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The value chain of heat production from woody biomass under market competition and different intervention systems: An agent-based real options model

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Abstract

Woody biomass in terms of short rotation coppice (SRC) could be a promising alternative for producing biomass to generate renewable energy. Even through, from a single farms point of view, SRC seems to be an interesting land use alternative, farmers do not cultivate SRC. Some studies found out that the real options approach (ROA) could at least partially explain farmers' inertia of cultivating SRC. Nevertheless, those studies do not take into account market competition between farmers and farmers' fear of not having an outlet market in order to dispose the harvested wood chips. This inertia can also cause an investment reluctance concerning building biomass heating stations. In the present study therefore, we focuses on the whole value chain from producing wood chips over generating energy and selling the energy to the end-consumers. We develop an agent-based model which is able to consider market competition and can picture the whole value chain. In order to further motivate farmers to cultivate SRC different types of incentives offered by the biomass heating station are investigated. Our results show that if no incentive system is offered, farmers cultivate SRC reluctantly which leads to a loss of profit of the biomass heating station. With regard to an investment subsidy, it needs to be equal to approximately 300% of the capital costs of investment to strongly motivate farmers to produce enough wood chips that largely decrease the loss of profit of the biomass heating station. If a price floor is offered, farmers' additional amount of wood chips produced is very small. Therefore, the loss of profit does not significantly decrease if the price floor amounts to 95%.

Keywords

Real options, value chain, competition, incentive systems, biomass, short rotation coppice

1. Introduction

In Europe, it is aimed to produce about 20% of the energy demand from renewable sources by 2020 (European Commission, 2014). For instance, the German government aims to generate at least 14% of the demand of heat and cold and 35% of the electricity from renewable sources by 2020 (§1 Abs. 1 EEWaermeG, §1 Abs. 1 EEG). To reach this aim, one important way is to generate energy from biomass production (ZSW, 2013). Therefore, the cultivation of crops for energy production has increased in Germany (ZSW, 2013). Besides generating energy from agricultural crops, one possible way for farmers is to cultivate SRC. SRC is defined as the cultivation of trees on agricultural land, which are harvested in a few years interval over a long time horizon (Zervos et al., 2011). The harvested wood chips are mostly used in biomass heating stations, which are able to produce and deliver heat to end-consumers in a particular region. For Germany, there are about 1,200 heating stations that ensure the heat for e.g. buildings (BBE, 2014).

With regard to sustainable land use alternatives, cultivating SRC could be of general interest because it is ecologically advantageous compared to intensive agricultural land use (Hall and House, 1995; Bryan et al., 2010; Lasch et al., 2010; Langeveld et al., 2012). SRC (poplar) generally does not require fertilizer, and pesticides need only to be deployed until plants are established (Dallemand et al., 2007; Marron et al., 2009, pp. 14-41). Moreover, there is a lower danger of soil consolidation as machinery is only used for planting, harvesting, and recultivating. In the face of these ecological advantages and the energy targets set by the EU and Germany, cultivating SRC in order to deliver the harvested wood chips to biomass heating stations may be an interesting way of producing more energy from renewable sources.

For farmers, SRC can be of high interest because it can be more profitable than traditional agricultural land use (Heaton et al., 1999; Schoenhart, 2008, Wagner et al., 2009). Especially in areas with marginal soil qualities and high levels of groundwater, SRC is competitive compared to cash crops as it obtains high and stable yields, despite poor soil qualities (Murach et al., 2009; Stolarski et al., 2011).

Nevertheless, farmers seem to behave very reluctant in terms of cultivating SRC. Although, the potential area for SRC is estimated at 200,000 ha just in northeastern Germany (Murach et al., 2009), merely 5,000 ha have been used for SRC in the whole of Germany (Marron et al., 2012, p. 116). This could be reasonable by the fact that cultivating SRC can be seen as an investment, which is characterized by irreversible investment costs, temporal flexibility of investment implementation and uncertainty with regard to the investment returns.

During the past one and a half decades, agricultural economists started to realize that the real options approach (ROA) is more advantageous for analyzing investments in agriculture than traditional investment models based on the net present value (NPV) rule. The reason is that the ROA explicitly takes into account sunk costs, temporal flexibility and uncertainty of the future cash flows in making the investment (Dixit and Pindyck, 1994, pp. 3-25). For SRC, Musshoff (2012) as well as Wolbert-Haverkamp and Musshoff (2014) have shown that the ROA can help to partly explain farmers' inertia to convert from annual crops to SRC. This is justified because, following the ROA, farmers should invest in SRC more reluctantly than following the NPV rule.

With regard to the studies of Musshoff (2012) and Wolbert-Haverkamp and Musshoff (2014) the cultivation possibility to SRC is only observed from the point of view of a particular farmer. This could be problematic because of the following two reasons: First, it is disregarded that more than one farmer in a particular region can cultivate SRC. With regard to the biomass heating station to which wood chips are delivered, it has a limited capacity. Therefore, farmers compete for the limited demand of wood chips which is needed for the biomass heating station. Therefore, farmers behave in a competitive market where the market price of wood chips is influenced by the cultivation behavior of all farms. Not considering such a sectoral view with fixed maximal production capacities can lead to misinterpretations regarding investment decisions of farmers (Feil et al., 2013). Second, farmers' reluctance of not cultivating SRC could cause an investment reluctance for building biomass heating station. The operators could fear of not receiving enough wooded biomass to charge the capacity of the biomass heating station. The operators' reluctance could increase farmers' inertia of cultivating SRC because farmers could be afraid of not having an outlet market for the produced wood chips. Therefore, we need to focus on the whole value chain.

