices.

functioning of the system under imperfect competition, both on the product and the emission allowance market, limitations in the geographical, sectoral and time coverage of the system, the existence of uncertainty and incomplete information within the system, the co-existence of the EU-ETS with other regulations affecting emissions, the method of emission allowances allocation, EU-ETS's complexity, and its connections with mechanisms applied in other countries. On this basis, the second supporting hypothesis should be rejected in favour of the alternative, stating that the EU-ETS is characterised by a number of deviations from the theoretical cap-and-trade model.

In addition, as shown in Chapter 3, some of the identified deviations of the EU-ETS from the model solution may have had a negative impact on its environmental effectiveness. The division of the EU-ETS into phases creates incentives for market participants to act in an unexpected way as compared to the model solution through intertemporal optimisation of emissions and the number of emission allowances hold. Limiting the geographical coverage of the system creates a risk of carbon leakage outside the area of its operation, leading only to apparent reduction of emissions. The still functioning (although to a decreasing extent) rules for free, primary allocation of allowances to installations generate incentives for excessive emissions (in the case of allocations based on historical emissions), the formation of interest groups within the system, as well as for obtaining unjustified profits by some installations (so called windfall profits). The environmental performance of the scheme is also weakened by the fact that there are other regulations in place aiming to achieve similar objectives in the countries and sectors covered by the EU-ETS. These regulations lead, *ceteris paribus*, to reduction of emission allowance price under the EU-ETS. Finally, high volatility of regulatory framework of the EU-ETS generates high uncertainty among its participants, making decisions to invest in low-emission technologies more difficult. Based of these observations, a third supporting hypothesis should be rejected in favour of an alternative, stating that at least some of the identified deviations of the EU-ETS from the theoretical cap-and-trade mechanism had negative impact on the environmental performance of the scheme.

The fourth supporting hypothesis has been verified by reviewing the empirical literature on the impact of the EU-ETS on carbon emissions summarised in Chapter 4 and the own study described in Chapter 5.

Conclusions from the review of empirical studies are not conclusive. Studies focusing on the first period of EU-ETS operation (and often even its first year of operation) have shown the emission reduction effect. However, most subsequent studies have not noted this effect anymore, suggesting that after 2008 the main factor influencing carbon emissions was the current economic situation. In this context, one should bear in mind the often

inadequate approach to controlling exogenous factors (including the economic situation) in the research developed in the early years of the EU-ETS.

In the own study, on the basis of empirical data for the years 1991-2016, with the use of DDD estimator, the impact of the EU-ETS on annual dynamics of carbon dioxide emissions was estimated. Table 1 summarises the results of binary variable estimation for models built for a complete set of variables[11]. A number of interesting conclusions can be drawn from the results of the modelling exercise.

Firstly, during the entire period under review (1992-2016), the dynamics of carbon dioxide emissions in the countries belonging to the experimental group (i.e. countries which, as at the end of 2016, belonged to the EU-ETS) did not differ significantly from the dynamics of emissions in the countries from the control group. Secondly, the variables P_t and S_k were also statistically insignificant. Thus, in the case of the whole set of countries analysed, there was, on average, no significant difference in the carbon emission dynamics before and after the introduction of the EU-ETS nor between the energy and transport sectors. Thirdly, the variable D_iS_k was statistically significant in all model specifications analysed. The estimated parameter for this variable (-0.0250) suggests that the energy sector in the experimental group showed, on average, lower emission dynamics than the energy sector in the control group and the transport sector in both groups.Fourthly, the variable P_tS_k was also statistically significant in all model specifications[12]. A negative sign of the estimated parameter for this variable (-0.0231) indicates that after 2005 the emission dynamics in the energy sector was on average 2.31 percentage points lower than in this sector before 2005 and in the transport sector in the whole period under review. It should be stressed, however, that this observation concerns the whole sample, i.e. both the experimental and the control group countries. This effect cannot therefore be interpreted as a consequence of EU-ETS introduction.

[11] The study also included models with a reduced number of variables. Unless stated otherwise, the conclusions from the analysis for reduced models were similar to the conclusions from models based on a full set of variables discussed here.

[12] Although not for the significance level of 95% (the p statistic ranged from 0.078 to 0.088, depending on the model specification).

Table 1: Results of binary variable estimation in models with all variables.

Explanatory variable: $d\_emissions_{itk}$	**Pooled OLS** (1)	**RE** (2)	**Huber-White Pooled OLS** (3)
D_i	0.0100	0.0100	0.0100
	(0.008)	*(0.008)*	*(0.008)*
	[0.211]	[0.210]	[0.210]
P_t	0.0039	0.0039	0.0039
	(0.009)	*(0.009)*	*(0.010)*
	[0.676]	[0.676]	[0.686]
S_k	0.0057	0.0057	0.0057
	(0.010)	*(0.010)*	*(0.011)*
	[0.565]	[0.565]	[0.587]
D_iS_k	-0.0250**	-0.0250**	-0.0250**
	(0.011)	*(0.011)*	*(0.012)*
	[0.026]	[0.026]	[0.037]
D_iP_t	-0.0214*	-0.0214*	-0.0214**
	(0.011)	*(0.011)*	*(0.011)*
	[0.053]	[0.053]	[0.045]
P_tS_k	-0.0231*	-0.0231*	-0.0231*
	(0.013)	*(0.013)*	*(0.014)*
	[0.078]	[0.078]	[0.088]
$D_iP_tS_k$	0.0187	0.0187	0.0187
	(0.016)	*(0.016)*	*(0.016)*
	[0.230]	[0.230]	[0.242]

Estimates based on a sample of 1,742 observations. The table does not include the results of estimation for control variables and the constant in the model.
Source: Own calculations.

