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Working Paper 3

<http://ceep.bit.edu.cn/english/publications/wp/index.htm>

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July 2009

This paper can be cited as: *Zhang Y-J, Wei Y-M. 2009. An overview of current research on EU ETS: evidence from its operating mechanism and economic effect. CEEP-BIT Working Paper.*

This study is supported by the National Natural Science Foundation of China under Grant Nos. 70733005, 70701032 and the Natural Science Foundation of Beijing under Grant No. 9082015, and the CAS Knowledge Innovation Program for KZCX-YW-Q1-10. The views expressed herein are those of the authors and do not necessarily reflect the views of the Center for Energy and Environmental Policy Research.

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An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect

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Abstract

The European Union Emissions Trading Scheme (EU ETS) is supposed to be an important mechanism for addressing climate change. Up to now, the theoretical foundation of EU ETS has been widely acknowledged, but empirical research on its current situation has only been published recently or is forthcoming. Therefore, this paper is aimed to summarize the main arguments of empirical studies on the EU ETS, in terms of two aspects, i.e., the operating mechanism and economic effect of the EU ETS, which are two crucial topics and have been attached much attention. Based on the shortcomings of current research and future requirements of the EU ETS evolution, finally, we also present some further directions of the EU ETS research. Overall, the research overview here may be helpful to recognize the features of the EU ETS and its effect on others.

Keywords: Kyoto Protocol; CO₂ emission; Carbon trading market; EU ETS

1. Introduction

On February 16th, 2005, the Kyoto Protocol was officially approved and took effect-an indication that governments have begun to get moving on mitigating global warming by reducing greenhouse gas (GHG) emissions. Under the Kyoto Protocol, different economies agree to take common but differentiated obligations, and European Union has proved to be a frontrunner in implementing the emission reduction targets by the Kyoto Protocol and addressing climate change. According to the Kyoto Protocol, the European Union (EU) is committed to reducing GHG

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emissions by 8% below its 1990 level during the period 2008-2012. Also in 2005, the EU Emissions Trading Scheme (EU ETS) for GHGs was launched within the EU. This new system is a drastic change of market paradigm, and the first step of EU member states to implement emission reductions agreed in the Kyoto Protocol, as well as the first multinational GHG cap-and-trade system in the world. Therefore, it is of great theoretical and practical significance to overview the research advance of the EU ETS.

Under the new market paradigm, market fundamentals have been markedly changed. Previously, environmental policies related to GHG emissions were mainly operated in a command-and-control manner, in which emission enterprises should strictly comply with emission standards or implement specified technologies. But under the emission cap-and-trade system of the EU ETS, CO₂ has become a kind of tradable goods. With the evolution of the carbon trading market, not only the carbon spot market but also some derivative markets such as the carbon futures market, options market and forward market have gradually emerged.

Under this circumstance, carbon trading market has provided new commercial opportunities for those enterprises with surplus emission allowances, but its market complexity has also been universally acknowledged, for example, the violent change of EU allowances (EUA) price has brought a large number of uncertainties to those risk managers, brokers and traders in carbon trading market.

Ever since 2005, the EU ETS has witnessed rapid progress. During its first commitment period (2005-2007), 2.2 billion tons of CO₂ emission allowances were allocated to 12000 emission installations of 27 EU member states. Those emission installations can trade their surplus emission allowances on exchanges or over-the-counter (OTC) markets within the EU. The trading CO₂ of the EU ETS was 260 million tons in 2005 and 1.44 billion tons in 2007, demonstrating dramatic development. This development to some extent reflects the process of the market participants continuously learning the emerging financial market, and also provides a huge driving force and favorable expectation for its promising prospect in the second commitment period (2008-2012) and post-Kyoto period (after 2012).

In fact, emergence of the EU ETS has produced an effective and practical background for

related research, so after the EU ETS was officially launched in 2005, related research on the EU ETS has become a hot topic. A body of studies have been conducted on the carbon trading market in terms of the topics such as institution, law, infrastructure etc. of the EU ETS, which have provided sound theoretical support for its current situation and future development.

Overall, up to now, theoretical articles concerning the foundations of the EU ETS have been widely acknowledged, while empirical or simulation contributions concerning its status quo, such as its performance in the first trading period, have been only published recently or are forthcoming. But the new research appears conducive for recognizing the current features and evolving path of the EU ETS in the future. To our best knowledge, there is no literature overview available for empirical or simulation research on the EU ETS to date, and our paper aims to starting to fill the gap.

In this respect, we shed light on the existing literature on the EU ETS, mainly focused on the operating mechanism evolution of the EU ETS itself (such as its allowance allocation, pricing etc.)¹and its economic effect on relevant energy-intensive industries. Actually, these two topics are crucial for the mechanism design and policy adjustment in the second commitment period of the EU ETS and have attracted much discussion.

Additionally, the operating mechanism in the EU ETS market largely determines its evolving path and situation and then fosters its current economic effect, so we would like to overview the operating mechanism research dynamics of the EU ETS first, and then pay attention to its economic effect up to now. To this end, we are focused on two kinds of literature. The first one empirically analyzed the current situation of the EU ETS, i.e., it is to explore what has come out so far. Another kind is aimed to address exploration of effects of the EU ETS based on the chosen design.

In brief, the overview sketch of current research on the operating mechanism and economic effect of the EU ETS is shown in Table 1. Based on the overview of existing literature, finally, we present some directions for further research on the EU ETS.

¹ Operating mechanism of carbon trading market here means the structure, function, and mutual relations of those factors which affect the movement of carbon trading market, as well as the function processes, principles and ways by which the carbon trading market is affected. Up to now, prior literature mainly talked about the operating mechanisms of carbon trading market in terms of allowance allocation and price dynamics.