All the aforementioned real options applications assume perfect competition. With this, they implicitly exploit the finding of Leahy (1993), who shows that a competitive investor finds the same optimal investment strategy as a myopic planner that ignores other firms' investment decisions as well as the resulting price effects. The implication of this finding is that the analysis of the optimal investment is simplified considerably due to the fact that competition does not need to be taken into account: The firms' optimal investment thresholds can be determined in closed form without the burdensome and iterative derivation of the endogenous equilibrium price process (cf. McDonald and Siegel, 1986). However, the preconditions for applying this optimality property of myopic planning are very restrictive and at least unrealistic. For example, any incentive system which directly or indirectly affects the price dynamics cannot be included. Dixit and Pindyck (1994, ch. 9) relax this constraint by numerically calculating the effects of politically induced price controls on the investment thresholds of the firms by using stochastic simulation. However, only one out of many other relevant policies (incentive systems) is analyzed. Furthermore, by this limiting perspective to only one (myopic) firm, possible interaction between different firms that compete for alimented production capacity, for example, given by a downstream biomass heating station, cannot be considered.

As mentioned above, it could be problematic to consider only a part or simply one element of the value chain especially in the case of cultivating SRC for energy production. For example, in the case of a biogas station various alternative substrates next to maize can be used, meaning that the elements of the value chain are not very associated. In terms of producing wood for generating heat, this is different. On the one hand, the farmers have invested in cultivating SRC, conducting them to be depended from the biomass heating station. If the biomass heating station would abandon production, farmers would have problems with selling the wood chips. On the other hand, the biomass heating station needs the wood chips. If no wood chips are delivered, it is very difficult to find a substitute to run the biomass heating station. Therefore, next to considering market competition, it is important to picture on the whole vale chain.

In the present study, we focus on a whole value chain of producing heat from wood chips. Within the value chain, we assume farmers who have lands with marginal soil qualities and high groundwater levels without much rainfall and no irrigation possibilities in a particular region. The higher groundwater levels cannot be used by annual crops but can instead be reached by SRC. Therefore, these lands are usually set-aside because, from a single farms' point of view, it is not profitable to cultivate agricultural crops (cf. Musshoff, 2012). Since a biomass heating station is built in the middle of the particular region, farmers have the possibility to cultivate SRC on their set-aside land. Up to a maximal production capacity of the biomass heating station, farmers can deliver their harvested wood chips. We take into account that farmers behave reluctantly regarding cultivating their land to SRC; the operator of the biomass heating station reflects on how he can increase farmers' willingness to cultivate at least a part of the set-aside land to SRC. To do so, he considers two different types of incentive systems. Following Marron et al. (2012, pp. 114-118), the relative high investment outlay of SRC in combination with missing financial capital may cause farmers' inertia. Therefore, we first suppose that farmers' willingness to cultivate SRC, should be increased through an investment subsidy. An investment subsidy for cultivating SRC was offered to famers in the UK and Sweden (Mitchell et al., 1999; SAC, 2008). Second, as prices for wood chips are volatile, a price floor is assumed to cover farmers' wood chip prices downwards. Minimal wood chip prices were offered to producers of wood chips in France (Ridier, 2012). At the end of the value chain, the generated heat from the biomass heating station is sold to end-consumers in the region which have the possibility to heat buildings with renewable energy instead of fossil energy sources. Within this study, we have the following objectives:

1. We develop an agent-based real options model which can consider the whole production of biological heat: from competing farmers who cultivate SRC, over the biomass heating station, which delivers heat to end-consumers. We calculate investment trigger prices for farmers, farmers' wood chip supply and the profit of the biomass heating station.
2. We make an impact analysis of different measures, the biomass heating station offers to farmers in order to increase farmers' willingness to cultivate SRC to further charge the capacity of the biomass heating station to increase its profit.

The model is based on Feil et al. (2013) and is expanded by the perspective of the whole value chain. Based on an endogenous demand of heat, a combination of genetic algorithm (GA) and stochastic simulation is used to derive an equilibrium price process for the harvested wood chips of SRC. We are the first who calculate investment trigger prices triggers for cultivating SRC under competition and adopt the ROA in order to build a competitive market model which is able to picture a whole value chain using the example of producing wood for generating renewable energy.

The rest of the paper is structured as follows: In section 2, we explained the theoretical background of the ROA in the context of considering market competition. In section 3, the real options market model for the application of the value chain from wood production to generating heat is described. Furthermore, it is explained how the incentive systems are implemented into the model. In section 4, cultivating SRC is pictured and model parameters are estimated. The results are discussed in section 5. The paper ends with a summary and an outlook of the model potential and some limitations (section 6).

2. The optimality property of myopic planning

In comparison to the ROA, the NPV rule evaluates a "now or never" decision, in which the firm cannot wait with an investment. Therefore, the investment decision in practice cannot be depicted sufficiently with the help of the NPV rule. Referring to SRC, the ROA can consider that farmers have the option to invest/cultivate now or to delay investment/cultivation. If a farmer invests now, he gives up the opportunity of waiting with an investment and perhaps generating new information which could positively affect the profitability. The lost opportunity of delaying an investment can be seen as opportunity cost which should be included as a part of the investment outlay. In conclusion, an irreversible investment under uncertainty should only be made if the present value of its expected returns exceeds the investment outlay by an amount equal to the value of waiting for additional information. In comparison to the NPV rule, this means that the critical product price at which the firm should invest (in the following referred to as investment trigger price) is shifted upwards (cf. Dixit and Pindyck, 1994) because the cash flows do not only have to compensate for the investment outlay. Additionally, they have to offset the lost value from deferring the investment.

As the ROA is based on the analogy between financial options and real investment projects, the direct transferability is problematic. In comparison to financial options, which constitute an exclusive right for the owner, real investment opportunities are also opened to other market participants in a competitive market. Following this, a change of investment trigger prices will cause similar reactions of other market participants, which influence the equilibrium prices. Therefore, the price process cannot be considered as exogenous. Due to the fact that the price process determines the value of the investments and the investment trigger prices, the direct valuation of the investments and the investment trigger prices is complicated. However, Leahy (1993) shows that an investor who behaves myopically and ignores potential market entries of competitors finds the same trigger prices as a competitive investor.

