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Emissions Trading for Cleaner Production in the Old and New EU Member States? *

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Abstract: *This paper examines the success of the European Union Emissions Trading System (EU ETS) in inducing cleaner production in the EU based on the first two trading periods. It fills a literature gap by constructing a measure of clean production and conducting an ex-post macro-level analysis of the EU ETS impacts in EU15 compared to EU12. Results of panel regression analysis robustly show that EU ETS in both EU12 and EU15 (i) has positive impact on clean production of regulated industries, (ii) does not induce spillovers of cleaner technologies and processes to non-regulated industries, and (iii) does not affect clean production at the national level. In addition, share of renewables in energy consumption has a positive and crisis a negative impact on the clean production. Results support further tightening and broader coverage of EU ETS regulation and provision of funds from the EU ETS for development of renewable energy technologies.*

Keywords: EU ET; Member States; greenhouse gas emissions; clean production; panel regression analysis

JEL Classification: Q52

Introduction

Stopping the climate change is in the focus of the European Union (EU) and its Member States. In 2005 European Union Emissions Trading System (EU ETS) was put in place in a hope to achieve emission reductions agreed by Kyoto protocol. This new system, now in its third phase, represented the first multinational cap-and-trade system of greenhouse gases (GHG) abatement in the world. The functioning and the achievement of its goals, including the analysis of its additional side effects is of great interest not

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only for the researchers but also for the governments and environmentalist groups since the management of the environment and the natural resources is of the utmost importance for the future economic growth of the societies around the world. (Koncul, 2009)

The goals of the EU ETS can be summed up into two broad goals. The system is expected, first, to ensure the reduction of GHG emissions, and secondly, to ensure that this reduction is achieved at minimum costs for regulated economies. The first goal is quite straightforward. The second goal includes various aspects of economic impacts, such as effects on production, competitiveness, innovation, productivity etc. At the same time, as an additional condition for the EU ETS, it is expected to be fair, i.e. it is expected that the developed countries of the EU bear higher costs of reducing GHG emissions than the countries that were less developed countries of the EU in the period of the establishment of the EU ETS[1]. The aim of this paper is to evaluate the success of the EU ETS in achieving these goals by researching if the EU ETS leads to cleaner production processes in the EU countries and whether there are differences in its effects in the EU12 versus EU15 countries.

Theoretical analysis of carbon trading as an instrument of GHG abatement policies are numerous, and so are empirical ex ante analyses, based mostly on computable general equilibrium (CGE) models. They, however, do not provide an answer to the question whether currently implemented EU ETS is effective at reaching its goals. This requires ex post econometric studies. Martin et al. (2015) provide a thorough literature review of the topic of interest for this paper. Namely, they survey literature that conduct ex post studies of the impacts the EU ETS has so far had on three variables: carbon dioxide (CO_2) emissions, economic performance (including competitiveness) and innovation. These ex post studies are still relatively few, which is mostly due to the lack of suitable data. Still, this represents the fast growing branch of literature on EU ETS (Martin et al., 2015).

Research regarding the effectiveness of EU ETS to achieve emission reductions suggests that EU ETS was successful at decreasing GHG emissions. These results prove to be robust for both energy and industry sectors in the EU (Martin et al., 2015). Despite having some obvious initial design issues (Betz and Sato, 2006), Laing et al. (2014) find that the EU ETS led to an average decrease in CO_2 emissions by 40 to 80 million tons per year, or 2–4% of the total capped. Bel and Joseph (2015) also showed that EU ETS contributed to the abatement during the financial crisis (although, as they state, the biggest share of abatement in this period was due to the effects of the economic crisis).

Whether EU ETS had a negative impact on the regulated sectors' economic performance is researched in several papers. According to Martin et al. (2015) the research mostly doesn't show that EU ETS had negative effects on regulated entities, although, as they point out, the studies and the results are fairly heterogeneous. Namely, power companies seem to have profited from freely allocated allowances, while the results for manufacturing sector are not robust.