Table 1 the overview sketch of current research on the operating mechanism and economic effect of the EU ETS

	Main issues	Typical motivations	Methods	Main results
Operating mechanism	Allowance allocation mechanism	How stringent the allocations for the next implementation period might be?	Scenario analysis	In the majority of Member States, the present allocations will impose a constraint for ETS installations and for the EU as a whole.
		Whether the 2005 emissions data revealed over-allocation or abatement?	Historical data comparison	Allowance over-allocation occurred in 2005, and its magnitude might be 100 million EUAs.
		What were the implications of the ban on banking when initial emission targets were lenient?	Simulation analysis and game-theoretic consideration	An EU-wide ban on banking would lead to efficiency losses in addition to those losses which arise from the lack of inter-temporal flexibility. However, an EU-wide ban on banking would be the equilibrium outcome.
		What were the generic problems of segmented carbon regulation in terms of information requirements for international carbon prices and domestic abatement costs of sectors outside the EU ETS?	Numerical simulation based on German data	Inefficiencies of actual German NAP can be much better explained by lobbying of influential EU-ETS sectors than by information problems of regulatory authorities.
	Pricing mechanism	What was the market liquidity features for the EU ETS futures market?	Statistical analysis	The liquidity of the carbon futures market had taken on a similar expiration effect to that of general financial markets, but did not show notable day-of-the-week effect.
		What the relation between carbon market and stock market might appear?	Panel GARCH model	Carbon price change was positively related to the stock returns of the most important European electricity corporations. However, this differed from country to country. Additionally, the EU ETS had an important impact on the financial markets and affected the value of those corporations concerned.
		What did the long-term or short-term interactive relationship between carbon price	Cointegration theory and Granger	There can be identified a weak relationship between energy price and the first-phase carbon futures price, but a long-term equilibrium relationship between the energy

	Main issues	Typical motivations	Methods	Main results
		and energy price look like? And how about their causality?	causality test	price and the second-phase carbon futures price as well as a bi-directional causality between them can be found.
		Whether the exceptional weather condition could significantly drive the change of carbon price?	Multivariate linear regression	The change of weather conditions affected energy demand, further affecting the volatility of the carbon market.
		What were the main drivers for carbon price change?	Multivariate linear regression	Energy price, exceptional weather change and political institutional decisions were considered as the three most prominent factors affecting the EU ETS carbon price change.
Economic effect	Effect on energy industry	What was the impact of carbon prices on generation-cycling costs?	The PLEXOS-SEM model and Irish case study	Carbon mechanisms resulted in a shift in the merit order with high carbon emitters becoming relatively more expensive compared to low emitters. And CO ₂ reduction benefits were outweighed by the added cycling costs and these costs were significantly affected by underlying assumptions regarding generator behavior, demand levels, fuel prices etc.
		What was the impact of the EU ETS on German electricity sector investment decisions during 2005-2007?	Case study in German power generation companies.	The EU ETS constituted the main driver for small-scale investment with short amortization times, while its impact on large-scale investment in power plants or in R&D efforts was quite limited.
		What long-term impact of CO ₂ emissions trading on CO ₂ emissions could be expected in power generation?	Agent-based simulation	The effect of emissions trading was small and materialized late, and even after the introduction of CO ₂ emissions trading, the capacity expansion plans in both countries indicated preference for coal.
		How did the carbon price influence power generation firm value?	Multi-factor market model	In theory, the carbon price and stock price of power generation companies should be negatively correlated. However, empirical results showed a positive relationship between the two variables, implying that the market predicts that firms are not only able to pass on their share of the regulatory burden to customers but even achieve

	Main issues	Typical motivations	Methods	Main results
				windfall profits by overcompensating for the costs.
		What was the influence of the EU ETS on integrated gasification combined cycle (IGCC) investment?	Stochastic simulation model	At current allowance prices, immediate installation of CCS did not seem justified from a financial point of view. This need not be the case, though, if carbon market parameters change dramatically, carbon capture technology undergoes significant improvements, and/or a specific governmental policy to promote these units is adopted.
	Effect on non-energy industry with high energy intensity	What would the potential impact of the newly proposed legislation from the EC have on aviation sector?	Scenario analysis, cost pass-through, price elasticity	The proposal from the European Commission (EC) would jeopardize the long-term viability of the European aviation sector if non-European airlines were only subjected to CO ₂ emissions limits when their flights entered the EU.
		Would the EU ETS instigate airline network reconfigurations?	Route-based analysis, scenario analysis and simulation	After limiting CO ₂ emissions, European airlines would have to meet the pressure of cost and price increase. But this would be unlikely to instigate significant diminishing demand from air passengers. Therefore, European airlines would not face dramatic reconfiguration.
		What was the expected impact of industrial production variation in the EU ETS sectors on carbon price change?	Multivariate linear regression	During 2005-2007, only three among nine industrial sectors had a significant effect on the CO ₂ permit price, i.e., the combustion, paper and iron sectors.
		What was the impact of combustion and iron sector production on CO ₂ emission allowance price in Germany, Spain, France, Italy, Poland and the UK, respectively?	Multivariate linear regression	For the combustion sector at the country-specific level, Germany, Spain, Poland and the UK each had a statistically significant impact on EUA price change. And neither the combustion sector nor the iron sector caused any shock to EUA price change in France and Italy, respectively.
		How to quantify the impact of the EU ETS on enterprise competitiveness for the iron and steel industry in the EU?	Partial equilibrium model	Overall competitiveness losses were quite small; specifically, production losses were weak while profitability was likely to rise. Hence arguments against tightening the environment stringency of the EU ETS in Phase II were not justified on the grounds of competitiveness loss.
		What was the relation of the carbon futures	Multivariate linear	The carbon futures market had only a very weak relation with the macro-economy,

	Main issues	Typical motivations	Methods	Main results
	socio-economy	market and macroeconomic variables?	regression	and the macro-economy change could not predict the volatility of the carbon futures market
		What is the influence of the EU ETS on enterprise performance and the employment situation?	Case study in Germany, Multivariate linear regression	During the Phase I (2005-2007), because of the surplus CO ₂ emission allowances allocated, the EU ETS had not exerted a significant shock on enterprise performance and employment.

According to the research path mentioned in Table 1, this paper has the following structure. Section 2 recaps the research on related mechanisms of the EU ETS, mainly including its allowance allocation mechanism and pricing mechanism. Section 3 describes the relationship between the EU ETS and energy industry, the relationship between the EU ETS and non-energy industries, and the interaction between the EU ETS and socio-economy. Section 4 puts forward some further research directions with regard to the EU ETS.

