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Abstract:
Since 2005, the EU ETS has provided a market-based price signal for European carbon emissions, accompanied by increasing economic research related to this policy instrument. In this paper, we carry out a review of the empirical literature examining allowance price formation. A consensus has emerged that allowance prices are significantly related to fuel prices and to variables affecting the expected amount of necessary abatement, such as economic activity or changes in the cap. However, the relationship is not robust, probably because the relevant abatement technologies change with the economic conditions they operate in. There is evidence that models explicitly accounting for uncertainty about future demand and supply of abatement are better at explaining allowance price variation during certain periods. Yet, our understanding of the level of the allowance price remains poor. We cannot say with any degree of confidence whether the price is "right," in the sense that it reflects marginal abatement costs, or whether there is a price wedge caused by transaction costs, price manipulation, or other sources of inefficiency. Nevertheless, the market has matured compared to Phase I, and the banking provision has induced it to incorporate future scarcity of allowances and to smooth the effect of transient shocks as intended.

Keywords: EU emission trading, allowance prices, market efficiency

JEL classification: Q56, Q58

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Introduction

The European Emission Trading Scheme (EU ETS) has been operating for more than eight years and is currently in its third phase. It provides the institutional framework for market forces to determine the price of carbon emissions in energy-intensive industrial sectors in Europe. The EU ETS is not only the central instrument for Europe's climate policy but also a globally observed experiment testing whether emission abatement can be achieved efficiently. First initiatives toward linking the EU ETS during Phase III with other emission trading schemes bolster the hope that the EU ETS will become the precursor for a global carbon market.

Generally speaking, the goal of emissions trading is to achieve a given emissions target at least cost by equalizing marginal abatement costs across firms (e.g., Montgomery 1972, Tietenberg 1985). Profit-maximizing firms will reduce emissions as long as this is cheaper than purchasing allowances on the market, and vice versa. The efficient allowance price is equal to the cost of reducing emissions to one unit below the cap, which is generally referred to as the market's marginal abatement cost. Accordingly, efficient abatement decisions require reliable allowance prices reflecting all available information on the cost of reducing emissions to achieve the cap. The role of allowance prices as an indicator for whether emissions trading works has spurred a sizeable literature on allowance price formation. In this paper, we review this literature with a focus on empirical analyses during Phase II of the EU ETS. For a more general review of the EU ETS and the implications of the EU-ETS on the firm-level, we refer the reader to Ellerman, Marcantonini and Zaklan (2014) and Martin, Muûls and Wagner (2014), respectively.

In the standard theoretical framework, the relevant drivers of allowance prices are current marginal abatement costs. However, this stylized view ignores important implications arising from such factors as banking and borrowing rules (Rubin 1996, Schennach 2000), imperfect information or transaction costs (Hahn 1989, Lewis and Sappington 1995), market power (Montero, 2009), and uncertainty about future emissions and prices (Seifert et al. 2008). Not surprisingly, there is evidence that observable determinants of supply and demand are not sufficient to explain price behavior in the EU ETS. In neither of its first two phases did the price immediately plunge toward zero, even when it became apparent that no further abatement was needed for within-phase compliance. While the positive price towards the end of Phase II can be explained by the possibility of banking allowances into the next phase, the price throughout most of Phase I (where banking into Phase II was not allowed) suggests that the allowance price is influenced by other factors besides marginal abatement costs in the purely engineering sense of the term. The existence of such factors is also supported by the considerable dynamism of the allowance price over time and by the positive spread between the price for allowances and Kyoto offsets.

In this review, we include papers covering a range of different aspects associated with allowance price determination. Because of the size of the existing literature, we had to make a selection. We focus on contributions that provide new insights or are characteristic for a larger set of papers and their findings, but ignore those that are only loosely related to allowance price formation. Where appropriate, we also included literature reviews. We generally gave preference to papers that are based on the – in our view - most rigorous and reliable methodological approaches. Beyond this pre-selection, we chose not to engage in any further quality differentiation between studies but to let the authors speak for themselves.

The first section in our review article addresses the dynamics of allowance prices. We start by explaining how fundamental factors like fuel prices are related to allowance prices according to marginal abatement cost theory and discuss the most influential empirical papers on this relation that cover Phase II. Due to the still limited ability of these deterministic models to explain allowance price variation, we then turn to models which explicitly include the influence of uncertainty by applying option theory. Finally, we briefly discuss solely technical analyses on allowance price dynamics.

However, price *changes* are only one dimension of allowance price formation. Equally important is the price *level*, the second issue that we discuss, and which has received much less attention in the literature. This is due to the absence of an observable counterfactual for business as usual (BAU) emissions, which have to be estimated by means simulation models, along with the required amount of emissions abatement and the associated costs. This is very challenging because the amount of necessary abatement within the EU ETS perimeter depends not only on economic activity, but also on other government policies with implications for the supply and demand of allowances, such as the link to the Kyoto Protocol's flexible mechanisms or the presence of feed-in tariffs and quotas for renewable energy. The relationship between BAU emissions, the cap and the allowance price is further affected by inefficient trading behavior, e.g. due to transaction costs or imperfect competition. Because all of these issues affect the allowance price level rather than marginal price changes, we discuss the literature pertaining them in the price levels section. Finally, we propose avenues for further research and offer some conclusions.

