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Simulation of a Swiss wood fuel and roundwood market: An explorative study in agent-based modeling

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ABSTRACT

This study discusses the potential of applying agent-based modeling (ABM) to wood markets. A corresponding model of the wood market of a Swiss canton, consisting of a coupled roundwood and wood fuel market, is presented. The model includes wood-producing agents, such as public foresters and private forest owners, roundwood-consuming agents, such as sawmills, different classes of wood fuel consumers, and in-between wood traders. Other important model elements include agent interaction and negotiation, execution and scheduling structures, and agent adaptation mechanisms. Two sets of scenarios demonstrate the model's power for scenario exploration. The first set of scenarios analyzes the effects of an excess and scarce supply of wood on both markets. The second set looks for the optimal number of roundwood agents in the market from the perspective of the various stakeholders involved. Taking a more in-depth view of important design decisions and their pros and cons, this study argues that ABM offers new opportunities for the explorative study of wood markets as a result of these markets' special characteristics.

1. Introduction

The analysis of wood markets is a difficult endeavor for several reasons. First, wood markets tend to be imperfect markets. Uncertainties exist regarding the long-term development of forest wood supply due to varying climate change scenarios and the possible occurrence of calamities. Second, the theoretically available amount of wood is limited by natural tree growth and long-term ecological concerns, leading to the prescription of the *annual allowable cut* (*AAC*). This measure can be relatively easily estimated, yet the actually available amount of wood on a market depends strongly on other factors. For example, technological advances, especially in the harvesting industry, have increased productivity in recent decades, leading to long-term changes in production costs. Political agendas and legal restrictions also can enforce increased or decreased wood production, beyond what is economically justifiable. Societal values might demand accessibility to forests for functions other than wood production. Suppliers and demanders alike are adaptable; they learn from past and anticipate future developments. Finally, individual psychological and behavioral factors apply. In many European and North American countries, non-industrial, private forest owners often pursue personal goals other than market participation or profit maximization (Beach et al., 2005; Bohlin and Roos, 2002; Conway et al., 2003), to the extent that some of them never even offer their wood on the market. Third, wood market analysis is difficult because of the tight intertwining of the roundwood and wood fuel markets, which results in hard-to-predict cyclic dependencies between them.

Therefore, when modeling wood markets, it is desirable to have a modeling technique that can accommodate the complexity of the situation. Agent-based modeling (ABM) — and more specifically, agent-based computational economics — is a technique that allows developing market models using a bottom-up approach that includes individual market participants' behavior. Whereas ABM shares some fundamental trade-offs with other modeling disciplines (i.e., model complexity versus traceability and understandability, degree of detail and richness of features versus desirable levels of aggregation and abstraction), it also offers some distinct promise. For example, ABM explicitly exposes the modeled relationship between the micro- and macro-levels of observed reality. It offers the possibility to observe emerging aggregate market behavior as a result of interactions of individualized agents. Therefore, it promises a means to investigate aggregated and averaged values, but it also can report individual data values at the micro-level. Similar to other simulation tools, ABM can tackle certain types of problems that are too hard to solve using classical analytical mathematical approaches (Maria, 1997). Simulation as a superclass of ABM also offers an alternative method to conduct otherwise infeasible experiments. One specific disadvantage of ABM is that it can aggravate the problem of limited computational power with regard to both processing speed and amassing data quantities.

Thus ABM has already been applied to a wide range of agricultural, land use, or ecological domains, though few authors have attempted

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to implement runnable agent-based models of wood markets. Troitzsch (2012) offers an introduction to the topic, and Gebetsroiter et al. (2006) describe a compound ABM consisting of two interlinked but otherwise independent agent-based submodels. One submodel simulates tree growth in a forest, with the trees modeled as competing agents, and the other simulates a market of suppliers and demanders of timber. Outside the field of wood market simulation but still related to forestry, several agent-based models have been developed to simulate forestry management decisions (Pérez and Dragićević, 2010; Purnomo and Guizol, 2006), explicate causal factors for deforestation in Mexico and the United States (Manson and Evans, 2007), and assess different demand-driven timber production strategies in Canada (Yáñez et al., 2009).

This study addresses the relative lack of applied knowledge in the field of agent-based wood market simulations by first expanding an agent-based model of a Swiss wood market and then exploring scenarios in which key supply and demand side parameters are varied. We followed the principles of the MAIA methodology (*m*odeling *a*gent systems based on *i*nstitutional *a*nalysis; Ghorbani et al., 2011) to create an agent-based model for the Swiss canton Aargau. It is based on precedent model versions, one first implemented by Olschewski et al. (2009), which was still relying on standard microeconomic assumptions, and a subsequent, more detailed version introduced by Kostadinov et al. (2012). We explored the model's capabilities by simulating two sets of economic scenarios and comparing them with a base scenario calibrated with default data from Aargau. In the first set of scenarios, we varied the supply side to simulate scarcity and excess supply situations. In the second set of scenarios, the demand side was varied through differing numbers of sawmills in the market. We used these sets of scenarios to conduct qualitative analyses of trading prices, traded amounts, and further measures.

