Studying the effects of CO_2 emissions trading on the electricity market: A multi-agent-based approach

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Summary. In this paper, we present a basic approach for modelling electricity and emissions markets under the paradigm of agent-based computational economics (ACE). Different market players will be modelled as independent entities using autonomous software agents; they operate and communicate independently on the power market and the market for emission allowances. The agent types involved and their relationships are described. The aim of the model is to investigate the interplay between the market players, with a focus lying on the dynamics in a market for CO_2 emission allowances and its effects on the electricity market. Simulations with this model will enable us to draw conclusions about the economic efficiency of different possible emissions trading options. These findings can possibly help decision makers to evaluate the testing phase of the EU emissions trading scheme (from 2005 to 2007) in a qualified way.

Keywords: Agent-based computational economics (ACE), liberalized electricity markets, multi-agent-based simulation, emissions trading, CO_2 allowance markets

1 Introduction

The start of the EU-wide emissions trading scheme, which is scheduled for the beginning of 2005, constitutes a new challenge for power generators and other players in the electricity market. The introduction of a price on CO_2 emissions will change the short-term merit order of power plants, as well as long-term investment decision patterns, resulting in a shift in power production structures. Participants in the power market will react differently to these new market conditions. Each actor has varying starting conditions, as well as an individual willingness to innovate and to take risks. Accordingly, each market player develops his own strategy. The actors will learn from their experience gained in the market and dynamically adapt their strategies in order to maximize their individual profits and to enhance their market positions. The resulting actor-specific behaviour is decisive for the development of the power market under an emissions trading scheme.

As a consequence of the distributed structure of these processes of change, it is difficult to predict the outcome that can be expected from the emissions trading scheme in terms of innovation, transformation in power production structures, and new emissions situations. Thus, new methods of modelling and simulating power and emissions markets are required in order to understand market dynamics and the according decision structures. A new approach for addressing distributed problem solving processes of that kind is agent-based computational economics (ACE), in which multi-agent systems (MAS) are applied. MAS originate from the research field of Distributed Artificial Intelligence and are increasingly applied in economic research for coordination and simulation problems. The special features of software agents make it possible to model decentralized, distributed problem solving processes. Multi-agent-based simulation, thus, constitutes a promising approach for addressing market coordination problems.

In this paper, we present a basic approach for modelling electricity and emissions markets under the paradigm of agent-based computational economics. The paper is organized as follows: section two gives a brief overview of the basic concepts of software agents, multi-agent systems and agent-based computational economics. In the third section, the first steps in modelling a multi-agent-based simulation of the German electricity and emission allowance markets are described. A closer look is taken on the emissions trading part of this model, focusing on the representation of the allowance trading process and its implications for power plant investment decisions. The last part of section three gives an outlook on the expected outcomes of the model implementation, including the hypotheses used, and finally section four concludes.

2 The multi-agent approach

The field of autonomous agents is a fast growing area of software technology development. One application of software agents is an emerging type of bottom-up simulation, in which multi-agent systems are applied for the computational study of complex systems. This section gives a brief overview of the agent-based simulation paradigm and introduces its constituting concepts.

2.1 Software agents and multi-agent systems

As the applications for software agents are manifold, there is no standard definition of what actually constitutes an agent. However, many attempts to specify characteristics of software agents exist. Pattie Maes [14] delivers a comprehensive definition of autonomous software agents, which she describes as "[...] computational systems that inhabit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals for which they are designed." Jennings and Wooldridge [10] define some key characteristics that all kinds of software agents have in common; these are: autonomy (agents require no direct intervention of humans or other agents), social ability (ability to interact with other software agents and humans), responsiveness (agents are able to perceive their environment and respond to changes which occur in it), and proactiveness (ability to exhibit opportunistic, goal-directed behaviour and to take the initiative). In their comparison of different agent approaches Fraenklin and Grasser [9] propose to classify agents according to the properties that they exhibit, of which they regard four (reactive, autonomous, goal-oriented and temporally continuous) as obligatory. The other properties (communicative, learning, mobile, flexible, character) are supplementary characteristics that produce potentially useful classes of agents for various tasks.

When a set of software agents act in a common infrastructure, this ensemble can be referred to as a multi-agent system (MAS). The interaction of the autonomous agents might take the form of cooperation, of competition, or of some combination of both. Decision making in a MAS is processed at the level of each single agent, without any central control unit that decides on the agents' actions. Likewise, knowledge about the state of the world in a MAS is stored in a decentralized manner and each agent collects her individual information according to her perception and interpretation of the environment. In addition, multi-agent systems may provide some protocols and languages for the agents to communicate with each other. This enables them to send and receive messages, e.g. for the purpose of negotiation or participation in an auction. In the following, we will concentrate on MAS used for social, or rather economic simulation. For a more general overview of multi-agent systems the reader is referred to a concise and detailed introduction provided by Vlassis [21].