Ideally, however, EU would want EU ETS to induce green innovation and a substitution process which would lead to both an increase in industrial production and a decrease in GHG emissions at the same time. Alternatively said, it would prefer to see an increase in the cleaner industrial gross value added due to environmental regulation in question. Positive role of renewable energy sources and greater energy efficiency in emissions reductions is established in the literature. Huisingh et al. (2015) provide an extensive literature review that shows that improvements in energy efficiency, alternative carbon emissions reduction approaches and implementation of more renewable-energy based systems are the most effective approaches to achieve carbon emissions reductions in different sectors at different scales. What is needed are the appropriate policy interventions to encourage these changes in production processes. The previous research indicates that there was an increase in innovation partly caused by the EU ETS (Martin et al., 2015) which in turn induces a transition to a low-carbon sectoral innovation (Rogge and Hoffmann, 2010). Naturally, these results make us question the spill-over effects of EU ETS on the entire industries and wider.

The impacts of the EU ETS on economic performance and GHG emissions were so far mainly analysed ex post and almost exclusively on micro-level data, potentially ignoring spill-over effects on the entire industries and entire EU economies. Acknowledging the possibility of innovation-led substitution and spill-over effects, there is a hope cleaner industries and industrial processes are replacing the dirty ones. Hence, there is a need to observe economic performance and emissions from a more aggregated perspective, which is what is done in this paper. This aggregated approach should allow for the capture of some indirect effects of EU ETS as well as direct. Also, analysing economic performance and GHG emissions jointly instead of separately might reveal some additional information. Namely, it might inform us on the changes in the cleanliness of production process induced by EU ETS. The measure constructed as a production per unit of GHG emissions will hence be used in this paper and referred to as a „clean production“. Increases in production per unit of emissions suggests cleaner production process i.e. increase in „clean production“. Additionally, there are so far no studies that compare these impacts of EU ETS in old and new EU Member States. Since their initial allocations were different, there is a gap in the literature that this paper also addresses.

Empirical Model

The empirical model used in the analysis is based on the profit maximization model with given product and production factor prices. When maximizing profits companies choose the optimal combination of production factors and the level of production. Formally,

$$\max_{q,z} pq - \sum wz \tag{1}$$

$$\text{s.t. } q = f(z) \tag{2}$$

$$\max_{z} pf(z) - \sum wz \tag{3}$$

where $\pi(p,w) = pq - \sum wz$ are profits, z is production factors' vector, w is a vector of their prices, and output is described as a function of production factors, $q = f(z)$, and p is the product price. Solution of this maximization problem is a vector of the optimal factor demands, $z*(p, w)$, and optimal output level, $q*(z*(p, w))$. Additionally, it is taken into account that the output of the production process is not only final products but also the GHG emissions. For this reason, output is defined as a production per unit of greenhouse gases, an indicator called "clean production" in the remainder of this paper. Furthermore, assuming that all companies are led by profit maximization in their decision-making, it is assumed that the amount of production factors used in the production process is exactly optimal, and the role of regulation of emission allowances is empirically analysed in an optimal production process.

The empirical model that is used to analyse the impact of regulation, as well as individual production factors on the cleanliness of the production process can be summarized as

$$\max y_{i,t} = \alpha + \beta \cdot ep_{i,t} + \gamma \cdot z_{i,t} + \delta \cdot x_{i,t} + u_{i,t} \tag{4}$$

where $y_{i,t}$ represents a growth rate of output per unit of emissions i.e. clean production, $ep_{i,t}$ represents the vector of regulation variables, $z_{i,t}$ is the vector of production factors' growth rates, $x_{i,t}$ vector of control variables, and $u_{i,t}$ is error term.

Increase of the clean production is manifested as an increase in production per unit of emissions and vice versa. Variable of regulation is represented by greenhouse gas emissions permits. In order to analyse the differences in the effects of regulation by emission allowances in the so-called old and new EU member states (EU15 and EU12), the model includes a dummy variable for slope that takes the value equal to one if the observed country is the old EU member state, and zero if it is one of the EU-12.

Data and Methodology

Data

The variables in the model are selected based on empirical model presented in the section 2. Series of spatial and temporal data are used for the EU Member States. The temporal range of data covers the period from 2005 to 2012, which corresponds to the first two phases of EU ETS. Spatial data include all Member States for the observed period, namely EU27.

