1. Introduction

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The European Emissions Trading Scheme (EU ETS) is the first international trading scheme for carbon dioxide (CO_2) emissions in the world. Its aim is to reduce the cost of meeting the Kyoto Protocol requirements by creating an explicit and common price for carbon.

The EU ETS covers several industry sectors of which power generation is the largest. Therefore, on the one hand, the performance of the trading scheme largely depends on the efficacy in inducing the power industry to reduce CO_2 emissions significantly in the short and long runs. On the other hand, it might have a considerable impact on consumer surplus and firms' profits and competitiveness. Either the performance of the EU ETS or its impact on social welfare depends on how and to what extent the CO_2 price is passed through into power prices.

Given this premise, it is easy to understand why researchers, operators and regulators are so interested in the interaction between carbon and power prices. Nevertheless, the current literature on this topic is quite controversial, from both the theoretical and the empirical points of view.

On the theoretical side, an open question is how the CO_2 cost pass-through is correlated with the structural features of the output market, namely the power market. In fact, while it is quite clear what can occur under perfectly competitive scenarios, opinions diverge when the assumption of perfect competition is abandoned. Some authors state that under imperfect competition electricity prices increase more than in a competitive scenario, while others argue in favour of the opposite result (electricity prices increase less under market power). This controversial framework emerges because each contribution is based on specific and different hypotheses on the strategic behaviour of the firms, the technology mix and the regulation of both power and allowance markets. Consequently the results of each study cannot be generalized as they offer only a partial view of the problem.

The empirical literature is even more controversial. Some authors estimate full or almost full pass-through rates (PTRs). Others find that power prices do not internalize carbon costs or that there is limited evidence that CO_2 is factored into wholesale price. Indeed, most empirical analyses are simply trying to check whether there is a full pass-through and generically attribute the 'deviation' from this 'rule' to various structural factors (among which the exercise of market power in the output market) without attempting to measure their specific effects.

In addition, these studies differ significantly in their methodological approaches. Some rely on forward markets whereas others analyse spot prices. Some are based on the econometric elaboration of time series, whereas others examine the change in the price and/or spread duration curves (the 'load duration curve approach') and so on. Thus, no one empirical study, if considered separately, is useful to check the robustness of the theoretical models and, once again, is able to provide results which can be generalized.

The question of how the ETS can affect emissions is no less disputed. All authors agree that emissions are highest under the most-competitive scenarios. Nevertheless some contributions show that emission reductions are lowest under perfect competition, while others state that generally higher emission reductions are achieved in the case without market power.

Moreover policy makers', regulators' and operators' declarations and position papers do not help to clarify the overall framework, proving that opinions are not convergent even outside the scientific community. For instance, in Germany throughout 2005, the energy-intensive industries debated with power firms the question of responsibility for the carbon price pass-through into product prices. In other countries, such as Italy, the power industry ensured that there was no CO_2 cost pass-through in the wholesale power prices and, consequently, no windfall profit (mostly due to the pass-through of the opportunity costs of freely allocated CO_2 emission allowances).

These positions, however, became very difficult to defend when the carbon price collapsed at the end of April 2006. Since this fall was immediately followed by a drop in wholesale power prices in some European markets, it appeared unequivocally clear that there was an interaction between carbon and power prices. In other words, the empirical evidence confirmed what the theoretical analysis suggested, and thereafter the debate moved from the question of whether power companies gain windfall profits or not to more interesting arguments which can be summed up by means of the following questions.

Why do power prices seem to be correlated with the carbon price in some markets and not in others? Why do power firms pass through into power prices in some cases more and in others less than the carbon opportunity cost? What is the relationship between the pass-through and the structure of the power market? What is the influence of the technology mix and of the available generation capacity? How can market power in the power market affect the pass-through and vice versa? Can 'carbon trading' determine a rise rather than a decline in carbon emissions of the power system, at least in the short and medium runs? Should efforts be focused on bringing the electricity price down? Should regulators change the method of allocating the CO_2 emission allowances in order to improve the efficiency and effectiveness of the ETS and eliminate the windfall profits? Should policy makers and regulators care about the redistribution of the cost of the EU ETS among industry and consumers?