In regards to Leahy (1993), his model considers a completely competitive market which consists of small homogeneous price-taking firms which produce the same product and have equal and constant returns to scale technology. The production output of all firms at time t equals the market supply X_t and is subject to depreciation with rate λ. The price P_t for the products is a result from the reactions of all firms in terms of X_t on the exogenous stochastic demand parameter μ_t. It is defined by a time-invariant inverse demand function D and is assumed to be isoelastic (e.g. Dixit, 1991):

$$P_t = D(X_t, \mu_t) = \left(\frac{\mu_t}{X_t}\right)^{\Pi} \tag{1}$$

with

$$\Pi = -\frac{1}{\eta}$$

η is the price elasticity of demand. Following Leahy (1993), the demand stock and in many other ROA applications, the prices processes as stochastic variables (e.g. Postali and Picchetti, 2006; Musshoff, 2012) are described by a geometric Brownian motion (GBM)[1]:

$$d\mu_t = \alpha \cdot \mu_t \cdot dt + \sigma \cdot \mu_t \cdot dz \tag{2}$$

α is the drift rate and σ the volatility. The volatility is multiplied by a Wiener process. The drift rate and the volatility are assumed to be constant. The stochastic demand process according to equation (2) can be translated into a stochastic price process (Odening et al., 2007):

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[1] The exposition is simplified by assuming a GBM. Nevertheless, the presence of a GBM is not essential for providing the validity of the optimality property of myopic planning. Baldursson and Karatzas (1997) deliver a generalization.

$$dP_t = \hat{\delta}(P_t, X_t) \cdot dX_t + \hat{\alpha} \cdot P_t \cdot dt + \hat{\sigma} \cdot P_t \cdot dz \tag{3}$$

with

$$\hat{\delta}(P_t, X_t) = -\Pi \cdot X_t^{-1} \cdot P_t$$

$$\hat{\alpha} = \Pi \cdot \alpha + \frac{1}{2} \cdot \sigma^2 \cdot (\Pi^2 - \Pi) + \lambda \cdot \Pi$$

$$\hat{\sigma} = \Pi \cdot \sigma$$

The regulated endogenous stochastic price process, as anticipated by a competitive investor, is described by equation (3). The first term on the right-hand side captures price changes induced by investments of competitive firms. As all firms behave in the same way, the price process will be truncated as soon as the product price climbs up to a specific trigger price level. The trigger price hence constitutes an upper reflecting barrier (Dixit and Pindyck, 1994: 254). A myopic investor, however, ignores these effects and assumes an unregulated exogenous stochastic price process:

$$dP_t = \hat{\alpha} \cdot P_t \cdot dt + \hat{\sigma} \cdot P_t \cdot dz \tag{4}$$

Figure 1 illustrates the respective difference between the regulated endogenous price process (cf. eq. (3)) and the unregulated exogenous price process (cf. eq. (4)) for the case of a GBM. Although both simulations utilize identical parameters with a drift rate of $\hat{\alpha} = 0\%$ and a volatility of $\hat{\sigma} = 20\%$, the sample paths look completely different.

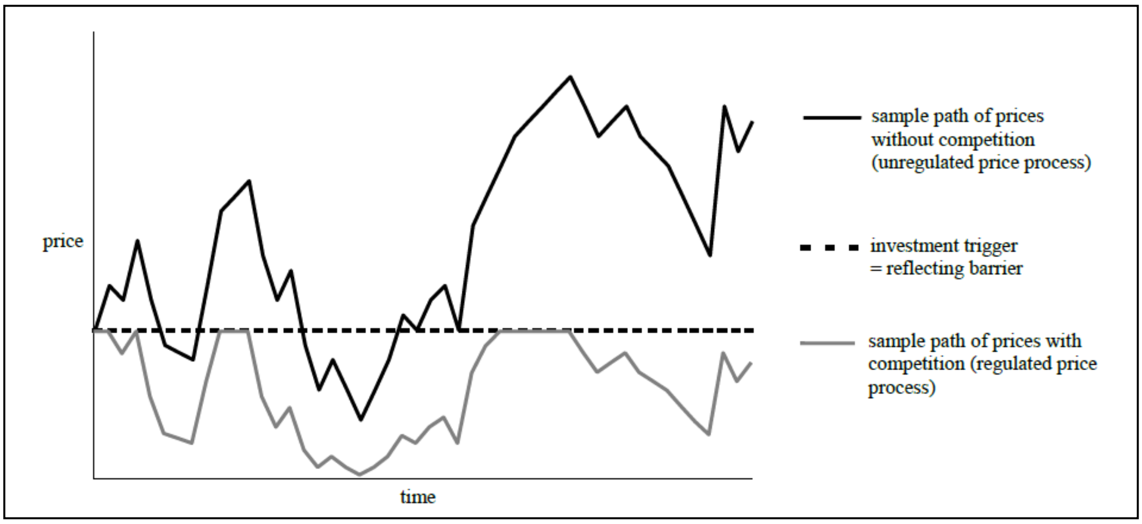

Fig. 1. Sample path with and without competition (Leahy, 1993)

Note: According to Feil et al. (2013)

GBM with $\alpha = 0\%$ and $\sigma = 20\%$, $\eta = -1$.

