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Buying green or producing green? Heterogeneous emitters' strategic choices under a phased emission-trading scheme

Lei Zhu[a], Linju Chen[b], Xueying Yu[a,*], Ying Fan[a]

[a] School of Economics and Management, Beihang University, Beijing, 100191, People's Republic of China
[b] Business school, Ningbo University, Ningbo, 315211, People's Republic of China

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ABSTRACT

Given the heterogeneous participants and temporal breaks involved in emission trading, it is reasonable to find permanent deviation of these markets from a rational expectation equilibrium (REE) status. However, the REE assumption underlies most existing studies, including those focused on the price-deviation phenomenon. They tend to ignore the heterogeneity among regulated firms, as well as the effects of such heterogeneity on emission trading, market equilibrium, and market efficiency. For the first time, we abandon the equilibrium assumption in the analysis of emission-trading markets and develop an artificial market in which regulated firms are modelled as heterogeneous agents with different allowance demands, abatement costs, technology preferences, and market expectations. Their behaviours are governed by a set of pre-specified rules, rather than directed by the economic optimization goals. The firms in China's iron and steel sector are selected for simulation. Our results identify some phenomena that can hardly be explained under a REE framework: 1) carbon price significantly fluctuates and deviates from the REE value; 2) regulated firms tend to over invest in emission-abatement techniques, which further results in allowance over-supply in the markets; 3) while the emission-trading scheme does promote abatement actions among regulated firms, the theoretical arguments for its advantage in mitigation cost-saving seems illusionary. The artificial emission market establishment here may help policy makers better understand the irrational behaviours and phenomena in real-world emission trading, and thereby improve the design of emission- trading schemes.

1. Introduction

Facing the tremendous task of curbing global green-house-gas (GHGs) emissions, quite a variety of regulation approaches have been sent on trial. Among them, the market-based instrument of emission-trading scheme(s) (ETS) is generally recognized as the most cost-effective one, especially when compared with the traditional command-and-control policies (Tietenberg, 2006). Under an ETS, voluntary trading of emission allowances can direct mitigation tasks to emitters with the lowest abatement costs and helps minimize overall social abatement cost.

Therefore, it is essential to understand the ETS's market mechanism, as well as its trading process, if the human community attempt to fight against the climate change challenges in an efficient way. Several unique characteristics of these markets have been identified in past works. First, since the emission-trading scheme is built upon artificially created markets, uncertainties embedded in the market design highly influences its performance. For example, emission trading is usually directed by a long-term emission cap, which is further divided into several phased caps for independent trading phases. Usually, phased caps are not announced until a new phase is approaching, and are subject to strategic adjustments even after being announced. The resultant uncertainty may cause significant intermittent price fluctuations between phases (Jaehn and Letmathe, 2010; Daskalakis et al., 2011; Creti et al., 2012; Daskalakis, 2013). Second, emission firms not only interact with each other when setting their trading strategies, they may also adjust their allowance trading in accordance with their own emission-abatement decisions. These interactions (interaction among competing firms' trading strategies and interaction between individual firms' trading and abatement decisions) not only cause long-term price correlations and excess price volatility, they also relates allowance prices with real-economy shocks outside the emission-trading markets, such as technology improvements (Christiansen et al., 2005; Mansanet-Bataller et al., 2007; Bunn and Fezzi, 2008; Hintermann, 2010; Creti et al., 2012; Daskalakis et al., 2009; Daskalakis, 2013; Paolella and Taschini, 2008). Aggressive abatement of a firm may reduce its demand for carbon allowances and drives down allowance prices, *vice versa*. Conversely, price signals somehow determine a firm's choice between

* Corresponding author.
E-mail addresses: leizhu@buaa.edu.cn (L. Zhu), chenlinju@nbu.edu.cn (L. Chen), xueying@buaa.edu.cn, xueying@umich.edu (X. Yu), yfan1123@buaa.edu.cn (Y. Fan).

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allowance-trading and self-abatement. Third, participants in the emission-trading markets are quite heterogeneous in terms of their business scales and scopes, their allowance demands, as well as their abatement costs, technology preferences, and market expectations (Martin et al., 2011; Brohé and Burniaux, 2015). They are also bounded rational with imperfect information, and may adjust their decision strategies continuously to adapt to the environment (Schennach, 2000; Chesney and Taschini, 2012).

The characteristics of temporal breaks, strategic correlation, and heterogeneous agents' bounded rationality all contribute to the deviation of the emission-trading markets from a static equilibrium status. Empirical evaluations on the Phase I trading under European Union Emission Trading Scheme (EU ETS) have shown that the carbon price does not equal the theoretical equilibrium, which should be determined by overall marginal abatement costs (Montgomery, 1972; Tietenberg, 1985; 2003, 2006; Cronshaw and Kruse, 1996; Rubin, 1996). The price neither fluctuates around the predicted equilibrium level (Alberola et al., 2008, 2007; Hintermann, 2010; Creti et al., 2012).

However, most existing studies on emission trading markets still seek to explain these non-equilibrium price phenomena under the rational-expectation equilibrium (REE) framework (Bernstein et al., 1999; Hidalgo et al., 2005; Anger, 2008; Stankeviciute et al., 2008; Marschinski et al., 2012; Böhringer et al., 2014). Environmental economists and engineers tend to frame the market's constant deviations from a stable static condition as multiple inter-connected temporary equilibriums, and refer to exogenous shocks as the reasons that drive the market from one temporary equilibrium to another. The most frequently referred exogenous shocks include changes in energy prices, economic conditions, and climate (Christiansen et al., 2005; Mansanet-Bataller et al., 2007; Bunn and Fezzi, 2008; Hintermann, 2010; Creti et al., 2012). Or they may refer to some deficiencies in the institutional design, for example, restriction on inter-phase allowance banking, as complications that keep emission-trading markets approaching the equilibria (Jaehn and Letmathe, 2010; Daskalakis et al., 2011; Creti et al., 2012; Daskalakis, 2013). These scholars are also keen to look for stability conditions for reaching such equilibria.