Allowance Price Dynamics

If the market works, the allowance price is determined by supply and demand. Allowance supply is primarily defined by policy decisions such as the level of the emissions cap, linkages to other emission markets, or rules about banking and borrowing. Because supply decisions predominantly affect the price level, we discuss them in the next chapter and now focus on factors determining allowance demand.

Price fundamentals

Business as usual emissions and weather variations

The main drivers of allowance demand are business-as-usual (BAU) emissions in the sectors covered by the EU ETS, which are primarily driven by economic growth and the economy's energy efficiency and (carbon) emission intensity. In the short term, BAU emissions are also driven by weather variation because they have an impact on the energy demand for heating or cooling[1] and on power generation from renewables (e.g., Considine 2000, Alberola et al. 2008, Hintermann 2010). Scandinavia, for example, experienced an exceptionally dry year in 1996. As a result, Danish carbon emissions subsequently almost doubled compared to 1996 levels, because instead of importing carbon-free hydropower from Sweden and Norway, Denmark was exporting carbon-intensive coal-based power to those countries (Christiansen et al. 2005).

Abatement of emissions

Based on survey data, Heindl and Löschel (2012) report that during Phase II, process optimization and investment in energy efficiency were the most popular abatement options. Because these investments affect the price level but not daily fluctuations, the literature on fundamental influence factors focuses on fuel switching prompted by the change in the "merit order" of electricity generation (the order according to which generators are brought on line, usually based on lowest cost) as the most relevant short-term abatement option (e.g., Christiansen et al. 2005, Kanen 2006, Bertrand 2014). Due to the structure of the electricity sector in Europe, fuel switching is expected to take place mainly between coal and gas.

Under perfect competition, power providers will base their supply bids on marginal generation costs. The cost of carbon emissions should induce fuel switching between all available generators as long as the implicit abatement cost (i.e., the difference in fuel costs divided by the difference in carbon emissions between coal and gas) does not exceed the allowance price. This implicit abatement cost is known as the "fuel-switching" price. Under oligopolistic competition, fuel switching may predominantly take place via substitution of generators owned by the same firm, but the nature of the abatement method (i.e. a switch away from coal and toward gas generation) is independent of the market structure. Using data from eight European countries between 1978 and 2004, Pettersson et al. (2013) provide evidence for fuel switching taking place, notably in countries with a high

[1] The relation between temperature and energy demand is U-shaped (Bunn and Fezzi 2008). Temperatures below a certain threshold can lead to an increase in energy demand for heating purposes; temperatures above a certain threshold can lead to an increase in energy demand for cooling purposes.

proportion of gas, coal, and oil generation. In general, an increase in the gas/coal price ratio increases the fuel switching price and should therefore result in an (equivalent) increase of the allowance price.

Evidence from Phase I

The relationship between marginal abatement cost changes and the allowance price has been studied since the launch of the EU ETS. Mansanett-Bataller et al. (2007) investigate how variations in fuel prices and weather variables influence carbon price dynamics. Alberola et al. (2008) additionally consider the influence of economic activity and electricity prices, and Hintermann (2010) further includes the influence of hydropower provision discounting and the time remaining before the end of the phase. For a detailed overview of the various studies of allowance price dynamics during Phase I, we refer the interested reader to Zhang and Wei (2010).

All studies about Phase I had to deal with the implications of a new and immature market, in which price formation was significantly influenced by political decisions and announcements. The most salient example is perhaps the announcements of lower than expected emissions during the first year, which led to the allowance price crash in April 2006. Considering this, it is not surprising that the early studies provided a mixed assessment of the influence of fundamentals on price dynamics. For example, even though most studies identify a positive impact from gas and oil prices, they disagree about the influence of the coal price and provide inconclusive results on the influence of weather variables and of stock indices (representing expected economic activity). Overall, they only explain a relatively small share of allowance price variation based on observed price fundamentals.

Evidence on the influence of price fundamentals in Phase II

Empirical investigations on the influence of the fundamental factors rely basically on time series models. In particular, the inclusion of the electricity price in the analysis requires estimation approaches to account for possible interactions with the carbon price. Because there is no single electricity price across Europe, studies including the electricity price focus on large countries (e.g., Germany) or regions believed to be large enough to influence the allowance price. Besides geographic coverage, studies also differ with respect to the time periods covered, the selected price variables, and the representation of weather variables, all of which makes it difficult to compare the results directly in terms of magnitude. Table 1 provides an overview of the studies discussed in this subsection. Across all studies, economic activity and growth announcements are found to positively influence allowance prices on an intra-day, daily, weekly, and monthly basis, and the same applies for the oil price.[2] We now discuss the influence of other fundamentals in turn.

Table 1 about here

Gas and coal prices

If explicitly included, the natural gas price is found to have a positive and statistically significant influence on allowance prices across all studies. However, the same is not the case for the coal price. Aatola et al. (2013) and Fell et al. (2014) find a positive influence of the coal price, however, the studies of Lutz et al. (2013), Koch et al. (2014), and Rickels et al. (2014) find either a non-significant or even positive influence of the coal price. The study of Creti et al. (2012) reports a significant influence of the fuel switching price, but does not investigate whether this is due to the price of natural gas, coal, or both.