2. Research on the operating mechanisms under the EU ETS

Ever since the submission of the EU ETS proposal, operating mechanism research has been regarded as a key part of the carbon market and attracted much attention, primarily including allowance allocation mechanism and pricing mechanism.

A strand of literature emphasized the relationship between the EU ETS and other environmental policy instruments. For example, Johnstone [1] and Sorrel and Sijm [2] investigated the interaction between the EU ETS and existing policy instruments such as energy taxes, subsidies to renewable energies, or energy efficiency standards. In their qualitative analysis, they concluded that the rationale for sticking to the existing policy instruments must rely on their contribution to overcome market barriers and market failures (other than carbon externalities) or in contributing to social objectives other than economic efficiency.

2.1. Research on the carbon emissions allowance allocation mechanism under the EU ETS

The carbon emissions allowance allocation mechanism appeared to be a crucial factor for the evolution of the EU ETS, but faced both praises and criticism.

A few studies were conducted with respect to the allowance allocation program and situation. For instance, Buchner et al. [3] discussed the emissions allowance allocation of the EU ETS, mainly including the experience, rethinking and general rules in the allocating process. Georgopoulou et al. [4] used the

scenario analysis approach to explore the constraints and available options of the carbon emissions allocation program for the EU ETS during its Phase II. They argued the next allocations would tend to be significantly more stringent than those in Phase I because of the combined effect of no inter-period transfer of allowances, the amount of CDM credits expected to be available compared to the amount of effort that would be required, and the yield of emission reductions from existing or planned policies and measures. Hence enterprises involved and national government should carefully examine the means to address their obligations. Furthermore, Ellerman and Buchner [5] started an empirical study with the installation-level data to verify emissions and allowance allocations in the first trading year of the EU ETS, shedding light on the extent to which over-allocation and abatement had taken place. They proposed a measure by which over-allocation can be judged and estimate the abatement based on emissions data. The author found that allowance over-allocation occurred in 2005 indeed, and its magnitude might have been as much as 100 million EUAs. These results give a convincing support for the carbon trading market operation analysis.

Overall, as for the emissions allowance allocation approach of the EU ETS, both praise and criticism can be found. Firstly, we argue the criticism. At the end of 2007, the spot price of the EU ETS approached zero. Some experts claimed that this resulted from the over-allocation of carbon emission allowances during the first phase of the EU ETS, and some even considered the EU ETS to be a complete failure based on this. Parsons et al. [6] did not totally agree with this argument. Their research indicated that the near-zero carbon price could not be completely attributed to the over-allocation of allowances. More importantly, it reflected the nature of the allowance allocation mechanism; specifically, this was mainly due to the allowance banking and borrowing mechanisms. According to the proposal of the EU ETS, allowance banking and borrowing between different phases were prohibited. Hence, at the end of 2007, when the first phase of the EU ETS came to its end, a palpable seam between the two phases appeared, which led to the carbon spot price approaching zero. In brief, we might say the dynamics of carbon price was caused by the allowance allocation mechanism design for carbon trading market.

There was also some research in favor of the rationality and inevitability of the current allowance allocation mechanism under the EU ETS. For instance, Convery et al. [7] stated that the division of the two phases of the EU ETS was conducive to taking the first phase as a trial period and learning some lessons so as to harmonize the allocation rules and tighten the allowances across member states in the second phase. This was apparently quite useful for controlling the overall risk of implementation of the EU ETS. On the other hand, they argued that freely allocated allowances in the first phase undoubtedly improved the

profitability of covered firms, at least in comparison with what would have been the case if allowances had been auctioned. More impressively, from the first trial period, all the big industrial and financial players began to accept that carbon was no longer free in Europe and that carbon emissions would continue to become costly in the future.

Also about the division of the two phases under the EU ETS, Schleich et al. [8] talked about the banking mechanism. After a simulation study, they pointed out that admitting banking in the emissions trading system reduced overall compliance costs by allowing for inter-temporal flexibility, because cost savings could be traded over time. However, this kind of mechanism was prohibited by the EU ETS. In light of this, the author explored the implications of such a ban on banking when initial emission targets were lenient using a simulation study. Their research results suggested that an EU-wide ban on banking would lead to efficiency losses in addition to those losses which would arise from a lack of inter-temporal flexibility. However, through a game-theoretic analysis, they found that such an EU-wide ban on banking was an equilibrium outcome. Thus, to avoid a possible prisoners' dilemma, member states should coordinate their banking decisions.

As for the allowance allocation, great attention has to be attached to the design of National Allocation Plans under the EU ETS. For the most part, we may say the uncertainties of NAPs determine the volatility and risk of carbon trading market. In fact, some authors have conducted empirical or simulation research on the NAPs, not only their current solutions but also their future changes.

For example, Soleille [9] qualitatively compared the similarities and differences of the command control mode and the EU ETS as two kinds of policy tools to reduce emissions. The author claimed that it was hard to judge which tool would be more effective, as their effectiveness did not lie in the policy tool itself but depended on the strength of the goal setting. As a result, the setting of an emissions reduction allowance by a NAP was considered important.

As for the future of carbon trading market, Daskalakis and Markellos [10] showed that its uncertainty was linked to various emerging industries, such as the aviation and transportation industries, but the largest uncertainty of the carbon market was the enactment of NAPs. Regarding the effectiveness of NAPs, Böhringer et al. [11], taking Germany as an example, quantitatively analyzed the excessive cost of the German carbon emissions system using a numerical simulation. The results imply that an effective NAP is not sensitive to the international carbon price but rests more on efforts to persuade emission-intensive

industries. Also, they argued that the EU ETS should be expanded in the future to include all domestic sectors of EU economies thereby creating a single emission market, and a comprehensive market-based trading regime would avoid the information problems of the regulator and was likely to reduce lobbying power of emission-intensive industries as burden shifting between different affected parties became more explicit. Furthermore, Klepper and Peterson [12] used a computable general equilibrium model for the European Union to quantify the economic impacts for a range of likely implementations of NAPs. Although their analysis implicitly captured inefficiencies due to diverging marginal abatement costs between sectors inside and outside the EU ETS, the focus was on the role of accession countries for alleviating overall compliance costs and adverse competitiveness effects.