Dependent variable of the model is clean production, i.e. production per unit of emissions. Production is represented by two variables - *GVAind* and *GDP10*. *GVAind* represents constant gross value added per capita in industry[2], in thousands of euro, chain-linked volumes, reference year 2005, at 2005 exchange rates, from Eurostat. *GDP10* is real GDP per capita, in millions of euro, chain-linked volumes, reference year 2010, at 2010 exchange rates, also from Eurostat. Emissions are represented by three variables – *GHGets*, *GHGenind* and *GHG*. *GHGets* are GHG emissions of EU ETS regulated industries (energy industries, manufacturing industries and construction and industrial processes and product use[3]) per capita from EEA. *GHGenind* are GHG emissions of energy and industrial sectors in tones of CO_2 equivalent per capita[4] from EEA. They cover the entire sectors of ETS covered industries to allow for the research into possible spill-over effects. *GHG* are total GHG emissions in tones of CO_2 equivalent per capita[5] from EEA. Accordingly, measures of clean production were derived by dividing the values of production by the GHG emissions: *GVAindGHGets, GVAindGHGenind* and *GDP10GHG*.

Regulatory variable of tradable emission permits is represented by total allocated emission permits in kt of CO_2 equivalent per capita for all stationary sources (*EUApc*) from European Environmental Agency (EEA). In order to allow for the difference in the effect of regulation in old and new EU member states, slope dummy variable for EU-15 countries was also included in the analysis (*EUApcdeu15*).

Theory based explanatory variables are labour, represented by number of employed per capita (*Lpc*) from Eurostat, human capital (*HC*) represented by enrolment in secondary education per capita from World Development Indicators (WDI) and physical capital represented by the net capital stock per capita at 2010 prices in billions of euro from Ameco (*Kpc*). Control variables used in the analysis are total factor productivity (*TFP*) from AMECO, electricity from renewables as a percentage of gross energy consumption (*RENEW*) from Eurostat and crisis dummy variable (*Crisis*).

Robustness analysis is undertaken using various additional variables. Above mentioned dependent variables are replaced by *GVAindVEUA, GVAindGHGenergy* and *GDP10CO2* respectively. *GVAindVEUA* is industrial gross value added per verified emissions in kt of CO_2 equivalent for all stationary sources (V*EUA*) from EEA, *GVAindGHGenergy* is industrial gross value added per GHG emissions from energy sector in thousand tons of CO_2 equivalent (*GHGenergy*)[6] from EEA and *GDP10CO2* is real GDP per ton of CO_2 emissions (*CO2*) from EEA. For the purpose of robustness analysis measure of physical capital *Kpc* is replaced by the share of gross fixed capital formation in GDP (*gfcf*) from Eurostat, measure of labour is replaced by the employment rate (*LR*) from Eurostat. Additionally, vector of production factors' growth rates from the empirical model is replaced by a vector of production factors' and product's prices. Price of labor is represented by the share of wages and salaries in GDP (*w*) from Eurostat, price of capital by net returns on capital stock (20101=100) (*r*) from AMECO and product prices by the inflation based on GDP deflator (*INFgdp*) from WDI.

All of the variables that were not stationary were modified according to the unit root test results. Specifically, *Kpc*, *gfcf*, *HC*, *r* and *w* proved to be I(1) and *Lpc* and *LR* I(2).

Finally, although not included in the regression analysis, the obtained results are discussed in the light of the world fossil fuel commodity prices published by IMF, namely Commodity fuel (energy) index which includes crude oil (petroleum), natural gas, and coal price indices.

Methodology

In accordance with the collected data for which there is spatial and temporal dimension, both of which are modest, static panel data analysis is used to analyse the impact of EU ETS on the cleanliness of production in the EU. Initially the tests of assumptions violations in the linear regression models were carried out, namely test for heteroscedasticity i.e. modified Wald test (Greene, 2000), autocorrelation (Wooldridge, 2002) and cross-sectional dependence (Breusch and Pagan, 1980, Friedman, 1937, Pesaran, 2004)[7]. Neither of cross-sectional dependence tests however could produce usable results due to data limitations, but it is assumed that the cross-sectional dependence for this EU data sample does exist. For that reason the analysis of the models was based on robust standard errors i.e. errors corrected for cross-sectional dependence, heteroscedasticity and autocorrelation with the help of Driscoll-Kraay estimators (Driscoll and Kraay, 1998) adjusted for unbalanced panels by Hoechle (2007).