In contrast to the analysis of the emission-trading markets based on REE assumptions, a vast amount of papers in modern financial literature have already abandoned the REE framework, and agreed that the long-lasting deviation of market prices from their theoretical equilibrium values is a rule rather than the exception. It is recognized that stock prices neither follow a random walk nor quickly and efficiently arbitrage new information, both against the REE predictions (Summers, 1986; Lee, 2001). In addition, large prices fluctuations and large volumes of speculative trading constantly occur in financial markets, without any shocks that can be labelled as "news" (Chiarella et al., 2007; Sordi and Vercelli, 2012). In sum, price trends in most financial market can hardly be *expected* with any *rational* measures of value.

While the REE framework fails to explain many price trends in financial markets, these non-equilibrium phenomena are not hard to understand if we consider the real-world market institutional settings and strategic trading behaviours. Pursuing a persistent equilibrium requires prices to adjust instantaneously in order to perfectly balance supply and demand. However, if the market infrastructure does not allow an infinite speed of price adjustment, we must experience at least some transient moments of disequilibrium (Donati and Momi, 2003). In addition, most modern financial markets are organized with either market orders (fixing transaction timing and leaving price option open) or limit orders (fixing price and leaving transaction timing open). Under this trading mechanisms, market participants do not possess complete information about both timing and price before they implement a transaction, which threats the complete-information cornerstone of the REE framework (or equilibrium multiplicity, Gao et al., 2013).

Another challenge to the REE framework lies in the fact that market participants are not that rational creatures. They may come to possess biased knowledge, hinge upon quite diversified but far-from-true models, use very imperfect strategies to estimate or approach the models, and finally form heterogeneous perception of values (Boswijk et al., 2007; Fischer, 2011). They may also abandon the strategy of value investing based on fundamentals, and rather follow the technical trading rules (*e.g.* De Jong et al., 2009; Frankel and Froot, 1990; Ter Ellen and Zwinkels et al., 2010).[1] In sum, the theory of REE is built upon the assumptions of perfect competition, rational expectations, market clearing, agent optimization, and full knowledge of prices in advance of transactions. All of these assumptions are questionable for the analysis of traditional financial markets, as well as its derivative of ETSs.

For non-equilibrium analysis of the emission-trading markets, Matsumoto (2008) represents the first and the only existing effort we could find. He constructs an artificial market with multiple heterogeneous agents that are all bounded rational. In contrast to the mainstream general equilibrium simulations, Matsumoto's model emphasizes on the behavioural aspects of trading, and produces more precise price prediction when compared with regression models. While Matsumoto's work exemplified how strategic trading rules shape the carbon market, it deliberately ignores the option of emission abatement as an alternative approach for emission regulation compliance. This simplification is in fact quite problematic because 1) the primary purpose of emissions trading is to realize efficient emissions abatement and 2) the existence of the abatement option is the key feature that distinguish emission-trading markets from other traditional financial markets. Without considering the potential abatement option, we can hardly understand emitters' trading behaviours in the carbon markets.

We bridge this gap by explicitly considering the abatement as an alternative option for emission regulation compliance. Specifically, we build a multi-agent, single-phased artificial emission trading market,[2] in which each emitter can strategically choose between buying emission allowances (buying green) or adopting new abatement technologies (producing green) to fulfil its mitigation obligation. We also assume that the investment in abatement technologies are irreversible. All other aspects of the market are also set in a realistic way. For example, emission-regulated firms are simulated as heterogeneous agents with different allowance demands, abatement costs, technology preferences and market expectations. The agents do not possess complete information about the trading market, but they can learn trading experiences from past phases and update their trading strategies over each period in a single phase. Moreover, the agents' behaviours are governed by a set of pre-specified rules (as specified in Section 2), rather than directed by the economic optimization goals.

Our simulation work generally presents such a picture in emission trading markets: the bounded rational agents are over prudent in regulation compliance and they tend to excessively adopt abatement technologies at the early stage of trading. Consequently, later on, there will be too many agents who would like to sell allowances that they either receive from initial allocation or produce with advanced technology adoption, and thus too many allowances available for sale in the market. The market finally turns into a buyer's market. In this sense, if an agent would like to sell allowances, it would always be a good timing to sell them at the early stage of trading. Thus, we observe price overshooting when the trading phase just starts, and the price declines gradually in the later stage. All these patterns fit well with our observations of the carbon markets. In summary, our modelling work renders explanation to at least three non-REE phenomena usually

[1] Farmer and Joshi (1999) argue that even the strategy of value investing would not necessarily cause prices to track values. For the simple value strategy, entering a position pushes the price towards the value, but exiting a position pushes it away from it.

[2] The artificial-market method has been widely used to simulate activities in complex economics systems. It has a unique application to the studies of financial markets, including the emission-trading markets (Palmer et al., 1994; Routledge, 1994; Lettau, 1997; Arthur et al., 1997; Hommes, 2006; LeBaron et al., 1999; LeBaron, 2006, 2012; Zawadowski et al., 2002).

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