Interestingly, the two studies finding a positive influence of the coal price include also the electricity price, either as an exogenous variable represented by an instrument variable or as an endogenous variable represented in an error correction model (Aatola et al. 2013[3] and Fell et al. 2014, respectively). Accordingly, it is possible that studies without an electricity price miss an important

[2] There is no consensus whether the influence of the oil price is due to it being a proxy for economic activity, natural gas prices, or (limited) fuel switching from coal to oil (Pettersson et al., 2013).
[3] The corresponding results in the VAR analysis of Aatola et al. (2013) are smaller than in the OLS and IV estimations so that we focus in our discussion of the results of the latter two models.

aspect of the European energy market and their results regarding the coal price are explained by omitted influences. Motivated by the results of Schernikau (2010) and Zaklan et al. (2012) regarding the coal market, Rickels et al. (2014) argue that our understanding of the European energy markets is still insufficient. They use a broad set of coal, gas, and oil prices to perform auxiliary single regressions to identify the price series that best explains variation in allowances prices. Their analysis reveals that while different fuel price series are highly correlated in level, the correlation is significantly lower in a stationary representation (i.e., first differences or first differences of log prices), which implies a different explanatory power of fuel prices in these two types of representations.

Cointegration among prices

The possibility of jointly determined electricity, fuel, and allowances prices has motivated several authors to engage in cointegration analyses. Despite excluding the electricity price (to avoid problems with the heterogeneity of the European electricity markets), Creti et al. (2012) find prices to be cointegrated, but show that since 2009, price predictions based on fuel prices have exceeded actual allowance prices. Using monthly data, Koch et al. (2014) do not confirm the existence of a cointegration relationship between allowance and fuel prices. Rickels et al. (2014) show that the identification of a cointegration relationship is sensitive to the specific fuel price series selected, and argue that conditional on the “right” combination of prices and estimation methodology, statistically significant cointegration can be found that nevertheless may not reflect an economically meaningful long-term relationship.

Studies including the electricity price report more robust cointegration between electricity, fuel, and allowance prices (Bunn and Fezzi, 2008 for the UK, and Fell, 2010 for the Nordic market), but they raise the question to which extent a regional market segment of the EU ETS can influence the allowance price. Using a multi-country framework, Fell et al. (2014) investigate cointegration between fuel, electricity and allowance prices not only within, but also between different electricity markets. They identify a significant positive equilibrium effect for gas and a negative effect for coal futures on the allowance price, although the estimate for the former is rather imprecise.

The relationship between allowance and fuel prices might be difficult to be explained by fuel price variations alone. For example, Delarue et al. (2010) argue that fuel switching is probably evident during some hours of the day but cannot be easily seen in the daily aggregated price series that are used to explain fuel switching across Europe. This is indirectly confirmed by Conrad et al. (2012) who show that the various variables representing (macroeconomic) announcement effects with significant influence on intraday allowance price dynamics become insignificant at the daily frequency. Accordingly, an issue for further research would be accounting for the fact that both the scope and the price of fuel switching should change with the demand for fossil-based electricity, because different generators can be substituted for one another at a different point in time. This may be of increasing importance since the demand for fossil-based generation has decreased over the years as more renewables enter the system.

Renewable energy supply and weather variations

Rickels et al. (2014) confirm the negative influence of reservoir levels in Nordic countries on allowance prices previously identified by Hintermann (2010) and Fell et al. (2010) for Phase I. Fell et al. (2014) provide indirect evidence in the sense that they find reservoir levels to be negatively correlated with the electricity price, which in turn is positively cointegrated with the allowance price. This link is confirmed by the study of Aatola et al. (2013) who use Nordic reservoir levels to instrument for electricity prices, which then influence the allowance price in the same manner. In contrast, Koch et al. (2014) find no significant influence of hydropower provision on a monthly basis. However, their data does not include hydropower provision in Scandinavia and focuses on production rather than storage levels.[4]

[4] Whereas an increase in hydro generation can reflect either increased supply of hydro power or demand for all electricity, a larger than normal reservoir level clearly indicates an increase in supply in the medium to long run.

Regarding the increasing share of other renewable energy supplies, Rickels et al. (2014) find no robust significant influence of wind power provision in Germany, Denmark and Sweden on the allowance price, whereas Koch et al. (2014) report a significant negative influence of wind and solar electricity supply in Austria, Belgium, France, Germany, Italy, Netherland, Portugal, and Spain using monthly data. In terms of variations in demand due to weather, Lutz et al. (2013) include variations in daily temperature but find no significant influence neither in their basic estimation nor in their switching regime analysis. This result is confirmed by Rickels et al. (2014) and Koch et al. (2014) who use variations in electricity consumption to account for weather driven demand variations. Although counter-intuitive at first sight, this result can be explained by the mean-reverting nature of weather-related shocks in combination with banking, to which we turn next.