2.2. Research on the pricing mechanism under the EU ETS

The pricing mechanism was considered to be an important part of the complex carbon market system, and was confirmed to be remarkably influenced by energy price, exceptional weather and political decisions.

The EUA spot price saw a sharp slump in April 2006, approaching zero at the end of 2007. All of this indicated that carbon emissions allowance allocation in Phase I of the EU ETS was not strict enough, and the price of CO₂ was not high enough to motivate the enterprises concerned to reduce CO₂ emissions on their own. Therefore, it was imperative to explore the potential mechanisms of carbon price change. With respect to this, Reilly and Paltsev [13] displayed the complex reasons for carbon price dynamics. They simulated the carbon market situation under the EU ETS, in particular the volatility of carbon price, and found that during 2005-2007, the carbon price should range between 0.6-0.9 euros per ton of CO₂, obviously differing from the real price in 2005, i.e. 20-25 euros per ton of CO₂. Subsequently, they analyzed several possible reasons for this discrepancy, for example, besides the shortcomings in the model's hypotheses and specification, the natural gas price was too high; the scarcity of both hydro power and nuclear power spurred the rate increase of coal-fired power; the fundamental conditions of member states had not prepared well enough, such that the trading volume of the carbon market seemed relatively limited. Actually, these reasons are all justified according to the real operation of the EU ETS, which also can demonstrate the complexity of the carbon trading market.

Essentially, carbon trading market should be seen as an emerging financial market. With the growing trading data of EU ETS, some literature has appeared on the pricing mechanism of the carbon market from financial perspectives, especially its current price dynamics. For example, Wei et al. [14], using some statistical measures for financial market liquidity, discussed the liquidity of the EU ETS futures market from a micro point of view, arguing that the liquidity of the carbon market had taken on a similar expiration effect to that of general financial markets, but did not show notable day-of-the-week effect. Oberndorfer [15] was the first econometric literature to explore the relation between carbon market and stock market by means of the panel GARCH approach, arguing that carbon price change was positively related to the stock returns of the most important European electricity corporations. However, this differed from country to country. For instance, the relation regarding the Spanish electricity corporation was shown to be negative, but was positive for corporations from other countries such as Germany and the UK. Furthermore, carbon price appreciation and depreciation did not have any asymmetric relation with the change of stock returns. Therefore, it was apparent that the EU ETS had an important impact on the financial markets and affected the value of the corporations concerned. Moreover, from an econometric perspective, Benz and Trück [16] proposed that since allowance trading mainly occurred in the US, major publications on price change of tradable emission allowances were focused on SO₂ emission under the Acid Rain Program of the US Environment Protection Agency (EPA), while little literature examined the CO₂ allowance price from an econometric or risk management perspective. Therefore, they introduced the Markov switching and AR-GARCH models to investigate the price dynamics of the CO₂ emission allowance spot price, especially the volatility of the underlying stochastic price process.

Besides the financial feature research from carbon price movement perspective, when studying price mechanism under EU ETS, a body of literature was concerned about its price forming mechanism, especially the drivers of carbon price change, such as energy price, unexpected weather conditions, institutional information disclosure and so forth [17-18].

It has been proved that the change of carbon price was closely linked to energy price, especially the power price. This mainly arose from the fact that power generation companies can switch generating fuels (oil, natural gas or coal). Thus, an upward energy price might drive up the carbon price and a downward energy price might coincide with a slump in the carbon price. This idea was supported by Kanen [19] and Convery and Redmond [20]. Kanen [19] held that oil price was the major driver of natural gas price change, and in turn, the change of the natural gas price might impact the change of the electricity price and carbon

price. Convery and Redmond [20] also confirmed that energy prices were the most important drivers of carbon prices due to the ability of power generators to switch between their fuel inputs. More specifically, through an empirical study, Wei et al. [14] adopted the cointegration theory to examine the short-term and long-term interaction between the EU ETS carbon price and energy price. They confirmed a weak relationship between the energy price and the first-phase carbon futures price, but they also identified a long-term equilibrium relationship between the energy price and the second-phase carbon futures price and a bi-directional causality between them.

There were some literature focused on the relation between carbon price and power price. For instance, both Linares et al. [21] and Smale et al. [22] argued that emission allowances could be considered as a direct production cost factor of power generation companies. Therefore, the emergence of the EU ETS had inevitably caused a rise of power price. Furthermore, Kara et al. [23] gave a specific result about this, they considered that during 2008-2012, a one euro/ton CO₂ price change might bring about an average power spot price rise of 0.74 euro/MWh each year in the Nordic region. Similarly, Zachmann and von Hirschhausen [24] found that the German wholesale power price was closely related to the EUA price change. And the influence of carbon price rise on the power price appeared stronger than that of carbon price fall. In other words, the influence of carbon price rise and fall on the electricity price proved asymmetric. Daskalakis and Markellos [10] confirmed that the links between the emissions and power markets were of great interest to practitioners, academics and policymakers. They stated that literature investigating the links between carbon and electricity markets in Europe and elsewhere was quite sparse and mainly focused on the impact of emission allowances on the cost of electricity, with little on the perspective of the price mechanism. Therefore, Daskalakis and Markellos [10] were the first to investigate the impact of carbon price variations within the EU ETS on electricity risk premium, finding a positive relation between the carbon allowance price and the electricity risk premium, and that the falling carbon price return had a larger impact on electricity price risk than that of the rising carbon price return. Hence, the carbon price was an indispensable element when evaluating electricity market risk, which had important policy implications for electricity futures and options pricing. Actually, in a normal market situation, carbon price and energy price were potentially affected each other, and when tackling the investment issues related with energy or carbon markets, both of these two factors should be considered. On the other hand, based on this, carbon trading market should become a typical commodity market for investors to avoid market risk.

