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An agent-based model of wood markets: Scenario analysis

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ABSTRACT

We present an agent-based model of wood markets. The model covers softwood and hardwood markets for sawlogs, energy wood, and industrial wood. Our study region is a mountainous area in Switzerland that is close to the border, and therefore partially depends on the wood markets of the adjacent countries. The wood markets in this study region are characterized by many small-scale wood suppliers, and a mix of private and public-owned forests. The model was developed to investigate the availability of wood in the study region under different market conditions. We defined several scenarios that are relevant to policy makers and analyzed them with a focus on the two most important assortments of wood in the study region, namely, sawlogs softwood and energy wood softwood. The development of the prices and amounts sold in the scenarios are compared to a business-as-usual scenario. The scenarios were designed to investigate i) the influence of intermediaries, ii) the influence of the profit-orientation of forest owners, iii) the influence of the exchange rate, and iv) the consequences of set-asides in the study region. The presented model has a large potential to support the planning of policy measures as it allows capturing emergent phenomena, and thereby facilitates identifying potential consequences of policy measures planned prior to their implementation. This was demonstrated by discussing the scenario findings with respect to Switzerland's forestry policy objective of increasing the harvested amount of wood to the sustainable potential. We showed that a higher profit-orientation of forest owners would be beneficial for this objective, but also revealed potential conflicts of different economic goals.

1. Introduction

Computer simulation has been an important instrument in forestry for decades. In the 1960s, already, a wide range of topics were modeled and simulated. Among others, growth models, forest fire protection models, and harvesting machine simulation models were developed (Newnham, 1968). Until today, not only the domains of application and modeling purposes have substantially widened, but also, the types of simulation techniques applied, making use of the continuously increasing computational power, have expanded. For example, system dynamics approaches have been used to simulate wood market scenarios (Schwarzbauer and Stern, 2010) and Monte-Carlo simulations have been used to analyze uncertainties in forest conservation set-aside scenarios (Kallio, 2010).

In this paper, we present a computer model of wood markets in Switzerland using the agent-based modeling (ABM) approach. ABM differs from other modeling approaches owing to its bottom-up perspective that allows each agent (in our case, each market participant) to be modeled individually (micro level). Simulating all agents together creates a system behavior due to their interactions. This approach has several advantages, such as the possibility to model the market in a natural and descriptive manner (as an interplay of many autonomous acting agents with different goals) or to capture emergent phenomena on any level of aggregation (macro level) (Bonabeau, 2002; Janssen and Ostrom, 2006; Macal and North, 2014). Owing to these reasons, ABM is widely used in economics (where it is sometimes referred to as agent-based computational economics, cf. Tesfatsion, 2006): for example, there are many models related to electricity markets (cf. Weidlich and Veit, 2008). There are even suggestions to model whole economies using the ABM approach (Farmer and Foley, 2009). In comparison to other simulation approaches, ABM, though, requires more computational power, which made this method popular only in the recent 10–20 years, and so far has not been used to model entire wood markets where multiple assortments are traded between a multitude of different kinds of market players.

An explorative study by Kostadinov et al. (2014) showed that ABM

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is a suitable method to analyze wood markets, particularly considering the peculiarities of our study region. The new version of that model presented here addresses some important improvements. We solved the model boundary problem, implemented a transport route model which calculates transport costs based on real road and rail routes in the study region, and gathered empirical data on the market participants' decision-making behavior with discrete choice experiments (Carson and Louviere, 2011; Louviere et al., 2010) and surveys. Additionally, the conceptual model was extended (more agent types, more markets), a rigorous validation was conducted, and finally, the performance of the model was significantly improved, allowing faster scenario simulations with more agents. Details on these improvements are described in Holm et al. (2018). Considering these improvements, the model can now be used for policy analysis by simulating and analyzing relevant scenarios.

The reason why we want to simulate such scenarios originates in the 2011 declared Swiss forestry policy objective to increase the utilization of forest wood (Swiss Federal Council, 2011). However, the sustainable potential of forest wood in Switzerland is currently not used. This situation is strongly related to market conditions. Our model was developed for a better understanding of markets for forest wood, with a focus on resource availability and allocation of different assortments. Our objective was to establish an agent-based model and apply it to regional wood markets. In the scenario analysis presented, different market situations were analyzed in terms of their impact on the markets of sawlogs and energy wood.