Fundamental analysis under allowance banking

Since the beginning of Phase II there have been no restrictions on the banking of allowances. By contrast, borrowing is only allowed within, but not between, market phases. Given the over-supply in Phase II, the borrowing constraint was not binding during the transition to Phase III, and considering the planned tightening of the cap after 2020, it is not likely to become binding at the end of Phase III either. The presence of banking allows for bi-directional price smoothing between phases, because an emissions-increasing shock can be countered by a reduction in the planned amount of banked allowances. In this sense, firms can "quasi-borrow" by reducing the amount of allowances planned to be banked.

Banking and (quasi-)borrowing imply that the considerations of marginal abatement cost theory apply to cumulative expected abatement costs rather than to the daily abatement decision -- with important implications for the ability to find empirical evidence for fundamental factors discussed above. For example, banking and borrowing should eliminate the impact of mean-reverting shocks to allowance demand, because such shocks will cancel out over time and leave cumulative demand unchanged. The insignificant influence of weather and electricity consumption variations during Phase II provide evidence for this hypothesis. Koch et al. (2014) show that explanatory variables for economic activity are significant as long they represent some forward-looking indicators while backward-looking indicators have no significant influence on allowance price dynamics.

Naturally, weather changes that are not expected to be mean-reverting (e.g., due to climate change), or an increase in the capacity of renewable generation, do not share this property and thus are expected to affect the overall demand and supply of allowances, and thus the allowance price.

Even in the absence of inter-phase banking, the fact that firms can fully bank and borrow within a phase implies that mean-reverting shocks to BAU emissions in the beginning of a trading period should not have a significant influence on allowance prices. This is because they are likely to be canceled out by shocks of similar magnitude but opposite sign before the end of the phase, a result derived by Hintermann (2010) and used in his empirical specification in the context of Phase I (where no banking was allowed). Applying a stylized partial equilibrium model with differences in the efficiency in the gas power plant portfolio, Bertrand (2014) shows that positive shocks in BAU emissions can result in an even greater influence of the gas price on the allowance price towards the end of the trading period.

To summarize, observed fundamental factors thus appear to affect allowance prices, mostly as predicted by theory, but they explain only a part of the observed price variation. Furthermore, the dummy variables for certain dates included by many studies significantly affect the results, indicating that the EU ETS might be described by different regimes and is still influenced by policy announcements, in particular those that have implications for the expectations of market participants. Accordingly, we turn now to additional or alternative explanations for EUA price dynamics.

The role of uncertainty

The results discussed so far disregard uncertainty related to the various price determinants. Future fuel prices and other observable allowance price drivers are uncertain, and unforeseen demand variations make BAU emissions stochastic as well. This implies that the allowance price should reflect the expectations of market participants about scarcity of allowances in a general sense, including the associated uncertainty.

The option value of holding an allowance

If abatement depends on irreversible investment in abatement technology, for example a new generator, holding an allowance provides the firm with an option to postpone abatement decisions until more information becomes available. Depending on its abatement costs, it might then decide to either use it for compliance or to sell it at the end of the period (e.g., Chao and Wilson 1993, Schennach 2000, Chesney and Taschini 2012). The allowance price should therefore exceed the marginal abatement costs by this real option value. In a numerical simulation, Carmona et al. (2009) show that if uncertainty and irreversibility of abatement decisions are factored in, allowance prices are only a poor indicator of marginal abatement costs. Without the possibility of banking, a non-zero probability of exceeding the cap is sufficient for the allowance price to remain positive, even if the market is over-allocated in expectation (Seifert et al. 2008, Chesney and Taschini 2012). In this situation, the uncertainty—and hence also the option value—is largest at the outset and diminishes during the trading period.

Hintermann (2012) applies options theory to investigate allowance price dynamics during Phase I and considers the case without abatement. Holding an allowance can then be interpreted as the right to be exempt from paying a penalty in the case the cap is exceeded, which makes an allowance a binary (i.e., “all or nothing”) option. Populating the model with residual demand for fossil fuel-based electricity generation, the author finds that an-option pricing formula that depends on the penalty for non-compliance and the probability of emissions exceeding the cap, explains a significant proportion of allowance price variation and the slowly declining value of allowances toward the end of the phase, even in the face of apparent over-allocation. To our knowledge, no similar application exists for Phase II.

Mixed approaches

The influence of uncertainty and hence the option value of allowances (or related concepts) may provide a better explanation of price dynamics in some periods, whereas "traditional" market fundamentals will dominate in others. To account for this possibility, Lutz et al. (2013) use a regime-switching model to distinguishing between regimes without a clear price trend but with high volatility and regimes with positive mean price changes and lower volatility. After introducing regime shifts, the authors find as theory predicts a negative influence of the coal price on the allowance price, which was not the case in the (single-regime) base model. Furthermore, they show that the high-volatility regime appears to explain price dynamics during the recent economic recession in 2008 and 2009 and argue that declining emissions were responsible for the increasing uncertainty on whether the cap was still binding. A study by Chevallier (2011) that also allows for regime-switching finds that the economic fundamentals affect carbon prices differently during different time periods.