Apart from the impact of energy price, some authors claimed that exceptional weather change also

caused notable shocks to the carbon market. This mainly resulted from the logic that the change of weather conditions might affect energy demand, further affecting the volatility of the carbon market[25]. In this respect, Alberola et al. [26] argued that the energy price, exceptional weather change and political institutional decisions were considered as the three most prominent factors affecting the EU ETS carbon price change. They adopted a multivariate linear regression method to empirically study the interaction between the EU ETS carbon and energy prices, and weather conditions during 2005-2007. They found that extreme cold weather had a nonlinear relation with the carbon price, and that seasonal adjustment for cold weather had a larger impact on carbon price change than that of cold weather itself; however, extreme hot weather did not exert any significant impact on the carbon price.

Also, besides the drivers above, some studies pointed out that the carbon price change might also arise more from the market system design and institutional information disclosure. For example, Alberola et al. [26] showed evidence that the EU ETS carbon price change over 2005-2007 followed two structural breaks; one occurring in April 2006, mainly for the verified carbon emissions data of 2005 disclosed by the EC; the other in October 2006, as a consequence of the EC's announcements regarding the restriction of the 2008-2012 allowance allocation. From the price breaks, we can see the influence of institutional and market events on carbon price change.

Similarly, Chevallier et al. [27] evaluated the influence of institutional information disclosure on the carbon market. They used the historical data of the carbon option price during 2006-2007 on the European Climate Exchange (ECX), and revealed that the influence of information disclosure on the carbon market was the exact opposite of that found on equity markets, whereby periods of increasing markets coincided with periods of higher volatility. This primarily concerned the allowance allocation system of the EU ETS, especially in the context of a low environmental constraint by the EU ETS. Differently, not only for the carbon price dynamics in ECX, Daskalakis et al. [28] studied the three main carbon markets for emission allowances within the EU ETS, i.e. Powernext, Nord Pool and ECX, finding that the prohibition of banking of emission allowances between different phases of the EU ETS had a significant impact on derivative pricing. Through an empirical study, they also suggested that the carbon spot price was likely to be characterized by jumps and non-stationarity. In the case of carbon futures price, they argued that only intra-phase contracts were found to be well estimated by the cost-of-carry model with zero convenience yields. And regarding inter-phase futures contracts, a stochastic, mean reverting convenience yield was needed for accurate pricing though the cost-of-carry model was also applicable.

It was universally acknowledged that the potential of the carbon market has not been fully exploited, and its future trend might be closely correlated with policy adjustment and system arrangement of global climate change. Regarding this, Streimikiene and Roos [29] claimed that the EU ETS had not yet delivered its real potential to reduce emissions in a cost-effective manner. And they also argued that during 2005-2007, the carbon spot price collapsed as a result of over-allocation of emission allowances. For 2008-2012, a more stringent carbon emission cap had been set, but the generous access to credits from JI and CDM could still limit the emission reductions taking place within the EU. In our opinions, although their arguments taking allowance over-allocation as the reason for carbon spot price collapse do not completely hold, their worry about the future operation of carbon market should be taken seriously.

With regard to the future evolution of EU ETS mechanism, according to Haar and Haar [30], there were many policy-making uncertainties under the EU ETS, including the underlying influence on economic development and the effect on GHG emission reduction and benefit/cost analysis etc.. Therefore, sufficient attention had to be paid by government and academics to the EU ETS. Besides, Ellerman [31] emphasized that the relation among the stringency of emission reduction targets, the differentiation of emission reduction responsibility and the harmonization of free allowances were the key unsolved issues for the EU ETS. Furthermore, the EU ETS should develop a central coordinating organization and devise an effective measure to encourage greater participation.

3. Research on the economic effect under the EU ETS

3.1 Research on the relationship between the EU ETS and energy industry

Among humankind activities, fossil fuel combustion was supposed to be the largest influential factor for climate change, accounting for 80% of total GHG emissions by humankind. And up to now, fossil fuels have been the main inputs for power generation, which brought about huge CO₂ emission in generation [32]. Here we are going to summarize the economic effect of EU ETS on energy industry according to the existing literature.

3.1.1. Research on the cost effect of the EU ETS on power generation

To recap existing related literature, we find that the carbon reduction mechanism under the EU ETS has caused increased cost of power generation companies, but its overall influence on the power generation sector still remains insignificant.

In recent research on the interaction between carbon trading market and electricity industry, some authors were focused on the cost increase of power generators caused by the EU ETS. For instance, Delarue et al. [33] argued that in the first trading period (2005-2007) of the EU ETS, part of the targeted GHG emission reductions presumably will have to result from a switch from coal-fired power generation to gas-fired power generation. It was possible to calculate the allowance cost necessary to switch a certain coal-fired plant with a certain gas-fired plant in the merit order, hence the allowance cost obtained is a so called switching point. When comparing historic European Union Allowance (EUA) prices in 2005 with the corresponding historic switching points after a simulation work, they found that the EUA prices were high enough to cause a certain switch in the summer season. This finding led to the use of switching points in establishing allowance cost profiles for several scenarios. Similarly, Denny and O'Malley [34] argued that the CO₂ emissions trading system required power generation companies to internalize their emissions costs, because it altered the marginal cost of generators such that heavy polluters became more expensive than lighter polluters. Therefore, they held that the carbon reduction mechanism could cause coal-fired units to become relatively more expensive compared to gas-fired units. Thus coal units might be shifted from operating continuously as base-load plants to operating on the margin. Cycling costs and carbon savings were compared on the electricity system in Ireland, with the finding that CO₂ reduction benefits were outweighed by the added cycling costs and these costs were significantly affected by underlying assumptions regarding generator behavior, demand levels, fuel prices etc. Therefore, we could see that the introduction of a CO₂ reduction mechanism indeed produced new shocks to the power industry, especially to the cost of power generation companies.

A little bit differently, not only focused on the cost issue above, Chen et al. [35] talked more about power generators' profit from carbon trading market. They used a transmission-constrained oligopoly model to examine the short-run implications of CO₂ trading for power production, prices, emissions, and generator profits in northwest Europe in 2005. Simulation results indicated that the rates at which CO₂ costs

were passed through to wholesale prices were affected by market competitiveness, merit order changes, and demand and supply elasticities. Consequently, they claimed that emissions trading resulted in large windfall profits, much but not all of which was due to free allocation of allowances. Profits also increased for some generators because their generation mix had low emissions, and so they benefited from power price increases. Therefore, Chen et al. [35] argued that most emission reductions appeared to be due to demand response not generation redispatch.