It is difficult to answer these questions without addressing first to what extent and under which conditions the CO_2 price is passed through into power prices. This requires carrying out a robust simulation model, on the theoretical side, and going beyond the results of a (country and methodological) specific study, on the empirical side. In other words, it is necessary to provide a comprehensive analysis that would be useful to understand how the pass-through depends on market structural features, on the one hand, and how methodological approaches affect the empirical results, on the other.

This book attempts to set out such an analysis and to answer these questions by bringing together and interpreting the contributions by the leading experts of each EU country or regional market. The volume is divided into two parts and has the following structure.

Part I includes an overview of the EU ETS, including its early results, and two chapters on the theoretical issues. These contributions are useful to interpret the empirical analyses in accordance with the statements of economic theory.

In particular, Chapter 2, by Chernyavs'ka, is organized as follows. First, the author describes the EU directive on emissions trading, discussing the CO_2 allowance market regulation (industrial sector covered, methods of allocation, regulatory periods and so on.).Then the allocation plans and the early results of the EU ETS are presented and discussed. Comments about the allowance price dynamic are proposed as well as considerations about the organization of the European CO_2 markets. Finally, the author explores the possibility of learning some lessons for the future, mainly by looking at the post-Kyoto and at the new EU targets (reducing emissions of greenhouse gases by 20 per cent by 2020).

In Chapter 3, Gullì examines the impact of trading of CO_2 emission allowances on electricity pricing in the short run. The author is mainly interested in exploring the role of electricity market structures. He uses a simple analytical model to verify whether (and under what conditions) the impact of the ETS under market power could be lower (or higher) than that under perfect competition. Furthermore, the author examines how emissions trading impacts on carbon emissions in the short run, that is, whether the environmental regulation can determine an increase (rather than a decrease) in pollution.

In Chapter 4, Reinaud focuses on the situation of energy-intensive industries going beyond the analysis of the spot electricity prices. She examines the way carbon price is passed through into end-user prices under different electricity pricing mechanisms such as short- and long-term contracts, regulated tariffs and so on.

Part II includes the empirical analyses of the main European markets. These studies are based on different methodological approaches and are collected and ordered so as to offer a comprehensive and thorough view of the topic.

In particular, Chapter 5, by Sijm, Hers and Wetzelaer, explores a variety of options to address EU ETS- induced increases in power prices and windfall profits, notably whether these options are effective and whether they also have other (adverse) effects. The study starts with the estimates of the average PTRs in Germany and the Netherlands. The authors find that empirical estimates of carbon cost PTRs on forward wholesale power markets varied from 0.4 to more than 1.0 in 2005–06.

Bunn and Fezzi (Chapter 6) address the economic impact of the EU ETS for carbon on wholesale electricity and gas prices. Specifically, the authors analyse the mutual relationship between electricity, gas and carbon prices in the daily spot markets in the United Kingdom and Germany. Using a structural co-integrated VAR (Vector Autoregression) model, they show how the prices of carbon and gas jointly influence the equilibrium price of electricity. Furthermore, the analysis derives the dynamic pass-through of carbon into electricity price and the response of electricity and carbon prices to shocks in the gas price.

Honkatukia, Mälkönen and Perrels (Chapter 7) examine the extent to which the costs of the EU ETS are reflected in the electricity prices in the Finnish power market. The study involves a simple theoretical illustration and an empirical exercise of electricity price formation. The authors use two econometric methods (the vector error correction model and the autoregressive conditional hederoskedasticity model) and find that about 50–100 per cent of a price change in the EU ETS is passed on to the Finnish NordPool spot price.

In Chapter 8, Chernyavs'ka and Gullì carry out an empirical analysis in the Italian context (an emblematic case of an imperfectly competitive market), which can be split in four sub-markets (North, macro-South, macro-Sicily and Sardinia) with different structural features. The authors use the 'load duration curve approach', which allows them to investigate how the pass-through depends on the degree of market power in power markets, other than on other structural features.

Finally, the contribution by Linares and Santos (Chapter 9) deals with the interaction between carbon markets and the policies supporting renewable energies. The authors look at how the EU ETS and a tradable green certificate system for the promotion of renewable energies may affect the Spanish electricity sector in the long term. The analysis was carried out using a generation-expansion model, which accounts for the possible oligopolistic behaviour of generation firms.