The choice of the fixed or random effects models was based on the modified Hausman test (Hoechle, 2007) instead of standard Hausman test (Hausman, 1978)[8] due to suspected cross-sectional dependence. However, after deciding on the appropriate model by the modified Hausman test, the alternative model was used as the robustness check.

Unit root tests are performed on unbalanced panel data with Im–Pesaran–Shin (IPS) test (Im et al., 2003) or Fisher-type tests, specifically Augmented Dicky-Fuller (ADF) and Phillips-Perron (PP) unit root tests when IPS test wasn't applicable.

Results

The results of the analysis of the impact of the EU ETS on the "clean production" in the EU are summarized in the three tables below. Each table in addition to the main model's results presents a results of a robustness analysis as well. Robustness analysis consists of:

a) An alternative to fixed i.e. random effects model chosen by the modified Hausman test by Hoechle (2007)
b) Alternative measures of labor and physical capital[9]
c) Prices of production factors and inflation instead of quantities of factors of production[10]
d) Alternative measure of the clean production for each model

Three basic models are analysed. Model 1 tests the impact of EU ETS on the clean production of regulated industries approximated by *GVAindGHGets* variable, Model 2 focuses on the clean production of the entire sectors of the regulated industries approximated by *GVAindGHGenind* variable and Model 3 assesses whether there are significant impacts of EU ETS on the clean production at the national level represented by *GDP10GHG* variable.

Table 1 presents results of the Model 1 analysis, including the robustness check. The results show that the impact of a decrease in EUA's, i.e. stricter regulation, on the regulated industries' clean production is expected to be positive. Decrease in the allocation of additional EUA's is expected to increase their gross value added per unit of emissions, which is the desired outcome of the regulator. In addition, there is a robust evidence that there is no significant difference in the magnitude of this impact between EU15 and EU12 countries.

The analysis additionally shows a positive impact of the share of electricity from renewables in a gross energy consumption on regulated industries' clean production. This result is also very robust.

Crisis proves to have had a relatively robust negative impact on the regulated industries' clean production.

Table 1: Impact of EU ETS on Regulated Industries' Clean Production (Model 1)

	Model 1	Model 1a	Model 1b	Model 1c	Model 1d
VARIABLES	**dGVAindGHGets**	dGVAindGHGets	dGVAindGHGets	dGVAindGHGets	dGVAindVEUA
dEUApc	**-0.0069*****	-0.0075***	-0.0065***	-0.0065*	-0.0095**
	(0.0015)	(0.0018)	(0.0013)	(0.0027)	(0.0034)
dEUApcdeu15	**0.0211***	0.0090	0.0202*	0.0217	0.0241
	(0.0111)	(0.0058)	(0.0116)	(0.0248)	(0.0169)
dKpc	**-1.79e-06**	-8.05e-05*			0.0002**
	(4.17e-05)	(4.67e-05)			(6.32e-05)
dgfcf			-0.0018		
			(0.0040)		
ddLpc	**177.7**	96.73			326.7
	(273.6)	(266.8)			(258.0)
ddLR			0.0032***		

Table 1. Continued

	Model 1	Model 1a	Model 1b	Model 1c	Model 1d
VARIABLES	**dGVAindGHGets**	dGVAindGHGets	dGVAindGHGets	dGVAindGHGets	dGVAindVEUA
			(0.0011)		
dHC	**2.277***	3.102	1.915		2.483
	(1.146)	(2.980)	(1.124)		(1.930)
dr				8.92e-11	
				(7.66e-11)	
dw				-0.0027	
				(0.0056)	
INFgdp				-0.0001	
				(0.0017)	
dTFP	**2.31e-10**	3.95e-10***	2.27e-10	0	8.12e-10***
	(1.72e-10)	(1.14e-10)	(2.25e-10)	(1.32e-10)	(2.16e-10)
dRENEW	**0.0091*****	0.0106***	0.00961***	0.0088***	0.0186***
	(0.0011)	(0.0028)	(0.00224)	(0.0021)	(0.0027)
Crisis	**-0.0323*****	-0.0205***	-0.0342***	-0.0253***	-0.0100
	(0.0081)	(0.0049)	(0.0078)	(0.0051)	(0.0167)
Constant	**0.0309*****	0.0293***	0.0292***	0.0239**	0.0197
	(0.0050)	(0.0056)	(0.0033)	(0.0073)	(0.0144)
Observations	**153**	153	153	185	153
R-squared		0.105			
Number of groups	**27**	27	27	27	27
Country FE	**YES**		YES	YES	YES