To summarize, including uncertainty provides promising avenues for future research but also provides new perspectives of interpreting the results of the deterministic empirical models which will remain an important instrument for analyzing allowance price dynamics. There is evidence that regime-switching models are able to capture the changing importance of different allowance price drivers from an ex-post perspective. Their drawback is that they identify neither the economic mechanisms underlying the different regimes nor the determinants for the switch between them. This drawback applies also to the "carbon finance" literature (which investigates allowance price dynamics from a technical perspective) to which we turn now.

Technical analysis of allowance price dynamics

The literature summarized under the term "carbon finance" focusses in particular on the volatility of allowance prices from an econometric point of view. For example, Paolella and Taschini (2008) were the first to show that GARCH models are suitable for accommodating heteroscedasticity and unconditional tail distribution in allowance price series. The partially stochastic behavior of allowance prices in the presence of volatility clustering has also been investigated and confirmed by Benz and

Trück (2009), Chevallier (2011), Feng et al. (2011), and Conrad et al. (2012). Daskalakis et al. (2009) and Gronwald and Ketterer (2012) allow for the possibility of price jumps, and Gronwald et al. (2011) estimate the relationship between allowance prices and financial markets by using copulas, a method that relaxes the assumptions on the underlying error structure. Generally, these papers are characteristic for a larger strand of literature that applies established methods for analyzing financial markets to the new EUA market. A detailed assessment of this rapidly growing literature is beyond the scope of this paper but would be a worthwhile endeavor. It is not always clear how to interpret the results of the econometric approaches that are not based on theoretical or conceptual models but try to let the data speak for themselves. What this literature clearly shows is that even though the scarcity of CO_2 emissions is only institutionally induced, the EUA market functions similar to other commodity markets.

Allowance Price Levels

The somewhat ambiguous empirical explanation of allowance price dynamics may be a sign of inefficiencies in an immature market, but it may also be due to the fact that various factors influence price *levels* rather than price *dynamics*. We now turn to the empirical literature that is, directly or indirectly, related to the price level and also discuss in more detail the effects of banking and borrowing and of additional climate policies like the link to the Kyoto market.

The price/quantity interaction for abatement costs

The assumption underlying the empirical literature discussed above is that the relationship between fundamentals and the allowance price is linear or subject to some other stable relationship. While this may be true locally, it almost certainly does not hold globally. If an increase in the natural gas price by €1/MWh leads to an expected increase of the allowance price by, say, €0.5, then this does not necessarily imply that a gas price increase by €40/MWh would raise the allowance price by €20. Furthermore, Schennach (2000) shows that the effect of positive and negative BAU emission shocks on the allowance price may differ when borrowing is not permitted.

Consider the economy-wide marginal abatement cost (MAC) curve that ranks different methods for reducing emissions by cost. The marginal abatement technology, i.e. the method employed to reduce emissions by one ton below the cap, depends on the required abatement amount, which is not fixed but depends on a series of variables, including fuel prices. A change in the gas price may influence a change in BAU emissions in all sectors to the point where the generators involved in fuel switching are quite different, or where fuel switching is no longer the abatement technology at the margin. This clearly indicates that the marginal effect measured by the studies discussed above is really the compound of a relative price effect (a change in the *level* of the MAC curve) and a quantity effect (a movement *along* the MAC curve).

Whereas the local estimate of the marginal effect is unaffected, the price/quantity interaction bodes ill for predictions of the effect of non-marginal changes, even if the assumption of fuel switching as the main abatement method is maintained. For example, if the EU were considering a reduction in the future emissions cap by 20%, the studies discussed above would be of little use in predicting the resulting allowance price, even if some of them include proxies for economic activity (such as stock indices or the oil price) in order to control for BAU emissions. Qualitatively similar to policy decisions regarding the cap is the introduction of alternative climate policies and the link to the Kyoto market, both of which affect the amount of abatement necessary to achieve the cap.

Several studies show that regulatory announcements (e.g. about National allocation plans or future caps) impacted allowance prices in Phase I (Alberola et al. 2008, Conrad et al. 2012, Manasanet-Bataller and Pardo 2009) as well as in Phase II (Manasanet-Bataller and Sanin 2014). However, since market participants' expectations are unobservable, this type of ex-post analysis does not enable us to predict the price level in response to a projected change in expected abatement amounts or costs.

One way to analyze price/quantity interactions in connection with abatement is to use numerical simulation models that can produce MAC curves for the entire EU ETS or compute the effects of different abatement and policy scenarios on the allowance price. For example, increasing the emission reduction from 20% to 30% in 2020 (relative to emission levels in 1990) is expected to result in an approximate doubling of the allowance price (Saveyn et al. 2011, Bosello et al. 2013).

Allowance banking and borrowing

The possibility of transferring allowances between phases implies that the overall long-term cap, rather than the phase-specific cap, will determine the path of the allowance price. Without uncertainty, efficiency implies that firms will abate emissions and bank and borrow allowances so that the allowance price increases at the rate of interest (e.g., Rubin 1996). Banking and borrowing links the allowance price levels in different periods and thus enables firms to smooth their abatement costs over time. The presence of uncertainty does not change the qualitative nature of abatement smoothing, but it can provide additional incentives for banking if firms hedge against emission risk. Without banking and borrowing, hedging becomes more expensive (Schennach 2000, Daskalakis et al. 2009).