According to Leahy, both the competitive investor and the myopic planner find identical optimal trigger prices representing the competitive equilibrium. The reason is that the myopic planner commits two errors which completely offset each other (cf. Leahy, 1993): First, he ignores the truncation of the price process and, therefore, overestimates the investment's profitability. Second, he wrongly assumes to have an exclusive option to postpone the investment. In this respect the value of waiting makes it less attractive to invest immediately. In other words, the myopic planner is right for the wrong reasons. The implication of Leahy's result is that the burdensome and iterative determination of an endogenous equilibrium price process can be avoided, when dealing with competitive markets. The complicated optimization problem of a competitive investor can be replaced by the simpler problem of a myopic planner without a loss of precision. By using the McDonald-Siegel pricing formula, the optimal trigger price $\overline{P}$ of a myopic planner can be determined analytically (cf. Dixit and Pindyck, 1994: 201; McDonald and Siegel, 1986):

$$\bar{P} = \frac{\beta}{\beta - 1} \cdot (r - \hat{\alpha} + \lambda) \cdot I \tag{5}$$

with

$$\beta = \frac{1}{2} - \frac{\hat{\alpha}}{\hat{\sigma}^2} + \sqrt{\left(\frac{\hat{\alpha}}{\hat{\sigma}^2} - \frac{1}{2}\right)^2 + \frac{2 \cdot r}{\hat{\sigma}^2}}$$

r denotes the time-continuous discount rate and I the investment outlay for one additional output unit. Variable costs are not explicitly considered.

Nevertheless, using the optimality property of myopic planning to competitive markets is problematic because it is not possible or at least very complex to consider market interventions which effects cannot be transformed directly into the price process, for example, production ceilings. To solve this problem, a derivation of the endogenous equilibrium price process would be necessary, instead of just using the above system of equations. In the literature, this is commonly assessed as not practicable (cf. e.g. Leahy, 1993). In the next section, we develop a real options market model, which allows the derivation of exactly this equilibrium price process in competitive markets. Therefore, we do not need the preconditions of applying the optimality property of myopic planning. Hence, we are more flexibly than other models and are able to integrate an assessment of different market interventions.

3. Methods and theoretical background

The following section is based on Feil et al. (2013). Their real options market model is extended by additionally considering a processing stage between the competing agricultural firms (farms) and the end-consumers. This processing stage represents a biomass heating station with a given maximum production capacity. The competing farms in the catchment area of the biomass heating station can invest in the cultivation of SCR to produce wood chips, which are then sold to the biomass heating station. The biomass heating station again converts the wood chips into heat and sells the head to the end-consumers. In subsection 3.1., the real options market model is explained in general. Based on this, it is illustrated in subsection 3.2. how the equilibrium investment thresholds of the competing farms are determined numerically by combining GA with stochastic simulation. To additionally analyze the effects of different incentive systems implemented by the biomass heating station, we integrate investment subsidies and price floors into the model and calculate the investment thresholds of the farms and the profit of the biomass heating station (subsection 3.3.).

3.1. Basic structure of the real options market model

Within the real options market model, $N = 50$ risk-neutral farms are considered. With regard to the cultivation possibility of SRC, the farms have homogenous investment and production capabilities. They plan in discrete time, which is a necessary assumption of numerical evaluation procedures.[2] Until an exogenously given maximum output capacity of wood chips X_{cap} is reached, each farm has the option to repeatedly invest in production capacity, i.e. cultivating SRC on its land, within the period under consideration T. The investment outlay (investment costs of SRC) and the production output per tons of dry material (t_{DM}) of wood chips are proportional, which means that, there are no economies of scale for the farms. In accordance with Ridier (2012) the investment project (here: cultivation of SRC) has an unlimited useful lifetime and is not subject to depreciation. Consequently, the production capacity of a farm n in time t, resulting in a production output of wood chips X_t^n, can be calculated via investments in cultivating SRC once in a period, resulting in an additional production output of wood chips of $\Delta X_{t+\Delta t}^n$ in the following period. Therefore, the production quantity of wood chips follows:

$$X_{t+\Delta t}^n = X_t^n + \Delta X_{t+\Delta t}^n \tag{6}$$

The aggregated production output of wood chips produced by all farms in the market represents the market supply X_t. Since the biomass heating station has closed supply contracts of wood chips with a few farms to ensure that at least a part of the wood chips is delivered before the biomass heating station has been build, we suppose an initial supply of wood chips X_0. This initial supply includes some limited wood chips out of other sources as, for example, forests.

Within the model, all farms maximize their expected NPV. Furthermore, fully market transparency is assumed, which means that all farms have complete information regarding the stochastic demand process of wood chips and the investment behavior of all competing farms in terms of cultivating SRC, whereby they build demand expectations for the respective next period. All farms should have the same optimal investment trigger price in the equilibrium. To determine the investment trigger price in

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[2] Feil et al. (2013) have built a more general model than this one which shows the same results according to an analytical model of Dixit and Pindyck (1994, 216ff.).

the equilibrium within the model, the competing farms interact by gradually adjusting their (initially different) investment trigger prices $\bar{P}^n$, as explained in the next subsection.

The investment volume of a farm is derived as follows: farms have initially different tendencies to invest. The farms with lower investment trigger prices have a stronger tendency. In the model, they are sorted by their investment trigger prices, starting with the lowest once, i.e. $\bar{P}^n \leq \bar{P}^{n+1}$. Hence, farm $n+1$ does not invest in cultivating SRC if farm n has not already invested in production capacity of wood chips up to X_{cap}. In every period t, it is technically ensured that de facto a marginal (or last) farm exists which invests to the extent that its investment trigger price equals the expected product price of wood chips of the next period. Due to the relatively large number of farms ($N = 50$), the market within the model can be seen as an approximately atomistic market. For the investment volume of a farm $\tilde{n}$ in t, corresponding to its additional production output of wood chips in $t + \Delta t$, follows:

$$\Delta \mathrm{X}^{\tilde{n}}_{t+\Delta t}\left(\bar{P}^{\tilde{n}}\right) = \max\left[0, \min\left(\begin{array}{c} X_{cap} - X^{\tilde{n}}_t , \\ \frac{\hat{\mathrm{E}}(\mu_{t+\Delta t})}{(\bar{P}^{\tilde{n}})^{-\eta}} - \left(\sum_{n=1}^{N} X^n_t + \sum_{n=1}^{\tilde{n}-1} \Delta \mathrm{X}^n_{t+\Delta t}(\bar{P}^n)\right), \\ X_{max} - \sum_{n=1}^{N} X^n_t - \sum_{n=1}^{\tilde{n}-1} \Delta X^n_{t+\Delta t}(\bar{P}^n) \end{array}\right)\right] \tag{7}$$