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The results in the Table 2 reveal impacts of EU ETS on regulated sectors' clean production. So called regulated sectors consist of both regulated and unregulated industries. Most of them are however regulated by the EU ETS. The results show that there are significant and robust differences between EU15 and EU12 countries. While the impact of a decrease in total allocated EUA's on regulated sectors' clean production in EU12 is positive, it decreases the clean production in EU15. This result can be explained by the higher costs that regulated industries in the EU15 need to take on in accordance with the fairness principle of the Kyoto protocol.

Again, *dRENEW* is expected to have a positive and *Crisis* a robust negative effect on clean production.

Table 2: Impact of EU ETS on Regulated Sectors' Clean Production (Model 2)

	Model 2	Model 2a	Model 2b	Model 2c	Model 2d
VARIABLES	**dGVAindGHGenind**	dGVAindGHGenind	dGVAindGHGenind	dGVAindGHGenind	dGVAindGHGenergy
dEUApc	**-0.0057*** **	-0.0056***	-0.0050***	-0.0057***	-0.0074***
	(0.0010)	(0.0008)	(0.0009)	(0.0013)	(0.0012)
dEUApcdeu15	**0.0110*** **	0.0145***	0.0129**	0.0132	0.0094***
	(0.0015)	(0.0040)	(0.0056)	(0.0081)	(0.0022)
dKpc	**-5.46e-05*** **	-3.19e-05			-4.66e-05**
	(1.89e-05)	(2.80e-05)			(1.93e-05)
dgfcf			-0.0021		
			(0.00252)		
ddLpc	**177.6**	159.9			231.9
	(170.5)	(140.3)			(178.7)
ddLR			0.00241*		
			(0.00114)		
dHC	**2.038**	2.545**	2.326**		2.169
	(2.014)	(0.921)	(0.982)		(2.264)
dr				6.10e-11**	
				(0)	
dw				-0.0039**	
				(0.0013)	
INFgdp				-0.0008	
				(0.0010)	
dTFP	**3.21e-10*** **	2.39e-10**	2.69e-10***	8.06e-11**	5.11e-10***
	(9.36e-11)	(9.06e-11)	(9.34e-11)	(0)	(8.34e-11)
dRENEW	**0.0039*** **	0.0020*	0.0022***	0.0016	0.00392**
	(0.0013)	(0.0010)	(0.0007)	(0.0011)	(0.0019)
Crisis	**-0.0101** **	-0.0166**	-0.0177*	-0.0120*	-0.0104**
	(0.0047)	(0.0080)	(0.0088)	(0.0051)	(0.0049)
Constant	**0.0163*** **	0.0202***	0.0179***	0.0160***	0.0185***
	(0.0043)	(0.0031)	(0.0034)	(0.0029)	(0.0058)
Observations	**153**	153	153	185	153
R-squared	**0.155**				0.202
Number of groups	**27**	27	27	27	27
Country FE		YES	YES	YES	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Finally, Table 3 shows that there is no significant impact of EU ETS on clean production at the national level and this is true for both EU12 and EU15 countries.

The result is fairly robust. Namely, only Model 3b reports a significant impact of EU ETS[11].

Variable *dRENEW*, as shown in Table 3, has a consistent positive and *Crisis* consistent negative effect on the clean production at the national level.