It is clearly beyond the scope of this introduction to enter into the details of each study, since the reader can find a full description of the methodologies and results in the corresponding chapters. The following provides a summary of the book's findings with regard to the theoretical and methodological issues as well as the empirical results and their policy implications.

The theoretical analysis shows that under imperfect competition the extent to which the carbon cost is passed through into power prices depends on several structural factors of the power market, namely: (i) the degree of market concentration; (ii) the technology mix; (iii) the available capacity; and (iv) the allowance prices. Depending on these factors, the marginal pass-through rate (MPTR) can be either above or below 1, that is, the increase in price under market power can be either higher or lower than that under perfect competition. Also, under certain conditions, the impact on power prices can even be slightly negative (at least, in principle), that is, the ETS can involve a decrease rather than an increase in prices. Market power, therefore, determines a significant deviation from the 'full pass-through' rule but we cannot know the sign of this deviation, a priori, that is, without first taking into account the structural features of the power market.

Another interesting result emerges from the theoretical analysis. The ETS causes a change in the degree of market power in the sense that, after the introduction of the trading scheme, the time (the number of hours in the year) over which power firms prefer to bid the maximum price (for example, the price cap) increases or decreases depending (again) on the structural factors of the power market. This means not only that the ETS can amplify or lessen the existing distortions in the output market but also that it might determine a rise rather than a decrease in carbon emissions, namely when the change in market power significantly expands the production share of the most-polluting plants. However, this does not necessarily imply that perfect competition is preferable to market power from the environmental point of view, but simply that under imperfect competition, and provided that certain conditions are satisfied, it might be more difficult to achieve the environmental targets.

With regard to the empirical results, Table 1.1 presents a summary of the estimated PTRs on the power markets analysed in this book. As can be noted, these values are significant in all cases and suggest that the

Table 1.1 Summary of the carbon cost pass-through rates

	Methodology	Price	Period	Average	Peak	Off-peak	
						Mid-merit	Very off-peak
Finland (Chapter 7)	Econometric VECM and AR-GARCH	Wholesale spot	2005–06	0.5–1.0			
Germany (Chapter 6)	Econometric VECM	Wholesale spot	2005–06	0.52			
Germany (Chapter 5)	Econometric OLS	Wholesale forward	2005		0.60	0.41	
			2006		0.57	0.64	
Italy–North (Chapter 8)	Load duration curve approach	Wholesale spot	2006		1.5−2.1	0.8−1.3	0.9−1.1
Italy–South (Chapter 8)	Load duration curve approach	Wholesale spot	2006		0.0−0.5	1.7−2.1	0.9−1.1
Italy–whole (Chapter 8)	Load duration curve approach	Wholesale spot	2006		1.1−1.5	1.2−1.5	0.9−1.1
Netherlands (Chapter 5)	Econometric OLS	Wholesale forward	2005		1.34	0.40	
			2006		1.10	0.38	
UK (Chapter 6)	Econometric VECM	Wholesale spot	2005–06	0.30			

Note: VECM = vector error correction model; AR-GARCH = autoregressive conditional heteroskedasticity model; OLS = ordinary least squares.

bandwidth for pass-through can be quite large, varying between countries and periods. The estimates range from 30 to 100 per cent if we refer to the average value, from 57 to 134 per cent in the peak hours and from 40 to 123 per cent in the off-peak hours. Furthermore, the analysis of how the PTR is distributed over time (between peak and off-peak periods) would seem to suggest that there is not the same behaviour everywhere (that is, no general rule). The PTR is higher in the peak than in the off-peak hours in Germany (2005), the Netherlands and Italy–South, and vice versa in Germany (2006) and Italy–North. The overall picture, therefore, would seem to support the conclusions of the theoretical analysis, that is, we cannot know how the ETS impacts on power prices (whether the PTR is low or high, more or less than 1) without first accounting for the structural features of the power markets under analysis.

Furthermore, the estimates have to be interpreted with due care as, to some extent, they depend on (shortcomings of) the data and the methodologies used or the assumptions made. With regard to the methodological issues, the contributors use many empirical methods to estimate carbon price PTRs. Each method has its own strengths and weaknesses, so that one approach cannot be considered as definitively preferable to another. Nevertheless, there are some important differences between the econometric and non-econometric techniques.