In Section 2, we provide an overview of the study region and the most important characteristics of the model and define the simulated scenarios. Further, we present the variables observed to analyze these scenarios and describe the simulation procedure. Section 3 presents the results of the scenario simulations and discusses the findings with respect to Switzerland's forestry policy objective, and Section 4 concludes the paper.

2. Material and methods

In this section, we first describe the study region and the most relevant parts of the model, followed by the simulated scenarios and their relevance to the forest sector in the study region, and finally, the observed variables and the simulation procedure.

2.1. Study region

The study region is the canton of Grisons, a mountainous region in eastern Switzerland, located in the border of Austria and Italy. The region has a size of 7105 km^2 (FSO, 2018) and a population of approximately 200,000 inhabitants (FSO, 2018). The total forest size in this region is 195,494 ha (Olschewski et al., 2015), that is, 27.5% of the study region is forest area. Forestry in Grisons is characterized by a high percentage of public (communal) forests (88% of the total forest size), subsidized protection forests (61% of the total forest size), and a high percentage of softwood (91%) (Olschewski et al., 2015).[1] The wood market is characterized by cooperatives of small suppliers on the supply side (hereinafter referred to as bundling organizations). On the demand side, there are small-scale sawmills in Grisons, and larger sawmills in the neighboring Swiss cantons and in the neighboring countries of Austria and Italy, to where a high percentage of the wood is exported. The total annual cut is approximately 500,000 m^3 and the most important assortment is sawlogs softwood.

2.2. Description of the market model

The model depicts the markets for sawlogs, energy wood, and industrial wood in the canton of Grisons. Fig. 1 shows (i) the combined markets of the main products (distinguishing between softwood and hardwood) and (ii) the nine different agent types. All the agents have a fixed geographical location, which, for public forest managers reflects their real-world position, while for other agents, the position is randomly assigned at the beginning of a simulation. A single time step in the model represents one month. In each time step, agents try to negotiate new contracts and/or fulfill their existing ones. A detailed model description according to the ODD/ODD + D protocol (a standardized way to describe agent-based models, Grimm et al., 2006, 2010; Müller et al., 2013) is available in Holm et al. (2018), where the validation procedure of the model is also described. Therein, a more comprehensive description of the agents, their decision behavior, their individual goals, and how they interact is provided. For the convenience of the reader, we repeat the agent descriptions as defined in Holm et al. (2018) here:

- **Public forest managers**: These agents manage the public forests in their area. In our study region, 88% of the forest is under public ownership (FSO, 2015), which makes them the most important agent group on the supply side of the markets. They sell wood of all six assortments.
- **Private forest owners:** In our study region, 8% of the forest is under private ownership (FSO, 2015) (the remaining 3.5% of the forest in the study region is hybrid property). In absolute numbers, there are 10,110 private forest owners in the study region who own a total forest area of 16,517 ha (FSO, 2015). With an average size of 1.65 ha per private forest owner, the wood is generally not harvested by the owners themselves, but with the help of public forest managers or contractors. They are often mentored by a public forest manager. In the model, these agents are aggregated such that there is only one private forest owner agent in the territory of each public forest manager, representing (for model simplicity) the aggregate of all private owners in this territory. They sell wood of all six assortments.
- **Traders:** Traders buy all six wood assortments in the model and try to sell them in the markets at a profit.
- **Bundling organizations:** These agents are cooperatives of small suppliers (private and public), structured to reduce distribution costs and increase market power. They are modeled as intermediaries who are strongly linked to the affiliated suppliers.
- **Sawmills:** They buy sawlogs and process them into different wood products (for which the downstream markets are not included in the model). While processing sawlogs, residuals (tree bark, woodchips, shavings, and sawdust) are accumulated as byproducts and are either used by the sawmill itself, or are sold in the market as energy wood and industrial wood.
- **Industrial wood buyers:** They buy industrial wood and process it into products such as pulp and paper. The downstream markets are not included in the model.
- **Energy wood buyers:** They buy energy wood, predominantly for heating purposes. This includes all consumers from single-family homes with a fireside up to district heating distributors. These market participants are modeled as aggregated agents.
- **Importers:** They import wood from the outside to the inside of the modeled region.
- **Exporters:** They export wood from the inside to the outside of the modeled region.
  In order to ensure simplicity, the term "forest owners" is used hereafter to represent the wood suppliers, and therefore includes both, the public forest managers and private forest owners.

2.3. Scenario definition

Based on a basic wood market situation, we simulated a set of economically and politically relevant scenarios to analyze the influence

[1] Note that these numbers do not add up to 100%, as they describe characteristics of the forest that are independent of each other.