Table 3: Impact of EU ETS on National Clean Production (Model 3)

	Model 3	Model 3a	Model 3b	Model 3c	Model 3d
VARIABLES	**dGDP10GHG**	dGDP10GHG	dGDP10GHG	dGDP10GHG	dGDP10CO2
dEUApc	**-9.280**	-11.11*	-11.04***	-1943	-11.23
	(5.605)	(6.219)	(3.153)	(8.623)	(9.264)
dEUApcdeu15	**-22.21**	-58.03**	-67.20	-15.56	-34.25
	(34.37)	(25.36)	(23.74)	(46.02)	(55.64)
dKpc	**0.0522**	-0.229*			0.0948
	(0.141)	(0.113)			(0.259)
dgfcf			13.93		
			-8705		
ddLpc	**812.266**	208.808			842.315
	(611.40)	(450.31)			(822.95)
ddLR			4.218		
			(3.019)		
dHC	**-6,599*** **	1,773	-6,641***		-9,145***
	(499.1)	(2.471)	(825.7)		(518.7)
dr				1.61e-07	
				(1.42e-07)	
dw				14.13	
				(13.36)	
INFgdp				7.276**	
				(2.212)	
dTFP	**2.52e-07**	4.54e-07	-1.93e-07	1.25e-07	4.02e-07
	(4.85e-07)	(3.25e-07)	(6.28e-07)	(3.11e-07)	(6.97e-07)
dRENEW	**35.85*** **	30.79***	38.02***	28.06***	58.44***
	(3.087)	(4.440)	(3.151)	(2.759)	(4.964)
Crisis	**-44.71*** **	-40.85**	-37.19***	-33.41*	-50.17
	(11.56)	(18.59)	-9862	(13.93)	(28.38)
Constant	**42.61** **	67.11***	48.14***	41.80*	45.33
	(19.61)	(17.05)	(12.36)	(21.29)	(34.83)
Observations	**153**	153	153	185	153
R-squared		0.137			
Number of groups	**27**	27	27	27	27
Country FE	**YES**		YES	YES	YES

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Discussion

Results show that the changes in the cleanliness of production processes induced by EU ETS differ depending on the level of aggregation (industry, sector or nation) and group of countries analysed.

Industry-level results from Model 1 suggest that even though their initial EUA allocations were different, i.e. more beneficial for EU12 than EU15 countries, there is on average no significant difference between the impact of EU ETS on clean production in regulated industries in the two groups of countries. Viewed in light of stricter EU ETS regulation of EU15 than EU12 industries, this interesting result is the consequence of an, on average, more easily adaptable EU15 industries and their lower initial marginal abatement costs. This outcome suggests that EU ETS during the first two trading periods successfully pursued its cost-minimizing goals.

Furthermore, results show that stricter regulation is expected to lead to an increase in clean production in regulated industries in both groups of countries. It means that an EU ETS-induced decrease in emissions reported by most researchers (Martin et al., 2015) was definitely not accompanied by a related decrease in the production. This increase in clean production of the regulated industries due to stricter regulation is the outcome desired by the regulator and provides support to further tightening of EU ETS regulation in the third phase of EU ETS.

Analysis at the sectoral level from Model 2 however shows a difference in the effects in the EU15 and EU12. In EU15 there is an effect of decrease in clean production due to tightening of regulation, while for EU12 results still report an expected increase in the clean production. When taken into an account that clean production variables in Model 1 and Model 2 are *GVAindGHGets* and *GVAindGHGenind*, this result reflects different impacts of EU ETS on GHG emissions of regulated industries versus the entire energy and industry sector (including both regulated and unregulated industries). In the EU15, compared to EU12, there was on average relatively greater decrease in GHG emissions in regulated industries compared to entire sectors. This reflects greater difficulties for EU15 countries' regulated industries to shift significant amount of abatement costs on the rest of the unregulated industries in the observed sectors. As far as green technological spill-over effects are concerned, the analysis shows no evidence of spill-overs of cleaner technologies and cleaner industrial processes to non-regulated industries of the observed sectors. The most probable reason is higher elasticity of demand for the regulated industries' goods in EU15 compared to EU12. This also implies easier substitution away from their dirty products and lower marginal costs in these still unregulated parts of energy and industry sectors (Vrankić, Oraić 2009). In addition, the effect of EU ETS on clean production in EU ETS is somewhat greater for the regulated industries than the corresponding sectors for EU12 as well. Hence, in order to achieve further emission reductions, coverage by EU ETS had to be expanded to the entire sectors in both EU15 and EU12. This expansion is happening in the third phase of the EU ETS and is supported by the results of this analysis.