Despite the shock of the EU ETS on power generation sector, some empirical and simulation research, however, stressed that because of the immature system and low carbon price, the overall influence of the EU ETS on the power generation sectors had not appeared significant currently. For instance, to answer the central question “what long-term impact of CO₂ emissions trading on CO₂ emissions can be expected in power generation?”, Chappin and Dijkema [36] carried out an agent-based simulation study on the power generation sectors in the Netherlands and Germany. They pointed out that the effect of emissions trading was small and materialized late, expressing a surprise that even after the introduction of CO₂ emissions trading, the capacity expansion plans in both countries indicated preference for coal. This corresponded to the findings of Convery et al. [7], indicating the EU ETS had not significantly guided the development towards a low carbon economy. This told us that the economic effect of CO₂ emissions trading on power generation was not sufficient to outweigh the economic incentives to choose coal, for which both a low carbon price and low coal price should be the main reasons.

Additionally, some literature also talked about the effect of the EU ETS on power generation firm value. This is mainly due to the fact that carbon emission allowance may be viewed as a benchmark for evaluating power generation firm value by investors. To investigate the influence of the carbon price on power generation firm value, Veith et al. [37] discussed the relationship between the carbon price and the stock price return of European power generation companies. The author considered that from the perspective of investors’ expectation, when the carbon price rose, the future profits of the power generation company would fall, further causing the stock price return to shrink. In other words, the carbon price and stock price of power generation companies were negatively correlated. However, empirical results showed a positive relationship between the two variables, implying that although the introduction of a carbon reduction mechanism increased the cost of power generation companies, they could pass their regulatory burdens to customers. Consequently, the EU ETS indeed provided opportunities for the value increase of power generation companies. Specifically, because of the low carbon price, the impact of windfall profits

compensated for that cost increase.

3.1.2. Research on the economic effect of the EU ETS on energy technology investment

Another point with respect to the effect of the EU ETS on energy industry is involved with the energy technology investment. Existing study results indicated that the carbon market had become a vital factor impacting energy technology investment, but had not pronouncedly promoted the upgrade of new energy technologies.

Due to the close relationship between carbon trading market and energy market, research on the interaction of the carbon market and energy technology has been advancing, especially on the influence evaluation of the carbon trading market on energy technology investment. After the introduction of the EU ETS, those enterprises with limited carbon emissions had two choices: one was to put a large sum of funds to upgrade energy technology so as to realize CO₂ emissions reduction; the other was to buy emission allowances from the carbon trading market.

Existing research showed that the carbon trading market had become an important factor for enterprises in the decision to invest in energy technology, while the extent of its impact appeared quite limited. In this regard, Hoffmann [38] empirically studied the impact of the EU ETS on German electricity sector investment decisions during 2005-2007, finding there was little empirical evidence regarding its actual effects on corporate investment decisions; specifically, the EU ETS constituted the main driver for small-scale investment with short amortization times, while its impact on large-scale investment in power plants or in R&D efforts was quite limited. To address this issue, the author suggested that policy-makers should reflect their long-term reduction intentions in the scarcity of allowances, provide more incentives to increase efficiency and reduce regulatory uncertainty. Also about the power generation technology, Laurikka [39] developed a stochastic simulation model based on the real option theory, and explored the influence of carbon emissions trading, the EU ETS in particular, on integrated gasification combined cycle (IGCC) investment. The results showed that a straightforward application of discounted cash flow (DCF) analysis could lead to biased results in competitive energy markets within the carbon emissions trading scheme, where a number of uncertainties potentially combined with several real options could make quantitative investment appraisals very complex. Moreover, the IGCC technology did not yet seem

competitive in power plant retrofits within the EU ETS, for its investment cost was too high for viable retrofit in investment.

As a promising energy technology for carbon emissions reduction, Carbon Capture and Storage (CCS) deployment has become a hot issue these years. Abadie and Chamorro [40] analyzed a coal-fired power plant which had the option of investing in a CCS unit, finding that at the permit prices during that period, immediate installation did not seem justified from a financial point of view. In other words, the low carbon price did not provide sufficient incentive for rapid adoption of CCS technology. The author also held the view that this case might be different, if carbon market parameters changed dramatically, or CCS technology underwent significant improvement together with specific governmental policy to promote the units.

After examining the degree of which emissions trading could actually provide financial incentives for investing in end-of-pipe-technologies (EOP-technologies), Klingelhöfer [41] held that the carbon emissions trading scheme had various effects on an investment and these effects did not always encourage environmentally beneficial investments. In some particular cases, a system of emissions trading might even be counterproductive and provide negative marginal incentives.

Therefore, it was evident that existing research results do not support the significant economic effect of the EU ETS on energy technology investment. For this, in our opinions, it is mainly due to the weak influence of carbon trading market. If the carbon price rises to an adequate high, related enterprises may feel stronger incentive for new energy technology investment, and the whole situation may be changed totally.

3.2. Research on the relationship between the EU ETS and non-energy industries

Up to now, a few empirical studies have been focused on the effect of the EU ETS on some non-energy industries with energy-intensive features, mainly including the aviation and some industrial production sectors.

3.2.1. Research on the economic effect of the EU ETS on aviation sector

Simulation results showed that if the carbon market covered the emissions from the aviation sector, it would influence the existing operation of aviation sector, but would not instigate significant reconfiguration of the sector.

Transportation is recognized as an important CO₂ emitter, but the preliminary draft of the EU ETS did not cover its emission. In recent years, whether some transportation sectors should be covered by the EU ETS, such as aviation, has been an ongoing subject of debate. In 2006, the EU reported that aviation should be included in the EU ETS, to reduce CO₂ emissions and address global warming. According to the report, specifically, intra-European airlines would be required to hold CO₂ emission allowances from 2011, while those airlines outside Europe should also start to limit CO₂ emissions from 2012 if their flights operated in and out of European countries [42]. Under these circumstances, by means of scenario analysis, Ernst & Young [43] claimed that the proposal from the European Commission (EC) would jeopardize the long-term viability of the European aviation sector if non-European airlines were only subjected to CO₂ emissions limits when their flights entered the EU.