The “max-query” of equation (7) ensures non-negative investment volumes. The “min-query” guarantees that a farm $\tilde{n}$ is not able to assemble more production capacity of wood chips in terms of cultivated land to SRC as its maximum production capacity (first line of the part of the “min-query” of the equation). Furthermore, the “min-query” ensures that the total quantity of wood chip supply is only expanded as far as the investment trigger price of the “last” invested farm equals the expected product price of wood chips of the next period (second line of the “min-query” of the equation). The third line of the “min-query” ensures that the production capacity of wood chips is not higher than the maximal production capacity of the biomass heating station X_{max}. As soon as X_{max} is exceeded, farms are not allowed to additionally cultivate SRC, even if their investment trigger prices are lower than the market prices of wood chips.

Finally, an objective function needs to be established which defines the optimal investment strategy of the farms. With regard to the assumption, that each farm aims to maximize the expected NPV of the future cash flows F_0^n, this value is in the real options terminology also referred to as an options value by choosing its farm-specific investment trigger price $\bar{P}^n$:

$$\max_{\bar{P}^n, \underline{P}^n}\{F_0^n(\bar{P}^n)\} = \max_{\bar{P}^n}\left\{\sum_{t=0}^{\infty}\left((P_t^F - Cv_F - k) \cdot X_t^n(\bar{P}^n)\right) \cdot e^{-r \cdot t}\right\} \tag{8}$$

P_t^F is the price for wood chips that the farm receives from the biomass heating station. Cv_F are the variable production costs and k are the capital costs of investment per t_{DM} in terms of cultivating SRC. k equals:

$$k = I \cdot (e^{r \cdot \Delta t} - 1) \tag{9}$$

Thereby, I is the investment outlay.

If the wood chips are delivered, the biomass heating station produces heat out of the wood chips. The profit of the biomass heating station G_t is calculated by the following equation:

$$G_t = (P_t^E - P_t^F - Cv_B) \cdot X_t - C_f - B_t \tag{10}$$

The generated heat per kilowatt hour (KWh) is delivered to the end-consumer at price P_t^E. For simplicity reasons P_t^E can be calculated in heat-equivalent t_{DM} of wood-chips. Cv_B are the variable costs for generating heat out of wood chips per t_{DM} of the biomass heating station. C_f are the fixed costs of the biomass heating station and include the annuity of the investment in the biomass heating station. As the operator of the biomass heating station searches for incentive systems which increase his profit, B_t equals the costs that the biomass heating station pays for the incentive systems (explained in subsection 3.3.).

At the end of the value chain, there are end-consumers to who the heat is delivered. They can decide to heat their buildings with renewable energy sources instead of fossil sources without having any additional costs. As they demand heat, the biomass heating station needs a particular amount (demand) of wood chips to produce this amount of heat. Therefore, farms' wood chip prices are a result from the reactions of all farms on the end-consumers' exogenous demand shock of heat. Hence, the prices for heat and therefore, for wood chips need to be determined endogenously within the model. The relationship between the market supply of wood chips X_t and the price of heat P_t^E is defined by an isoelastic demand function according to equation (1). With regard to modeling the stochastic demand parameter of heat μ_t of the end-consumers, any stochastic process can be applied as flexibly as needed.[3]

3.2. Solving the model by combining genetic algorithms with stochastic simulation

The model is solved numerically by combining GA with stochastic simulation because there is no closed-form solution for the optimization problem described in the previous subsection existing. GA are a heuristic search method, which are oriented on the natural evolution (Goldberg, 1998). GA have been applied in many disciplines during the last two decades including economics (e.g. Allen and Karjalainen, 1999; Altiparmak et al., 2006; Graubner et al., 2011; Wolbert-Haverkamp and Musshoff, 2014). In the present analysis, the GA is used to examine the optimal investment strategy in terms of the optimal investment trigger, of competing farms under different types of market interventions (e.g. Arifovic, 1994; Dawid, 1999).

Usually, all GA have three standard features in common: a number of genomes, a fitness function and the operators of the GA. A number of genomes ($N = 50$) generally describe a collection of possible solutions to a given problem. In this case, each genome represents the investment trigger price of a farm n. The fitness function generally serves as the evaluation measure for the quality of a solution. The higher the fitness of the particular genome, in comparison to the others, the higher is the quality of the solution. In our model, the fitness function is represented by the objective function (equation (8)), through which the options value F_0^n of a farm n with its investment trigger price is

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[3] Besides industry-wide shocks, firm-specific shocks are not considered within the model for complexity reasons. For a combination of both industry-wide and firm-specific shocks see Dixit and Pindyck (1994, 277ff.).

calculated. The calculation of the options value is done by using the stochastic simulation. Through the stochastic simulation, the options value F_0^n is calculated over an approximately infinite time horizon and many simulation runs. Finally, the GA operators are applied to the number of genomes. Usually, the GA operators consist of the following operators: selection, mutation and recombination. Through these operators, the solutions with high options values, meaning a high quality, are identified and new, possibly superior solutions are incorporated for the next generation of genomes. A detailed description can be found in appendix A.

3.3. Consideration of market interventions in the model

In this subsection, we describe how the market interventions of the biomass heating station to increase farmers' willingness to cultivate SRC are implemented in the model. Thereby, we first begin with the description of the price floor. Second, an investment subsidy is considered. The incentive systems are offered to the additional production capacities after year zero.

With regard to a price floor P_{min}, the determination of the farms' wood chip price needs to be modified for the additional amounts of wood chips after the year zero. Considering farms' wood chip price P_t^F according to equation (1), the farms' effective price for the additional amount of wood chips after year zero $P_t^{F'}$ follows:

$$P_t^{F'} = \max\ \{P_{min}, P_t^F\} = \max\left\{P_{min}, \left(\frac{\mu_t}{X_t}\right)^{\Pi}\right\} \tag{11}$$

As a result, P_t^F in equation (8) is replaced by $P_t^{F'}$, where P_{min} will be exogenously fixed as a proportion of the total costs of investment k.