The most important variable in the model was the variable $D_iP_tS_k$, which was the DDD estimator. This variable turned out to be statistically insignificant in all model specifications (the p statistic ranged from 0.230 to 0.242). This means that the EU-ETS did not have a significant impact on carbon emission dynamics in the energy sector between the years 2005-2016 in the countries from the experimental group[13]. This conclusion was also held for the model built during the robustness analysis, where the start of the intervention was moved from the year 2005 to 2008[14]. Therefore, the results of the own study indicate that the fourth supporting hypothesis should be rejected.

[13]It should be noted that during the period under examination, the EU-ETS rules for the energy sector were more restrictive than for other sectors covered by the system.

[14]The purpose of this model was to check whether the results would have been affected by the removal of the first phase of EU-ETS from the intervention period, which in fact was a pilot phase with a relatively large supply of emission allowances and a very large share of their free allocation, including for the energy sector.

The results of the analyses summarised above confirm the validity of the main thesis of the dissertation: in the years 2005-2016, the EU-ETS was not an effective mechanism for reducing of carbon dioxide emissions. Confirmation of the main thesis of the study indicates that the implementation of the cap-and-trade mechanism in the European Union and the economic conditions in which the system operated in the years 2005-2016, significantly worsened its environmental performance.

5. Conclusions for the literature and economic policy

This dissertation complements the literature of the subject in several areas.

Firstly, the research describes in detail the theoretical model of the emission allowance trading system, with particular emphasis on the channels of the system's impact on emissions and the role of the emission allowance price in shaping the incentives to reduce emissions within these channels. The distinction of the above channels together with the analysis of the significance of price signals in the individual channels constitutes the author's own contribution to the literature on the subject.

Secondly, the paper contains an in-depth analysis of the EU-ETS system's deviations from the model solution based on the cap-and-trade mechanism. Available papers contain a partial analysis of selected aspects of the high complexity of the EU-ETS system as compared to the theoretical model, however, to the author's knowledge, this issue has not been the subject of a comprehensive research so far.

Thirdly, the paper systematises empirical literature examining ex-post the impact of the EU-ETS system on carbon emissions. To the author's knowledge, to date there have been few studies containing a comprehensive review of the literature on the environmental performance of the EU-ETS system[15]. The available studies focus mainly on the summary of research results, without an in-depth analysis of the research methods applied. The dissertation fills this gap by indicating the limitations of the techniques used, and in some cases even by questioning the reliability of the estimates obtained.

Fourthly, the method of self-study used in the dissertation avoids many errors that have appeared in previous works. In particular, by using the DDD estimator, to a greater extent than in the case of many other techniques, it was possible to identify the true impact of the EU-ETS functioning on the dynamics of carbon dioxide emissions. Thus, this study is an

[15] These include, among others, the works by Convery (2009), Martin et al. (2010), Wrake et al. (2012), Lainga et al. (2013) and Martin et al. (2016).

important contribution to the literature examining ex post the environmental performance of the EU-ETS.

An important conclusion for the economic policy from this thesis is that the practical implementation of mechanisms that have so far existed mainly in theoretical terms is extremely difficult, and the model solution, by its very nature, is unable to take into account the complexity of environment in which it is to operate. This leads to the necessity to accept many deviations of the practical solution from the theoretical concept, with further consequences of those deviations.

According to the dissertation, a large part of consequences of EU-ETS deviations from the model solution was not foreseen at the time of mechanism introduction. As a result, it was indispensable to respond to problems observed on an ongoing basis and to make numerous changes to the operating conditions of the system during its existence. This, in turn, led to a further reduction in the effectiveness and efficiency of the mechanism.

Since the beginning of 2019, the EU-ETS has been equipped with the Market Stability Reserve, which is intended to reduce part of the problems identified in the dissertation. In particular, by making the supply of emission allowances more flexible, the market stability reserve is intended to increase the stability and predictability of allowance prices, which should foster the long-term environmental performance of the system. Nevertheless, it should be stressed that the structural reforms introduced have not eliminated all the shortcomings of the EU-ETS described in the study. Moreover, the changes introduced (including the market stability reserve) also constitute a deviation from the model solution on their own and their potential consequences have not yet been fully analysed. In particular, future studies should devote significant attention to an in-depth analysis of the consequences of a Market Stability Reserve in the EU-ETS, including its impact on the environmental effectiveness of the mechanism.

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