The positive allowance prices toward the end of Phase II indicate that market participants bank allowances into Phase III in awareness of regulatory uncertainty and the expectation of an overall short position in future years. For example, Trück et al. (2012) show that during Phase II the market changed from initial backwardation to contango, indicating that firms were taking out insurance against rising prices. Therefore, as discussed earlier, the allowance prices reflect both expectations about the future condition of the market and the required risk premium for holding them.

Policies with implications for the allowance price level

In general, any policy affecting the emissions of installations or sectors participating in the EU ETS can be expected to exert an influence on the demand for emission allowances and hence on allowance prices. This is particularly true of carbon or energy taxes and policies designed to promote energy efficiency and renewable energy (Sorrell and Sijm 2003). As a result of the different support policies, the share of electricity from renewable sources (RES-E) in the EU's gross electricity generation rose from 14.6 percent in 2005, when the EU ETS came into being, to 19.6 percent in 2010 (Sturc 2012).

Most renewable energy still comes in the form of hydropower (about 57 percent), but in 2005, the share of wind power in RES-E had reached 22 percent, whereas solar power still accounted for only 3 percent. The remainder comes from biomass and biogas.

When the EU agreed on its 20 percent renewables target, a number of simulation studies analyzed the effects of this additional target on the EU allowance price (e.g. Traber and Kemfert 2009, Böhringer and Rosendahl 2011). These studies show a wide range of allowance price reductions for different renewable scenarios. While some studies find almost no effect at all, others predict that allowance prices will be reduced to zero. In the end, results depend very much on the specific model and the assumptions behind the scenarios. The one empirical study by Koch et al. (2014) in this context that examines to what extent renewable polices can explain the EUA price drop in mid-2008, finds only a very modest effect.

Another important policy that affects the price level is the link to the Kyoto Protocol's flexible mechanisms, as outlined in the EU's "Linking Directive" (EU, 2004), which allows firms to use a limited number of Kyoto offsets to cover their emissions in lieu of EUAs. This creates an additional supply of allowances and hence lowers equilibrium price levels. To trace the potential effect of Kyoto offset use on allowance price levels, we again have to rely on numerical studies. Klepper and Peterson (2006) and Anger (2008) show that allowance prices are between 30 to 50% lower than in a situation without offset use. However, these simulations presume one single allowance price—contrasting the reality with a positive spread between the allowance and the offset price.

Mansanet-Bataller et al. (2011) find that this spread decreases with the allowance price level and attribute it to transactions costs. Likewise, Fitzgerald et al. (2014) show that transactions costs explain at least part of the variation in the heterogeneity of offset use across sectors and countries. Beside transaction costs, the price differential could be caused by import limits restricting the permit flow to an amount smaller than would be needed for full convergence. Such limited linking leads to a decrease, of the original price differential, but not its elimination (see, e.g., Grüll and Taschini 2011).

Note that although the import limit for Phase II itself had not been met, the EU decided in 2010 that any unused offset allowances could be banked into Phase III.

Another factor explaining the price spread may again derive from uncertainty. Due to a lengthy process of certification that is prone to delays and attrition, the total number of offsets available by a certain year is uncertain (Trotignon and Leguet 2009). Demand for CERs from outside the EU ETS is also uncertain, as this depends on Annex B-countries' total emissions and national climate policies. Given this uncertainty about demand and supply of CERs, the import limit may or may not turn out to be binding. Nazifi (2013) shows that the uncertainty surrounding offsets (e.g., default risk connected with financial institutions guaranteeing the provisions of offsets) reduces their (substitution) value and explains a significant portion of the price spread. In a theory paper, Barrieu and Fehr (2014) derive the relationship between Phase II EUAs, Phase III EUAs, and CERs under uncertainty. With positive banking of EUAs, the price of a CER turns is a probability-weighted combination of the expected end-of-phase prices for EUAs and the opportunity cost of offsets. Unpublished work by the authors suggests that an empirical formulation of Barrieu and Fehr's (2014) can explain the CER price collapse at the end of 2012 by market participants expecting the import limit for offsets to be binding with almost complete certainty.

In short, a large set of policies overlapping with the EU ETS have probably decreased the level of EUA prices, and the same applies to the link to the KP's flexible mechanisms. But the fact that they are unlikely to become evident in daily allowance price fluctuations also means that aside from the findings of a few numerical studies, we know very little about the strength of these effects.

Thin trading and transaction costs

Transaction costs are not only important to explain offset prices. The strong presence of market intermediates providing consultation services and decision tools for firms dealing with the financial risks and opportunities arising from their involvement in the carbon market implies that transaction costs are an issue also in the EU ETS itself. Transaction costs and resultant low-level trading might imply that, even when the market is supposed to be in a long position, there is an insufficient supply of allowances in the short run. Installations with a combined allocation of almost 30 percent of the total cap did not engage in any trade through April 2007, thus effectively removing this quantity from the market (Hintermann 2013).[5] Survey data show that only about 51 and 54 percent of German firms under the EU ETS were involved in trading in 2009 and 2010, respectively, and almost two-thirds of them traded only once a year (Heindl 2012). In particular, though small firms tend to hold a surplus of allowances, transaction costs appear to make them abstain from trading (Jaraitė et al. 2010, Heindl 2012). If firms with an allowance surplus do not offer their permits for sale, the resulting market price will be inefficiently high.