In Section 2 we present the model and its constitutive elements (e.g., markets, agents, agent interactions), as well as its scheduling, execution, and negotiation processes. Section 3 demonstrates the model's application using explorative scenario analysis, including a base scenario and two sets of scenarios. In Section 4 we provide a critical review of the model's fundamental design issues, before we conclude in Section 5 with a short summary of ABM's strengths when applied to a Swiss wood market, as well as some limitations and suggestions for further research.

2. Model

The high degree of complexity and size of the model prevent us from giving a complete overview; we focus instead on core model elements. A complete model description, following the ODD protocol (*o*verview, *d*esign concepts, and *d*etails; Grimm et al., 2006, 2010) is available elsewhere.[1]

2.1. Model region and data

We chose the Swiss canton Aargau as the model region for several reasons. First, the data for this canton are relatively available. Second, Aargau takes a representative position among Swiss midland cantons in terms of its geographical location and conditions for wood production. Aargau is important for wood fuel production in Switzerland. Third, the number of agents to be modeled seemed manageable computationally and yet still sufficient to provide a high number of agent interactions. The model also could be transferred to and calibrated with data from other regions, whether other Swiss cantons or regions in countries with similar market structures, such as Germany or Austria.

Aargau has a size of 1404 km^2 and a population of approximately 620,000 people. The forest area in Aargau is approximately 49,000 ha (i.e. about one-third of the canton's area is forested). Public and semi-public organizations, such as municipalities and corporations, own 78% of the forests, whereas 22% are under private property. In the past years, an average of 435,000 m^3 wood was used yearly, including 60% as stem wood and 40% as wood fuel or industrial wood. For the model, we refer to stem wood as roundwood, and the term wood fuel also includes industrial wood (Kanton Aargau et al., 2010).

The simulation model focuses only on forest wood production and consumption, including wood fuel produced from industrial waste wood; it excludes other sources, such as post-consumer wood.

The following data sources were used for model calibration:

- The number, size, and location of wood fuel heating systems in Switzerland, as provided by Holzenergie Schweiz (Primas et al., 2011).
- The number of foresters and amount of forest managed, provided by the third Swiss National Forest Inventory (2010).
- Past oil price developments (US Energy Information Administration, 2011), to determine, among other factors, how attractive it is for new wood fuel consumers to install wood fuel heating systems and thus enter the market.
- Classification and typification of foresters, private forest owners, and certain wood fuel consumers, based on qualitative interviews conducted with market participants, scientific studies of non-industrial private forest owners (Beach et al., 2005; Schaffner, 2008), and the authors' own expert knowledge.

2.2. Model elements

The model consists of markets in which agents, representing real-world market participants, sell and buy wood. Agents are grouped into classes, according to their market roles. They also are assigned a certain type, which represents the market participant's behavioral or decision characteristics.

2.2.1. Markets

Forests are modeled rudimentary as homogeneous, renewable resources of a certain size, with a natural upper growth limit equal to the AAC. Tree growth is equally distributed over time. The model does not include seasonal influences, changing weather conditions, calamities, or natural preconditions for forestry. We model both the roundwood and the wood fuel market. On the roundwood market, only roundwood is traded, whereas on the wood fuel market, only wood fuel is traded. Both are assumed to be homogeneous goods. We omit differences in tree species, product segments, and product qualities. Fig. 1 provides an overview of these markets and their agents.

We model five markets purely exogenously: the timber products market, the pulp and paper market, the district heating market, the electricity market, and the oil and gas market. Although some agents depend on these highly aggregated markets in one way or another, no real agent interaction occurs, as is the case for the roundwood and wood fuel markets. In other words, these markets constitute the system's boundaries.

2.2.2. Agents and agent classes

Table 1 provides an overview of the agent classes. The presented agent characteristics are based on the data sources cited in the section “Model region and data”. All agents have a fixed geographical location and a portfolio containing the agent's resources, which consist of forest (wood producers only), a stock of roundwood and/or wood fuel (wood consumers only), money (all agents), and possibly contracts. Agents act as suppliers, demanders, or intermediaries of roundwood and wood fuel. Not all agent classes are active in both markets. The columns “roundwood market” and “wood fuel market” in Table 1 show the roles of agents in a market.

Agents also maintain a “phone book” of other agents located nearby, which they use to find suitable trading partners during the negotiation

[1] This ODD protocol document is available at http://www.wsl.ch/fe/waldressourcen/produktionssysteme/publikationen.