However, not all authors were pessimistic about the shock of the EU ETS on aviation sector. Alberts et al. [44] pointed out that after limiting CO₂ emissions, European airlines would have to meet the pressure of cost and price increase. But this would be unlikely to instigate significant diminishing demand from air passengers. Therefore, European airlines would not face dramatic reconfiguration.

3.2.2. Research on the economic effect of the EU ETS on industrial production sectors

Industrial production was also an essential source of carbon emissions. Therefore, the relationship between the carbon market and industrial production has been a focus in recent years. After checking an array of related literature, we found that the production of the combustion, paper and iron sectors observably impacted the EUA price, with the extent varying from country to country.

In theory, the carbon price is a function of marginal abatement costs that vary depending not only on industrials' emissions abatement options, but also on the relation between emissions caps and counterfactual CO₂ emissions resulting from business-as-usual production growth forecasts. Thus, EUA

price changes may be affected by economic activity of various sectors covered by the EU ETS for two main reasons. First, industrials are able to influence the carbon market price through their choice of emissions abatements options. Second, according to many market observers, industrials have hedged their allowances based on actual production during 2005-2007.

Based on this, Alberola et al. [45] were the first to empirically study the expected impact of industrial production variation in the EU ETS sectors on carbon price changes. Their results showed that during 2005-2007, only three among nine industrial sectors had a significant effect on the CO₂ permit price, i.e., the combustion, paper and iron sectors. Based on that paper, Alberola et al. [46], focusing on the country level, made a further investigation on the impact of combustion and iron sector production on CO₂ emission allowance price in Germany, Spain, France, Italy, Poland and the UK, respectively. The empirical results indicated that for the combustion sector at the country-specific level, Germany, Spain, Poland and the UK each had a statistically significant impact on EUA price change, totaling 59% of the allowance allocated in the combustion sector. The impact of its combustion sector on EUA price change appeared larger than others, especially in Germany, confirmed by the fact that the German power sector totaled 27% of the allocated allowance in the EU. However, neither the combustion sector nor the iron sector caused any shock to EUA price change in France and Italy, respectively, probably resulting from their low rates of allocated allowances.

In addition, the EU Emissions Trading Directive was expected by European energy-intensive industries to harm their competitiveness vis-à-vis non-European competitors. Many additional measures have thus been proposed to level the playing field and to protect the competitiveness of European energy-intensive industries within the larger effort of reducing Europe's greenhouse gas emissions and of meeting its obligations under the 1997 Kyoto Protocol.

Just against concern about loss of competitiveness of Europe's energy-intensive industries by the EU ETS, Asselt and Biermann [47] qualitatively evaluated a range of proposed measures based on a set of political and legal criteria, including environmental effectiveness; the need to consider differentiated commitments, responsibilities and capabilities; conformity with world trade law and European Union law; and Europe's overall political interests. And they claimed that those measures could be adopted by the European Union and its member states, such as direct support for energy-intensive industries, restrictions of energy-intensive imports into the European Union through border cost adjustments, quotas or technical regulations, and cost reimbursement for affected developing countries. And they also analyzed measures

available to multilateral institutions such as the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol and the World Trade Organization (WTO).

In order to obtain convincing evidence for the competitiveness loss, Oberndorfer and Rennings [48] overviewed recent literature on model-based assessment of the competitiveness effect of the EU ETS, but found that the scheme did not exert any considerable shock on enterprise competitiveness and creativeness. Similarly, Demailly and Quirion [49] introduced a partial equilibrium model to quantify the impact of the EU ETS on enterprise competitiveness (including production and profitability) for the iron and steel industry in the EU, concluding that overall competitiveness losses were quite small; specifically, production losses were weak while profitability was likely to rise. Hence arguments against tightening the environment stringency of the EU ETS in Phase II were not justified on the grounds of competitiveness loss.

Moreover, based on the historical data in the first commitment period of the EU ETS (2005-2007), Convery et al. [7] quantitatively analyzed the shock of carbon price on short-term competitiveness (including market share and profitability) of the EU's cement, refining, steel, and aluminum sectors, identifying only weak influence of carbon price change on these four sectors. However, the author held that the influence might be strengthened with the change of market environment in the future.

In a word, we may say, from the existing research, the enterprise competitiveness loss caused by the EU ETS has not been strong, but may get stronger in the future.

3.3. Interaction between the EU ETS and the socio-economy

In theory, those enterprises covered by the EU ETS have to adopt a set of arbitraging strategies to adjust their production capability. This should indicate a close interaction between the carbon futures market and enterprise operation or the socio-economic environment. However, the existing literature did not display strong interaction between them. This might have a bearing on the fact that the international carbon market only had a very short history with few participants and a monotonous structure. Moreover, the link between the carbon market and financial institutions remained weak.

It has been found that return of the EU ETS had a relatively weak connection with the macro-economic environment, with a quite limited influence on social employment.

As an emerging market system, what influence has the carbon trading market played on the whole socio-economy? Moreover, would the macro-economy change affect the carbon market volatility? These were important questions for policy makers and practitioners. For these issues, by means of the multivariate linear regression, Chevallier et al. [50] shed light on the relation of the carbon futures market and macroeconomic variables, including the stock, securities and commodity markets. The author stated that the carbon futures market had only a very weak relation with the macro-economy, and the macro-economy change could not predict the volatility of the carbon futures market. Similarly, Anger and Oberndorfer [51] empirically studied the influence of the EU ETS on enterprise performance and the employment situation in Germany. They found that during the Phase I (2005-2007), because of the surplus CO₂ emission allowances allocated, the EU ETS had not exerted a significant shock on enterprise performance and employment.

In fact, research on the effect of the EU ETS on socio-economy appears sparse up to now and needs more attention in the future.