With regards to an investment subsidy s, which will be paid to those farms which invests in cultivating SRC to produce wood chips after the year zero, the initial investment outlay I per t_{DM} is reduced by a fixed proportion. Thus, k in equation (8) is replaced by the producers' effective capital costs of investment k':

$$k' = I \cdot (1 - s) \cdot (e^{r \cdot \Delta t} - 1) \tag{12}$$

The biomass heating station has to pay costs for offering those incentive systems B_t (cf. equation (10)). If a price floor is offered, the costs of the biomass heating station B_t equal:

$$B_t = \max\left[0, \left(P_{min} - P_t^F \cdot \left(X_t - X_0 - \frac{\mu_t}{(P_{min})^\eta}\right)\right)\right] \tag{13}$$

In the case of an investment subsidy, B_t is defined as follows:

$$B_t = \sum_{n=1}^{N} \Delta X_t^n \cdot I \cdot s \tag{14}$$

In order to compare both incentive systems among themselves and with the situation without offering incentive systems, the profit of the biomass heating station G_t (equation (10)) is compared in this study.

4. Model assumptions for the application to the competitive wood chip market

The real options market model is applied to the wood chip market. In regards to the given production conditions, we assume $N = 50$ farms which have set-aside lands. From a single farms point of view, these lands are only interesting to be used for SRC. Without a loss of generality, we assume that farms' maximal production capacity of wood chips X_{cap} is about 20 t_{DM}, allowing each of the 50 farms to deliver wood chips for maximal 20 t_{DM} per year. In terms of the biomass heating station, there is a maximal production capacity X_{max} = 661 t_{DM} (C.A.R.M.E.N. e.V., 2010). If X_{max} is reached, farms are not allowed to cultivate further SRC. Since all farmers are able to cultivate SRC on their set-aside land, they react in a perfect competitive market. We suppose that there is an initial supply of wood chips X_0 which equals 300 t_{DM}. That is nearly 45% of the production capacity of the biomass heating station.

If the farms cultivate SRC, the initial investment outlay per ha is about 2,736 €/ha.[4] Related to average yield of 10 t_{DM}/ha over an infinite useful lifetime, the initial

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[4] We conducted literature research on SRC and interviewed experts to gather the data needed to determine the costs of investment, production, and recultivation. Because the data varies in the literature (Dallemand et al., 2007; Kroeber et al., 2010; Marron et al., 2012, pp. 53-54), the costs are average values of the collected data.

investment outlay per t_{DM} I is about 273.60 €/t_{DM}. Assuming a risk-free interest rate of 3.69%[5], the capital costs of investment per t_{DM} k are about 10.10 €/t_{DM} (cf. equation (9)). The variable production costs, which include harvesting, drying and transporting amount to about Cv_F 32 €/t_{DM}.

For the biomass station variable costs for generating heat out of wood chips Cv_B arise to 42 €/t_{DM}. Furthermore, annual fixed costs C_f of 53,779 € accrue (cf. C.A.R.M.E.N. e. V., 2010).

The biomass heating station produces heat which is delivered to the end-consumer. The end-consumer pays the biomass heating station a price for heat (which can be calculated in t_{DM} of wood chips) P_t^E. End-consumers' heat price is equal to the price paid for farmers' wood chips P_t^F plus an extra charge for the biomass heating station. In order to calculate the additional charge of the biomass heating station Wolbert-Haverkamp and Musshoff (2014) have shown that heating oil prices per KWh are higher than wood chip prices per KWh. From there, we compare the heat prices per KWh (AGFW, 2014) with the wood chip prices between 2003 and 2011 (C.A.R.M.E.N e. V., (2012)). To calculate the additional charge of the biomass heating station, the differences of the particular years are multiplied with the heating value of wood chips of 4,057 KWh/t_{DM} in order to calculate the differences per t_{DM}. The additional charge of the biomass heating station is equal to the mean of these differences and amounts to about 165 €/t_{DM}. The calculation of the additional charge of the biomass heating station is done in Table 1.

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[5] To calculate the risk-free interest rate, the mean of the nominal returns of the German federal bonds with a residual lifetime of 15 to 30 years from 1988 through 2011 of 5.70% per year (Deutsche Bundesbank, 2012) is used. The average inflation rate of the same period is 1.94% per year (IHK, 2012). Consequently, the corresponding real interest rate, which we employ as the risk-free interest rate, is about 3.69% per year.

Table 1

Determination of the additional charge of the biomass heating station

Year		**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Prices for heat	€/KWh	50	51	56	60	60	69	65	66	73
Wood chip prices	€/KWh	15	16	17	21	23	25	17	28	23
Difference	€/KWh	34	35	39	38	37	45	49	38	50
Additional charge of the biomass heating station [a)]	€/t_{DM}	140	142	160	156	150	181	198	155	201
Mean of the additional charges	€/t_{DM}					165				

[a)] Heating value of wood chips: 4,057 KWh/t_{DM}

To determine the stochastic process for the prices of heat P_t^E, we cannot make use of the time series which is used to calculate the additional charge. To estimate the parameters of the stochastic process as reliable a longer time series is needed (Campbell et al. 1997, p. 363; Chevalier-Roignant and Trigeorgis 2012, p. 438). Therefore, we make use of the inflation-adjusted prices of oil per liter from 1970 to 2011 per KWh (Hawliczek, 2001; IWO, 2012). To calculate the inflation-adjusted heat prices per t_{DM} of wood chips, the heating oil prices are multiplied by the heating value of wood chips of 4,057 KWh/t_{DM}. Heat prices in terms of one t_{DM} for end-consumers are shown in Figure 2.