Thin trading may cause a market to be inefficient because not all available information is reflected in the price. Montagnoli and de Vries (2010) apply a number of variance-ratio tests to detect persistence in allowance price trends; if markets are efficient, such trends should not exist. The results confirm the presence trends during Phase I, but that efficiency increased during Phase II. Crossland et al. (2013) investigate the extent to which the EU ETS market can be regarded as weakly efficient in the sense that prices are not predictable. Basing their analysis on daily spot prices from the beginning of Phase II to June 2011, they investigate whether profits can be realized by following a momentum strategy (buying outperformers and selling underperformers) or a reversal strategy (selling outperformers and buying underperformers). They find that, in the short term, the market is characterized by momentum in the allowance prices, whereas there is evidence of over-reaction and hence potential for a reversal strategy in the medium term. In the long-term perspective (up to 12 months), the market again displays under-reaction and the momentum that goes with it. They conclude that the EU ETS market is not yet information-efficient.

Daskalakis (2013) also investigates the extent to which the EU ETS market conforms to the weak form of market efficiency and focuses on the futures market because of its role in price discovery and its

[5] Since trading data is kept confidential for five years (recently reduced to three), the corresponding figure for Phase II is not yet known. Data for 2008 suggests that although trading has increased, many firms are still rather inactive.

higher liquidity compared to the spot market. The investigation covers Phase II up to December 2011 and shows that simple technical analysis rules could have generated substantial risk-adjusted positive returns, at least in the period from 2008 to 2009, while from 2010 onwards there were signs of growing market efficiency. Niblock and Harrison (2013) confirm this view and show that the EU ETS became more efficient during Phase II, emphasizing that this development took place during a period of sustained market volatility due to the European sovereign debt crisis and fairly low allowance trading volumes. However, applying spot data from up to February 2012, they find that the application of simple trading rules cannot generate higher profits than a buy-and-hold strategy. Despite contradictory findings about the performance of trading rules, the results indicate that (a) market efficiency increased during Phase II and (b) market participation is still relatively low.

Cost pass-through and market power

Thin trading provides opportunities for exerting market power. Although the presence of market power is unlikely to affect price dynamics, at least not in the short run, it would affect the allowance price level by leading to a price that is either below or above marginal abatement costs. The theory about market power in permit markets is well established and reviewed by Montero (2009). Laboratory experiments indicate that market power may negate some or all of the gains from trade in emission permit markets (Godby 2002, Cason et al. 2003), but empirical studies carried out in the context of the sulfur dioxide and nitrous oxide markets in the U.S.A., also reviewed by Montero (2009), do not find evidence for market power.

An important difference between the EU ETS and the US permit markets, and which changes the implications for the exercise of market power, is the degree of electricity market liberalization. A number of empirical studies find that electricity prices in many European countries contain the full carbon (opportunity) cost (Fell 2010; Sijm et al. 2010; Fell et al. 2014), and the same appears to be true for other sectors (Smale et al. 2006, de Bruyn et al. 2010).[6] The combination of free allocation

[6] Note that cost pass-through is not a sign of market failure but rather of market efficiency, as allowances are simply a required input for production and should be priced like any other input.

and cost pass-through led to a situation where firms' profits increased due to the introduction of the EU ETS, an issue which has become known under the label of "windfall profits" (Sijm et al., 2006; Lise et al, 2010). This is consistent with empirical results by Oberndorfer (2009), who reports that in the first phase of the EU ETS, stock prices of firms covered by the scheme were positively related to the allowance price. In the US emission market context, the continued regulation of electricity prices in many areas means that carbon costs are not passed through, at least not on the margin, such that an increase in permit prices does not necessarily imply and increase in economic rent.

Theoretical papers have shown that taking the interaction between the permit and output markets into account qualitatively changes dominant firms' objectives (Misiolek and Elder 1989; DiSegni Eshel 2005; Hintermann 2011). Instead of minimizing compliance costs, firms now aim to maximize overall profits, which include the economic rent embedded in free allocation. Given the generous free allocation in Phases I and II, Hintermann (2013) shows that all major EU electricity firms profited from a high allowance price, despite being net allowance buyers. Intuitively, the increase in the value of free allocation exceeds the increase in compliance costs. This suggests that the presence of market power would lead to a higher allowance price level, in contrast to the U.S. studies where the underlying (and unsubstantiated) hypothesis was downward price manipulation. De Feo et al. (2012; 2013) show that upstream-downstream strategic competition generally leads to allowance prices that exceed marginal abatement costs. It is therefore possible that market power is a reason for the (in hindsight very high) allowance price during most of Phase I, as well as the beginning of Phase II.

No direct tests of market power exist in the context of the EU ETS, mainly due to data limitations. However, Hintermann (2013) shows that the largest electricity firms accumulated excess allowance holdings that are consistent with strategic over-purchasing. Inconclusive as the results are, they suggest that market power may be of policy relevance in permit markets after all, especially in new markets characterized by thin trading and high cost pass-through.