4. Further research on the evolution of the EU ETS

Currently, the EU ETS has covered four energy-intensive sectors in the EU, i.e. the energy sector (such as power generation, oil refinery etc.), the ferrous metal producing and processing sector, mineral sector (such as cement, glass etc.) and the pulp and paper sector. The CO₂ emissions of these four sectors account for 46% of the total CO₂ emissions of energy-intensive industries in the EU. In the future, with the number of energy-intensive sectors covered by the carbon trading market growing, the relationship among the carbon market and the energy sector and non-energy sectors with high energy intensity must be getting closer.

To recap what has been discussed above, we might safely recognize that the EU ETS was a complex system and its carbon price change was commonly influenced by numerous risk factors. In addition, due to the short history of the EU ETS, the limited impact on the socio-economy and also the greater time necessary to respond to the emerging financial system, our recognition and research about the carbon trading market remained elementary, and existing research conclusions contained a large number of uncertainties. Hence, there were still some gaps that needed to be addressed in the future research on the

EU ETS. For this reason, based on the existing literature, we propose the following directions for future research on the EU ETS, mainly in terms of its economic effect, operating mechanism, etc.

(1) The influence of the EU ETS on energy industries

Most existing research indicated that because of the low carbon price, the current influence of the EU ETS on the energy sectors was fairly limited, and its steering role to promote energy technology upgrade and low-carbon development remained restricted. However, with adjustment of the global climate change policy in the future, when the carbon price rises to some level, what influence will the carbon market have on the cost of power generation companies and their CO₂ emissions? Moreover, what is the potential of the carbon market to improve its technology? These issues need close and continuous attention in the future.

(2) The interactive mechanism between the EU ETS and energy markets

According to the existing literature which was mainly focused on the first phase of the EU ETS (2005-2007), the energy market indeed has become an important factor for carbon market change, but the magnitude of its influence was still relatively weak. With the future environment of the carbon market changing, greater attention should be paid to the interaction between the carbon market and various fossil fuel (coal, oil, natural gas and electricity) futures markets, especially its interaction with the coal and natural gas market, which take the heaviest and lowest CO₂ emissions respectively.

On the other hand, existing research about the relationship between the carbon market and the energy market often had a linear focus, primarily on the mean perspective. In the future, in order to better characterize the situation, further research should be conducted nonlinearly and from the volatility and risk perspectives. Also, because of the co-evolution of carbon market and energy market, we have to address them at the same time when planning some investment or modeling the related markets.

(3) The influence evaluation of the EU ETS on socio-economy complex system

With the beginning of the second phase of the EU ETS and the approach of post-Kyoto era, what kind of shocks will the carbon trading market have on the macroeconomic environment, including financial markets (such as stock market and bond market)? And whether the EU ETS will bring about a large benefit or loss for the operating performance of enterprises, in particular their competitiveness and creativeness? and how about the extent? These questions are bound to be crucial for new mechanism design of the EU ETS and need further investigation.

(4) The influence of the EU ETS on giant non-Annex I countries

According to the Kyoto Protocol, in the first commitment period of the EU ETS, non-Annex I countries did not have to undertake quantitative emission reduction targets. However, the severe situation requires some non-Annex I countries, especially those giant emerging countries such as China and India, take some pragmatic measures to address the global climate change. And it is hard to project they do not have to take emission reduction targets forever. Therefore, currently, how to comprehend, participate in and take advantage of the EU ETS should be the central questions for them. Hence some research should be considered and prepared in advance.

Firstly, how to indirectly engage in and make use of the EU ETS is crucial for non-Annex I countries. Though the EU ETS is mainly limited to the countries within the EU, to indirectly but effectively engage now in the EU ETS is also feasible and conducive to the future practice of non-Annex I countries, especially for China and India. For example, some financial products connected with the carbon price change under the EU ETS can be designed, and research on the financial product design should be a meaningful job.

Secondly, the future influence of the EU ETS on aviation sectors in non-Annex I countries needs further consideration. According to the proposal of the EC mentioned above, when the flights of those giant non-Annex I countries enter into the EU, they will have to undertake CO₂ emission limits. Hence, an urgent task for giant non-Annex I countries is to identify the shocks on their aviation sectors due to the new proposal and tune their strategic planning of aviation sector, hence more research needs to be done to evaluate the shocks and design some constructive solutions.

Finally, the real action in the EU ETS provides a good case for non-Annex countries in the course of their future carbon emissions reduction. As responsible countries, China and India have declared explicit carbon emissions reduction targets, and under the huge pressure of arduous international negotiation on climate change, more non-Annex I countries may have to do this. In China, the national 20% energy-intensity reduction target in its 11th Five Planning (2006-2010) has been declared previously and distributed to every province and municipality, and some preliminary experience has been obtained. Recently, on November 25th of 2009, China announced to cut carbon emissions intensity 40%-45% by 2020 compared to 2005 levels. This is an ambitious but challenging task for China. Then, more research should be conducted to consider the carbon emissions reduction target decomposure, emission monitoring,

performance assessment, responsibility cognizance etc.

An array of literature has proved theoretically that market mechanism was supposed to be a cost-effective way for emission reduction. Therefore, under these circumstances, to establish a domestic carbon trading market for China may be a nice choice, and China definitely can learn a lot from the rich experience of operating mechanisms under the EU ETS. Similar situation may be identified in India.

Consequently, it is imperative to summarize the features of the EU ETS (including the positive and negative aspects) for giant non-Annex I countries and further design reasonable, effective and practical solutions based on their own situations, especially the foundation of allowance distribution, the pricing mechanism of carbon market.

(5) The operating mechanisms of the EU ETS

Recently, through an empirical study, we found that due to the overreaction in the EU ETS, the carbon price volatility moved in a very emanative fashion, which reflected the complexity of price dynamics in carbon trading market and generated huge risks for related enterprises investment.

In the post-Kyoto era, should the EU loosen its restriction on carbon emission allowance banking and borrowing? What kind of complex interactive mechanism exists between the carbon market and its various risk factors? How should a reasonable emission allowance NAP be drawn up so as to promote the stable development of the EU ETS, raise its operating efficiency and enlarge its social influence to address climate change? All of this needs further work not only in terms of methodologies but also practice.

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