The econometric approach uses sophisticated statistical tools in order to measure carbon price PTRs. It is based on the statistical elaboration of time-series of either forward or spot prices (of both electricity and carbon) and estimates the impact of the ETS on the average price, eventually distinguishing between the peak and off-peak hours. The specifications of these models are generally quite simple. The set of drivers commonly includes the fuel costs and the temperature (Sijm et al., Chapter 5; Bunn and Fezzi, Chapter 6). Only one model (Honkatukia et al., Chapter 7) uses additional variables (namely, the production capacity and the utilization of the transmission capacity). Furthermore, models neither consider the real marginal technology hour by hour nor are suited to capture (by using appropriate drivers) the effect of market power. They assume that during the observation period power prices are set by a single (marginal) technology with a fixed, generic fuel efficiency. In other words, the econometric models are very useful for providing a precise (statistically significant) value of the carbon pass-through but they are not able to justify this value, that is to explain why a PTR is high, low or zero.

The non-econometric approach consists of two steps: (i) estimate the PTR by means of an analytical model; and (ii) compare the estimates with the observed data. It does not elaborate time series but carry out the pass-through distribution over time (the pass-through curve) starting from the load duration curve. This allows us to obtain the PTR hour by hour. The non-econometric approach has several advantages compared with the econometric one. First, as pointed out before, it provides a detailed analysis of the pass-through over time, on an hour-by-hour basis. As a result, it seems to be well suited to describe the impact of market power whose extent depends on the level of power demand (and hence on the time of consumption). Moreover, by using this approach, market power can be effectively simulated by means of a theoretical model assuming oligopolistic competition or (as in Chapter 3) a dominant firm framework. Second, the non-econometric approach allows us to take into account other important structural factors which cannot be included in econometric models, for example, the technological mix and the available capacity in the market. However, unlike the statistical approach, it does not provide a precise value of the pass-through but only a range of its variability. In this sense, the two approaches are complementary. The non-econometric one is useful to improve the specification of the statistical models and to interpret their results.

Finally, concerning the policy implications, this work can help to shed light on two issues: (i) the effectiveness and efficiency of the ETS itself (regardless of its specific design); and (ii) how the current design of the EU ETS should be changed in order to improve its performance.

With regard to the ETS itself, the theoretical and empirical analyses highlight that under imperfect competition power prices may increase less than under perfectly competitive scenarios. Thus, provided that certain conditions are satisfied, imperfect competition can partly lessen the ETS effectiveness in terms of emission abatement. Also, under certain conditions, the ETS can determine a rise rather than a decrease in carbon emissions, at least in principle. At the same time, the change in emissions becomes high only when the carbon price is above the 'switching price', that is, when the carbon cost internalization determines a switch in the merit order of power plants, for example between coal and gas-fired plants. Thus, in designing the ETS, regulators should mainly ensure that the allocation will create an adequate scarcity of tradable permits. Furthermore, policy makers should also take into account the interaction of the scheme with other energy and environmental policies. For instance, a combination of both carbon reduction and renewable promotion policies may result in lower costs than carbon reduction policies alone, with the additional benefit of increased deployment of the renewable technologies.

Looking at the design of the scheme, we have to be aware that the increase in power prices due to the pass-through of the (opportunity) costs of (freely allocated) CO_2 emission allowances is a rational and intended effect from an efficient carbon abatement policy perspective. Nevertheless, the supposed ETS-induced increases in power prices and generators' profits (windfall) have raised several concerns about its impact on the international competitiveness of some power-intensive industries, the purchasing power of electricity end-users such as small households or, more generally, the distribution of social welfare among power producers and consumers. As a result, in several countries, a variety of options have been suggested in order to address these concerns, such as changing the ETS allocation system, taxing windfall profits or controlling the market prices of EU carbon allowances, electricity or both. Some contributions of this book, and especially Chapter 5, examine these options in order to address their performance and suggest the best way of improving the design of the scheme.

Overall, this volume attempts to offer a comprehensive analysis of the relationship between carbon and power markets. As such we hope it will provide a useful contribution to the debate on the perspective of the EU ETS and to the literature on the interaction between environmental policy and the structure of the environmentally regulated markets.