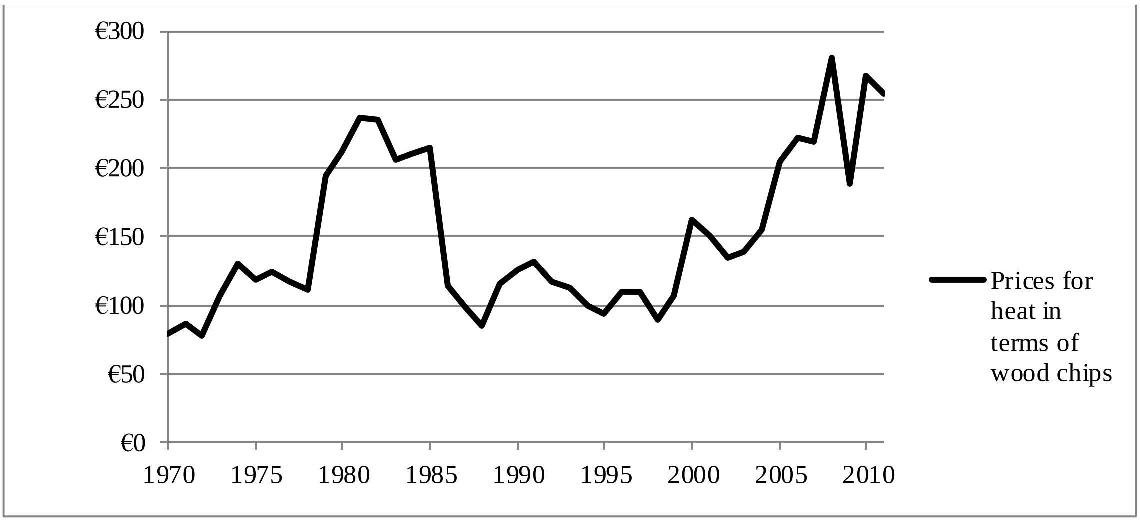

Fig. 2. Historical prices of heat per t_{DM} derived from the inflation-adjusted heating oil prices

Since an augmented Dickey-Fuller-test (Dickey and Fuller, 1981, Enders, 2003, pp. 76-80) and a KPSS-test (Kwiatkowski et al., 1992) have shown that the time series of wood chip prices is non-stationary, we apply a GBM, which does not allow a change of sign. With regard to the parameters of the GBM, the drift rate α and the volatility σ, are estimated from the empirical price data. A two-tailed t-test has shown that the drift rate is not significantly different from zero (p-value: 0.395). The volatility equals 21.16%. Association of German Energy Consumer (German: Bund der Energieverbraucher (2014)), we consider the price elasticity of heating oil η to be -0.32.

Having this information, the parameters of the demand process of heat can be calculated on the basis of equation (3). The drift rate of the demand process is 0% and the volatility equals 6.77%. Due to the fact that the GBM as stochastic demand process (equation (2)) assumes infinitesimal small time steps length, which is not useful for the simulation purposes, we use a time-discrete version the of the GBM using Ito's Lemma (Hull, 2009):

$$\mu_{t+\Delta t} = \mu_t \cdot e^{\left[\left(\alpha - \frac{\sigma^2}{2}\right)\cdot\Delta t + \sigma\cdot\varepsilon_t\cdot\sqrt{\Delta t}\right]} \tag{15}$$

Thereby, ε_t is a standard normally distributed random number and Δt a time step length. Equation (15) represents an exact approximation of the time-continuous GBM for any Δt. An overview of the model assumptions is shown in Table A1 in the appendix.

5. Results

In Table 2, the effects of investment subsidies and price floors at different levels implemented by the biomass heating station on the investment trigger prices of the farms, their supply quantity of wood chips and the profit of the biomass heating station are illustrated.

Table 2

Farms’ investment trigger prices, wood chip supply and the profit of the biomass heating station depending on the amount of investment subsidy

Incentive system	**Amount of incentive system**	**Farms’ investment trigger price ($\bar{P}^n$) in €/t_{DM}**	**Farms’ supply quantity of wood chips (X_{max}) in t_{DM} a)**	**Profit of the biomass heating station (G_t) in € per year**
Without	-	66	362	-12,901
Investment subsidy in % of k	100%	50	383	-11,333
	200%	35	423	-8,075
	300%	19	500	-1,813
Price floor in % of $k + Cv_F$	80%	54	379	-11,640
	95%	49	386	-11,160

a) Given X_0= 300 t_{DM}

The results show that without offering any incentive system, the investment trigger price $\bar{P}^n$, according to the ROA at which a farm should cultivate SRC is 66 €/t_{DM}. This is considerably above the total production costs of about 42 €/t_{DM} representing the investment price trigger according to the NPV rule. Therefore, it is shown that the real options effects with regard to the cultivation of SRC are strongly pronounced.

In the initial situation, where there is no incentive system, the farms delivers 362 t_{DM}/ha. With this capacity of wood chips, the biomass heating station generates a profit of -12,901 € per year. In the face of the maximum production capacity of the biomass heating station of X_{max} = 661 t_{DM}, an increase of the wood chip supply could decrease the loss of the biomass heating station. Therefore, the operator reflects how to motivate farms to produce and deliver more wood chips in order to produce and sell more heat to end-consumers. As an investment subsidy was provided to farms in the UK and Sweden, the operator first considers to pay farmers 100% of the capital costs of investment of cultivating SRC k.[6]

The results show that farms’ investment trigger price decreases up to 50 €/t_{DM}. Receiving the complete capital costs of investment, fams deliver 383 t_{DM} of wood chips. In this situation, the biomass heating station makes a profit of -11,333 € per year. Following this, an investment subsidy in the amount of the total capital costs of investment only leads to a little increase of wood chip supply and to a very small improvement in terms of the profit of the biomass heating station.

