Modelling investments in short rotation coppice under uncertainty: A value chain perspective

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**Abstract**

Short rotation coppice (SRC) for biomass production seems to be an interesting form of land use both from an ecological and economic perspective. However, farmers still behave reluctant in cultivating SRC. Recent investigations show that the high (partially irreversible) investment costs and the uncertainty of the future returns, in the literature jointly known as the real options approach, are main reasons for this reluctance. For complexity reasons, these studies do not, amongst others, consider interactions between different stages of the value chain of woody biomass, which, however, are existent in reality and can affect SRC cultivation decisions. Examples for this are the maximum capacities of biomass heating stations (BHSs), which could represent de facto production restrictions for the surrounding farmers, or possible incentive measures implemented by BHSs to increase farmers' willingness to cultivate SRC. This paper develops an agent-based real options model, which considers these interactions and comprises all stages of the value chain of woody biomass, from farmers who cultivate SRC, over the BHS which converts the wood chips into heat, to end consumers to whom the heat is delivered. Within this framework, the model analyzes farmers' optimal SRC cultivation decisions and the respective effects of potential incentive measures to the farmers implemented by the BHS to increase its utilization. Under a given stimulation of the total quantity of wood chips supplied by the farmers, investment subsidies are advantageous to price floors because they lead to a stronger increase in the profitability of the BHS.

1. Introduction

In Europe, it is aimed to produce about 20% of the energy demand from renewable sources by 2020 [1]. To reach this target, one important way is to generate energy from biomass production. Besides generating biomass from conventional annual agricultural crops, such as maize, one possible way for farmers is to cultivate short rotation coppice (SRC). SRC is defined as the cultivation of trees on agricultural land, which get harvested in a few years interval over a long time horizon [2]. The harvested wood chips are often delivered into biomass heating stations (BHSs), where they are converted into heat, which again is delivered to end-consumers through a district heating system in a particular region. In Germany, for instance, there are more than 1200 BHSs operated with wood chips which supply particularly large public buildings with heat, such as schools or administration buildings [3].

Many studies in the literature have shown that cultivating SRC can be an interesting form of land use. First, it is ecologically advantageous compared to conventional intensive agricultural land use forms [4–7]. SRC does usually not require any fertilizer, and pesticides do only need to be deployed until the plants are established [8,9]. Furthermore, there is a lower danger of soil consolidation due to a lower number of machinery passes and a higher resulting biodiversity compared to conventional agricultural production methods. Second, dependent on the location, SRC can be more profitable than traditional agricultural land use forms and, therefore, it can also be of interest from a farm-level perspective [10–12]. Especially in regions with marginal soil qualities and high levels of groundwater, SRC is competitive compared to cash crops because it obtains high and stable yields despite these weak production conditions [13,14].

Nevertheless, farmers still seem to be very reluctant in cultivating SRC on their land. For instance, in North-Eastern Germany the potential area for SRC is estimated at 200 000 ha because of relatively low soil qualities and precipitations levels [13]. However,
merely 5000 ha have been cultivated with SRC in Germany as a whole [9]. A possible explanation for this is that, from a farmers’ perspective, cultivating SRC can be seen as an investment with high and (partially) irreversible investment costs followed by uncertain returns in future periods by the time the SRC can be harvested [15].

Several recent investigations have shown that the real options approach (ROA), which exploits the analogy between a financial option and a real investment opportunity, is generally better suited to explain SRC cultivation decisions than traditional investment models based on the net present value (NPV) rule [16–18]. This is due to the fact that agricultural investments in general, and SRC cultivation decisions in particular, are commonly afflicted by uncertainty of the future cash flows, irreversibility of investment costs and temporal flexibility in conducting investments. The ROA explicitly takes these characteristics into account by analyzing investment decisions under dynamic-stochastic conditions and extending the NPV by the value of entrepreneurial flexibility, which is also referred to as the value of waiting [19,20].

For complexity reasons, all existing real options applications, including the aforementioned applications to SRC cultivation decisions, do not explicitly consider competition when determining firms’ optimal investment and disinvestment thresholds. On the contrary, they merely focus on one myopic firm which behaves like a price taker, that is, it takes the stochastic price for the produced commodity, in this case wood chips, as exogenously given [21]. This simplifying assumption, however, considerably complicates the applicability of the ROA to SRC cultivation decisions in specific. First, hereby the assumption of a perfectly competitive market with an atomistic market structure is implicitly made [21]. Yet, specifically with regard to the potentially low number of farmers cultivating SRC in many regions, for instance within Germany, the simplifying assumption of an atomistic market structure does not seem to be realistic.