On the national level, cleanliness of production is on average not significantly affected in neither EU12 nor in EU15 (Model 3). This result was expected since an intended decrease of CO_2 emissions in regulated installations compared to business as usual scenario was merely 14% in the first two phases of EU ETS (Commission of the European Communities, 2000). Nonetheless, the result indicates that there were so far no significant spill-over effects of EU ETS on a national level. However, further tightening of the emissions cap and widening of sectoral coverage in the third phase of EU ETS could very well change this outcome at the national level.

In addition, all three models show robust and positive impact of the share of electricity from renewables in gross energy consumption on the clean production. This means that ensuring the funds from the EU ETS for development of innovative renewable energy technologies in the third phase of EU ETS will definitely support clean production in the EU.

Finally, all analysed models robustly show a negative impact of crisis on the clean production. Previous research suggests that crisis had a negative impact on both production and GHG emissions (Martin et al., 2015). The results obtained in this paper imply that on average crisis hits production more than it does emissions and this is true on both national and industrial level. This suggests that at least a partial switch to more dirty production inputs and processes occurs during crisis. The result is in accordance with the events on the coal, oil and gas market during 2008 financial crisis which recorded steep decline in coal, oil and gas prices. Paired with an excess of EUAs on the market which kept price of permits low, this made a substitution to dirty inputs more affordable for the European industry in crisis. Once in the upward phase of the business cycle, however, the EUAs become scarcer which increases the cleanliness of production once again. It is worth noting that the maximum allowed level of emissions during the crisis was not crossed even though the relative cost of polluting decreased due to very high non-compliance fines. Also, the regulator could have intervened and additionally limited the supply of permits, thereby rendering them scarce, increasing their price and stimulating cleaner production. However, the phase of the business cycle was acknowledged and enough permits were left in the market in order not to slow down the recovery.

Conclusion

The main aim of this paper was to determine if the EU ETS leads to cleaner production processes in the EU. The analysis was based on the first two trading periods. Results robustly show that in both EU15 and EU12 EU ETS does significantly affect clean production of regulated industries and corresponding sectors, but does not have a significant effect on a clean production at a national level. Discerning between EU ETS effects in the EU12 and EU15 shows that (i) EU ETS is expected to increase clean production of regulated industries and there is on average no significant difference between these impacts in the EU12 and EU15, (ii) at the sectoral level there is a difference between two groups of countries – in the EU15 tightening of EU ETS is expected to decrease and in EU12 to increase clean production, (iii) in both EU12 and EU15 there was on average relatively greater decrease in GHG emissions in regulated industries compared to corresponding sectors, although this difference was more pronounced in the EU15, compared to EU12, and (iv) on the national level, cleanliness of production is on average not significantly affected in neither EU12 nor EU15.

This ex post analysis provides statistically tested impacts of the EU ETS on both economic performance and emissions, i.e. on a measure of "clean production" which represents a contribution of this paper. In addition, the ex post analysis was conducted from a more aggregated perspective than in the available literature rendering some interesting insights which represents another contribution of this research. First, analysis suggests that EU ETS during the first two trading periods successfully pursued its cost-minimizing goals on the regulated industries' level. Second, EU ETS-induced decrease in emissions was not accompanied by a related decrease in the production of the regulated industries. Third, regulated industries show difficulties shifting regulation costs on the rest of the economy and inducing spill-overs of cleaner technologies and industrial processes to non-regulated industries and sectors of economy. And finally, crisis had a negative impact on the clean production suggesting at least a partial switch to dirtier production inputs and processes. Although these results were anticipated by the earlier ex ante analyses, this is the first ex post study to bring forth the implications of EU ETS on the EU-level.