Avenues for future research

In our view, research on emissions allowance markets is motivated by three fundamental questions: i) Do real-world emission markets actually deliver what they are designed to deliver in theory, i.e. achieving a given emissions reduction at least cost? ii) Are they reasonably efficient, or is much of the gain relative to command-and-control approaches absorbed by transaction costs and other market imperfections? iii) What can we do to make these markets function better? We have reviewed the literature in this article with these questions in mind. Clearly, substantial progress has been made using a range of different approaches, data and methods. Despite these advances, major gaps remain in our understanding of emission permit markets.

Analyzing the interplay of energy markets and the EU ETS

Prices for electricity, fuel inputs and the allowance price may be determined jointly. Some models explicitly allow for an interaction between prices using cointegration techniques, thus identifying one or several long-term relationships between prices. Unfortunately, current models do not allow for this relationship to change over time, although this may be crucial given that marginal generation technologies can be expected to evolve as more renewables enter the system. Developing econometric techniques that allow for a time-varying price relationship would therefore be very useful. Also, our understanding of the interaction among energy markets can only be as good as our understanding of the functioning of these energy markets themselves, which is another area where more research is needed. Notably the coal market is poorly understood, as the cost for coal relevant for power generators may exhibit substantial spatial heterogeneity due to transportation costs.

Understanding the drivers of price levels

Relative to allowance price dynamics, our understanding of the relationship between the abatement effort induced by the cap and the resulting price level remains limited. This makes it difficult to assess the effect of interactions with alternative climate policies in the EU, linkages with Kyoto and other markets and the sensitivity of the price to the setting of future caps, all of which are crucial factors for improving the design of the EU ETS. Furthermore, it prevents us from speaking with authority about whether or not the price signal provided by the carbon market is approximately right, or whether there is some deviation that would have to be explained by issues such as transactions costs, high aversion to engaging in risky abatement decisions under uncertainty or imperfect competition. Research that improves our understanding of the efficient price level, however, is anything but low-hanging fruit: any effort to understand the price level relies on knowledge of BAU emissions and of firms' abatement costs, which are unobserved and therefore have to be modeled.

Simulation models that incorporate detailed information about economy-wide abatement opportunities and a realistic representation of firms' abatement and production choices would allow us to obtain a better understanding of the relationship between the cap and the resulting price level. Furthermore, research about the likely level of transactions costs or the extent (or absence) of imperfect competition could help assess the magnitude of price distortion and thus the likely loss in efficiency.

Determining the efficient amount of trading

Transaction costs appear to play an important role in the EU ETS, especially for smaller firms restricted in the manpower they can devote to optimizing their abatement, allowance purchase, and selling decisions. One proxy for the presence of transaction costs is the amount of allowance trading that takes place. However, low levels of trading can also be a sign of an efficient initial allocation. To our knowledge, no paper addresses the question of how much trade would be efficient, conditional on an initial permit distribution and the uncertainty regarding production and abatement decisions. Research along those lines would enable us to infer the importance of transaction costs or other market imperfections from the level of trading actually observed.

Integrating financial and empirical models

A body of literature has materialized that draws upon finance and banking theory to derive particular properties of the allowance price (such as the volatility term structure), but these papers are usually not directly testable via the use of market data. On the other hand, most empirical papers steer clear of uncertainty. To close this gap, better integration of financial and empirical models will be necessary.

Concluding remarks

Even though the EU ETS has been criticized from an environmental perspective because of its rather low carbon price signal, the scheme performed reasonably well from a market point of view because it correctly reflected a substantial over-supply in both phases by a significant price drop. Furthermore, the non-zero price toward the end of Phase II, despite a nonbinding cap for the phase, reflected expectations of a long-term binding cap on overall emissions and the utilization of the opportunity for banking. Remarkably, this development took place during a significant economic crisis that also caused turmoil in other (particularly financial) markets. In that perspective, the trading scheme proved its flexibility with respect to changing economic conditions by reducing the carbon costs during a period of economic stress. This would not have been the case using a rigid command-and-control approach nor with a carbon tax, although the latter would probably have achieved a greater reduction in emissions. Furthermore, because the experience of the first two phases resulted in efficiency-increasing adjustments—for example, the central allocation of allowances and the move towards auctioning in Phase III—continued collaboration between research and policy can be expected to further improve the functioning of the market.

However, the emission market in its realized form will never represent an economically optimal—and therefore idealized—market, but rather a compromise between economic theory and political reality, including distorting overlapping regulations or linkages to other imperfect markets to keep allowance price levels in politically acceptable ranges. Furthermore, market efficiency depends crucially on the attention firms devote to optimizing their abatement decisions in response to allowance prices, but current allowance price levels may not make the effort worthwhile. Inducing efficient abatement is also decisive in the light of stricter future emission targets, as for example implied by the EU Roadmap for 2050. These are arguments in favor of new mechanisms (such as price floors and ceilings) ensuring a sufficiently strong price signal also in case of economic crises. Nevertheless, we believe that the market has lived up to many of its expectations and can therefore be judged a successful implementation of economic theory to an important environmental problem.

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