Multi-agent-based simulation in the social sciences uses the aforementioned concept of software agents for modelling individual behaviour of specific individuals constituting the real-world system to be analyzed, e.g. a market, a society or the electric power industry. The emerging structure from a repeated interaction of individual autonomous agents in the simulation system is in the centre of interest for the modeller. By explicitly modelling individual choices and social interaction, agent-based simulation can be more flexible and responsive than alternative modelling methods. The application areas of agent-based social simulation are manifold and range from the analysis of social structures and institutions over physical and biological systems to all kinds of software systems [13].

2.2 Agent-based computational economics (ACE)

The agent-based bottom-up analysis of economic systems constitutes the new research field of agent-based computational economics, which is a promising approach for complex economic research questions such as the interaction of markets for emission certificates and electric power markets. As Tesfatsion [19] puts it, "Agent-based computational economics (ACE) is the computational study of economies modelled as evolving systems of autonomous interacting agents." This approach allows modelling learning effects and relaxing the strict assumption of many conventional models (e.g. perfectly rational players, perfect information or symmetry of knowledge, static environment, equal size of firms). It facilitates the analysis of how global regularities result from the repeated local interactions of self-seeking autonomous agents that represent individual players in the studied economy. ACE models also offer the possibility of testing alternative structures and market designs ahead of their introduction in the real-world economy. They can, thus, serve as testbeds for market designs or political instruments and help deriving conclusions about market results under different environmental conditions without changing the real-world settings.

The ACE approach has been applied to many fields of economics, such as entertainment and automated internet exchange systems, financial and electricity markets, labor, retail and business-to-business markets and markets for natural resources [19]. For the case of electricity, many studies focus on the question of market power and price formation in restructured electricity markets ([4], [7], [8], [6], [5], [20], [16], [15], [12]). Others use MAS as test-beds for policies and market mechanisms for power markets ([1], [17]), or concentrate on the general design, the agent architecture, or on learning techniques for agent-based power market simulations ([2], [3], [11], [18]).

3 A multi-agent electricity and emissions market simulation

Projekt auch aus dem Bereich ACE

- Each agent carries out one function in the power market
- A power market player can be represented by several agents
- The single agents fall into the following categories

Dann die Beschreibung der Agentenstruktur mit Darstellung;

3.1 Considered markets and scope of the simulation model

Hier wird beschrieben, welche Mrkte wir betrachten und wie wir die regionale Eingrenzung vornehmen (mit Grafik).

3.2 Representation of emissions trading in the simulation model

Examples: Allowance trader and strategy planner agents; each agent is characterized by individual initial attribute values; values for the non-energy players are aggregated over the industry sector.

Beschreibung der Attribute und Methoden, soweit bereits definiert.

Beschreibung des modellierten Marktes:

How will the agents trade emission allowances?

The market design should realistically reproduce the trading specifications in the real market.

Real market specifications are largely unknown at present

Starting point:

- Two trading days per year
- Double-auction with closed order book
- Uniform price calculation
- Bids and asks consist of specifications on {bid/ask, price, quantity, period} and are submitted to a central market maker
- Forwards on emission allowances can be traded
- Information on market prices and traded volumes are publicly available
- Banking allowed within trading periods (2005-2007 and 2008-2012)

3.3 Hypotheses and outlook

Questions to be answered by our approach:

- Can the agents find the cost-efficient solution?
- Will some agents be able to influence the market price?
- Which market model for emissions trading achieves the "best" results? ("best" has to be defined first)
- How do different options of first allocation effect the market result?

Hypotheses to be tested:

- "In an allowance market with high initial allocation, liquidity will be low, and thus the market will fail to give the right price signals.“ (zu trivial?)
- "The market outcome (efficiency, profit allocation, and overall reduction costs) depends on the design of the market for emission allowances.“
- "Electricity players will make windfall profits through emissions trading.“(brauchen wir dazu Agenten?)

Integration of the findings into the PowerACE model:

Operational level: effects of ET on bidding strategies and the merit order

Long-term level: effects of ET on decisions on capacity expansion

The anticipated findings of the emissions market simulation will be integrated in the power market model.

Work left to be done: Data collection (emission reduction costs for the different sectors, investment alternatives for power market players), more detailed representation of realistic behaviour, esp. learning algorithms, assure high efficiency of the simulation implementation.

4 Conclusions

First steps in designing the PowerACE model have been presented; multi-agent-based simulation (MABS) is well suited for the study of complex systems, such as electricity and emissions markets; MABS offers some advantages over experimental studies; but: It is yet to be shown that MABS delivers realistic results for emissions trading simulations; thus: importance of sound model validation and verification!

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