Second, the limitation of focusing only on the myopic planner further complicates the applicability of the ROA to markets in which interactions between different stages of the value chain exist, which is particularly the case for woody biomass from SRC. Because of high transport and storage costs, farmers who cultivate SRC rely on a nearby outlet for their wood chips, such as a BHS. Therefore, the maximum production capacity of a BHS could de facto represent an overall production restriction for the farmers in its catchment area who (consider to) cultivate SRC. This again can lead to interactions in the farms’ investment and disinvestment decisions, for instance, if several farms want to expand their SRC cultivation area, a necessary condition would be that other farms reduce their cultivation area or exit the market completely. However, these effects on the cultivation decisions of competing farms cannot be captured by existing models which merely focus on one myopic firm.

Third, against the background of recently decreasing energy prices and the elimination of eco-electricity subsidies in countries like Germany or Austria, many existing wood chip fired BHSs have been under substantial economic pressure [22,23]. The operators of BHSs, therefore, could consider taking measures which encourage farmers to deliver more biomass, for instance price incentives for wood chips [24] or investment subsidies for cultivating SRC [25,26], in order to increase the BHS’s utilization. Such interactions between the different actors of the value chain and the respective effects on the farmers’ SRC cultivation decisions, however, cannot be captured by existing real options models, which merely focus on the myopic planner, either.

Hence, the objective of this paper is to model SRC cultivation decisions within the context of the whole value chain for woody biomass. For this purpose, the generic agent-based real options model of Feil and Musshoff [29], which merely focuses on one production stage, is extended in the way that the interactions between agents of different production stages of a value chain can be considered as well. In the model, farmers in the catchment area of an existing BHS decide upon cultivating SRC and selling the resulting wood chips to the BHS. The BHS again processes the wood chips to heat. This heat is finally delivered to end-consumers in the surrounding region, whose respective demand is exogenous and stochastic. By means of the model, the optimal thresholds for cultivating SRC (investment thresholds) and for harvesting the SRC in full without re-cultivation (disinvestment thresholds) of the farms are simultaneously determined. This is done by explicitly considering interactions between different stages of the value chain, which has not been achieved yet. For instance, the maximum capacity of the BHS represents a de facto production restriction for the farms (potentially) cultivating SRC in the surrounding region. Additionally, incentive measures by the BHS to the benefit of the farmers are implemented. In specific, the BHS grants price floors for wood chips or investment subsidies for cultivating SRC to the farmers in order to increase its utilization and achieve economies of scale. The effects of these incentive measures at different levels on the utilization and the profitability of the BHS can be assessed. The model is solved numerically by linking genetic algorithms (GAs) and stochastic simulation.

In the following section, the decision situation is explained and the agent-based real options model to solve the decision problem is developed. Following this, the used parameters for the application of the model to the value chain of woody biomass from SRC are derived from the literature. In the results section, the main model results are presented and discussed. The article ends with a summary of the main findings and the derivation of some implications for entrepreneurs in the value chain for woody biomass as well as for politicians.

2. Decision situation and methodological approach

In the first subsection, the decision situation is described. Based on this, the agent-based real options market model is developed in the second subsection. Finally, the numerical solution procedure for the model is presented in the third subsection.

2.1. Description of the decision situation

This study exemplarily examines an already existing BHS in North-Eastern Germany which converts woody biomass to heat. This heat is delivered to nearby end-consumers, for instance schools or public administration buildings, through an existing district heating system. The demand for heat from end-consumers is exogenously given and assumed to be stochastic, for instance due to weather fluctuations. In the catchment area of the BHS are several farms of which each of them has a given area which is currently been set-aside. This is due to the fact that, because of the low soil quality and the low average precipitation levels in the cultivation period from April to September, it is not possible to generate any positive gross margins from conventional annual crops, for instance wheat or canola [16]. However, it could be economically interesting for the farmers to cultivate SRC on their set-aside land for two reasons: First, SRC can generally provide high and stable yields despite poor production conditions [13,14]. Secondly, with the BHS, the farmers have a potential nearby outlet for their harvested wood chips.

The competing farms in the catchment area of the BHS are assumed to be risk-neutral as well as homogenous with regard to their capabilities of planting SRC and producing wood chips from it. Each farm has the option to repeatedly invest in SRC within the period under consideration, until its set-aside land, which is
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