The main limitation of this study is the data, namely the short time span of just eight years (2005-2012). This had an impact on the choice of methodology i.e. static instead of dynamic panel data analysis which could address possible endogeneity in the data. However, extending the analysis for the time period beyond 2012 was impossible because the EU ETS coverage of regulated industries/sectors in the third trading period is very different compared to the first two EU ETS trading periods and most data are incomparable. It makes this limitation unavoidable in this ex post panel data analysis at a macroeconomic level. Another limitation of this study is lack of perfect precision of clean production variables because the sectors classified following emission source sectors as established by the IPCC which define emissions variables cannot be directly compared to economic sectors classified by NACE which define production variables. This is why the variables of clean production are only approximations of clean production at the regulated industry or sector level. This study focuses exclusively on EU ETS as a policy instrument for GHG emissions abatement. For future research it would be insightful to add other environmental policy instruments into the analysis and research the possible synergy of their combined use.

To conclude, this study has provided robust ex post evidence on the impacts of EU ETS in the EU countries. It has shown that EU ETS was successful at pursuing its cost-minimizing goals during the first two trading periods. It also provides support for further tightening of EU ETS regulation for the regulated industries, expanding the coverage of sectors in both EU15 and EU12 and ensuring the funds from the EU ETS for development of innovative renewable energy technologies. The progression of the third phase of EU ETS is hence supported by the results of this ex post analysis.

APPENDIX

Table A.1: Testing the Assumptions of Basic Models

	Model 1	Model 2	Model 3
Modified Hausman test	F(8, 26) = 2.65	F(7, 26) = 1.58	F(8, 26) = 13.00
H0: random effects model	Prob > F = 0.0286	Prob > F = 0.1862	Prob > F = 0.0000
Wooldridge test for autocorrelation in panel data	F(1, 23) = 1.153	F(1, 23) = 10.114	F(1, 23) = 0.096
H0: no first-order autocorrelation	Prob > F = 0.2941	Prob > F = 0.0042	Prob > F = 0.7600
Modified Wald test for groupwise heteroskedasticity	chi2 (27) = 39638.96	chi2 (27) = 10685.14	chi2 (27) = 1870.64
H0: homoschedasticity	Prob>chi2 = 0.0000	Prob>chi2 = 0.0000	Prob>chi2 = 0.0000

Table A.2: Results of the Modified Hausman Test

Model 1-1a	F(8, 26) = 2.65	**Model 2-2a**	F(7, 26) = 1.58	**Model 3-3a**	F(8, 26) = 13.00
	Prob > F = 0.0286		Prob > F = 0.1862		Prob > F = 0.0000
Model 1b	F(7, 26) = 3.66	**Model 2b**	F(7, 26) = 2.56	**Model 3b**	F(8, 26) = 10.89
	Prob > F = 0.0070		Prob > F = 0.0382		Prob > F = 0.0000
Model 1c	F(7, 26) = 3.88	**Model 2c**	F(6, 26) = 3.96	**Model 3c**	F(8, 26) = 6.39
	Prob > F = 0.0051		Prob > F = 0.0060		Prob > F = 0.0001
Model 1d	F(8, 26) = 4.07	**Model 2d**	F(7, 26) = 1.46	**Model 3d**	F(8, 26) = 11.65
	Prob > F = 0.0030		Prob > F = 0.2240		Prob > F = 0.0000

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NOTES

[1] The Kyoto Protocol's (currently in the literature dominant) attitude (Aldy et al., 2008) is that it is fair that the largest overall cost of reducing pollution is borne by those who have also caused it the most.

[2] NACE Rev2 Industry B-E

[3] Energy industries CRF_1A1, Manufacturing industries and construction CRF_1A2 and Industrial processes and product use CRF_2

[4] Energy CRF_1: Energy industries CRF_1A1, Manufacturing industries and construction CRF_1A2, Transport CRF_1A3 and Other fuel combustion sectors CRF_1A4; and Industrial processes and product use CRF_2

[5] Energy CRF_1, Industrial processes and product use CRF_2, Agriculture CRF_3 and Waste management CRF_5

[6] Energy CRF_1

[7] The results of these tests for all of the models are presented in the Appendix.

[8] Results of the Hausman test can also be found in the Appendix.

[9] Note: variable *dgfcf* shows moderate correlation with variables *ddLR*, *dTFP* and *Crisis*

[10] Solution of profit maximization problem is a vector of the optimal level of output, $q{*}z{*}p,w$, which is a function of optimal amount of production factors that are in turn a function of prices.

[11] However, as it was noted earlier, there is a significant correlation of dgfcf with other variables in the model.