The very small effect of the investment subsidy can be explained because capital costs of investment per unit of are approximately 10 €/t_{DM} have only a small part of

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[6] We assume that the biomass has no shortage in liquidity.

farms' total costs of producing wood chips as the variable costs c are about 32 €/t_{DM}. With this in mind, the operator of the biomass heating station thinks about offering an investment subsidy of 200% of the capital costs of investment. In this situation, farms' investment trigger price decreases to about 35 €/t_{DM} and the total supply of wood chips is 423 t_{DM}. With an investment subsidy of 200%, the biomass heating station gains a profit of -8,075 € per year. Therefore, an increasing amount of investment subsidy which is larger than the farms' capital costs of investment of cultivating SRC, leads to an additional amount of supply and a decrease of the loss. As a result the operator of the biomass heating station reflects to offer an investment subsidy of 300% of the capital costs of investment. In this situation, the investment trigger price decreases to 19 €/t_{DM}. With this price, farms deliver 500 t_{DM} of wood chips which still leads to a profit of the biomass heating station of -1,813 €.

With regard to a price floor, an amount of 80% that is approximately 34 €/t_{DM} of the total production costs leads to an investment trigger price of 54 €/t_{DM}. The wood chip supply quantity is about 379 t_{DM} which leads to a profit of approximately -11,640 €. In the face of this small decrease of the loss of the biomass heating station, a price floor of 95% (about 40 €/t_{DM} of the farms' total production costs) is considered. In this case, the investment trigger price is about 49 € by a wood chip supply of 386 t_{DM}. When considering the wood chip supply, it is not surprising that the effect on the profit is also very small. If the two incentive systems are compared, an investment subsidy of 100% has a higher effect on the wood chip supply than the price floor of 80% and nearly the same effect than a price floor of 95%.

6. Discussion and conclusion

Land use alternatives for biomass production to generate renewable energy take an important part in reaching the targets of renewable energy production of the EU in general, and Germany in particular. Thereby next to typical crop production, SRC shows a promising way because it obtains high and stable biomass yields on poor soils. Although studies have shown that SRC can be, from a single farms' point of view, competitive compared to traditional agricultural land use, only few farms cultivate SRC. Some studies have shown that the ROA can serve to explain at least a part of farmers' inertia of cultivating SRC. This can be justified, because investment trigger prices, at which farms should cultivate SRC, following the ROA are higher than those of the traditional investment theory. Nevertheless, these studies observe the cultivation possibility of SRC only from the farmers' point of view. On the one hand, more than one particular farm interacts in a competitive market. From there, wood chip prices are endogenous and market competition needs to be considered. On the other hand, as farmers are reluctant concerning cultivating SRC, this behavior could cause investment reluctance of investors and operators of biomass heating stations. The investors (operators) could be afraid of investing in such a biomass heating station as they do not know if farms cultivate SRC in order to deliver enough wood chips. This, inertia could increase farmers' reluctance of not cultivating SRC. From there, it is important to observe the whole value chain.

In this study, we built an agent-based real options market model which is able to picture the value chain of producing wood chips to generate heat which is sold to end-consumers under competition and different incentive systems. Within the value chain, there are farms which have the possibility to cultivate SRC on their lands. As many farms have this possibility, they interact in a fully competitive market. The produced wood chips are delivered to the biomass heating station which we suppose to be built in the region. As farmers behave reluctantly regarding cultivating SRC, we take into account that the operator of the biomass heating station reflects to offer two different types of incentives in order to further motivate farmers to cultivate SRC. On the one hand, he offers an investment subsidy and on the other hand he provides price floors to capture the farms' market prices for wood chips downwards.

Our results show that in the initial situation where no incentive systems is offered to farms, farms produce not enough wood chips resulting in a negative profit of the biomass heating station. If an investment subsidy in the amount of the capital costs of investment is provided to farms, there is only a little effect with respect to the produced wood chips and therefore on the profit of the biomass heating station. This can be justified due to the fact that the capital costs of investment have only a small part of the total production costs of wood chips. If an investment subsidy of 300% is served, farms deliver much more wood chips and the loss of the biomass heating station can be decreased considerably. The price floor in the amount of 95% has a very little effect on the additional amount of delivered wood chips and the profit of the biomass heating station. Although an investment subsidy of 300% is able to improve the profit of the biomass heating station, there is still a loss of profit making the investment, form the operator of the biomass heating stations' point of view unprofitable.

As SRC provides some ecological advantages compared to traditional agricultural land use, it could be of general interest to expand the area used for SRC. With regard to investment subsidies, it might be an option that the government pays a part of the investment subsidy. As a result, farmers would cultivate SRC and the biomass heating station could be interesting from an investors' and operators' point of view. Therefore, further research is needed to determine how additional governmental incentives may increase farmers' willingness to convert to SRC.

With regard to our model, we have to outline some limitations: First, only one stochastic variable is considered. As farmers' land is, from a single farms' point of view, interesting for traditional agricultural land use, we have to take into account the gross margin of competing crops as an additional stochastic variable (cf. Wolbert-Haverkamp, 2014). Second, farms are homogeneous having equal production capacities (land and capital). In practice, farms have heterogeneous production capacities. Third, the operator of the biomass heating station is assumed to have no restrictions of liquidity. In reality, there are restrictions in liquidity which could result in not having the opportunity of offering farmers investment subsidies of 300% of the capital costs of investment. Furthermore, an infinite useful lifetime of SRC is assumed in this study. With regard to the interpretation of the model results, it needs to be taken into account that this is a simplifying assumption from reality.

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Appendix

A. Description of the structure of the combination of GA and stochastic simulation

In the following, the combination of the GA and the stochastic simulation in this model is explained.

1. For the initial (first) generation of genomes an investment trigger price for each particular genome is randomly selected out of given ranges. These ranges are defined by considering the level of the total costs of investment k.
2. In a second step, the options values of all farms can be calculated using stochastic simulation. Thereby, the stochastic demand parameter of heat μ_t and therefore biomass heating stations' demand of wood chips is simulated in $S =$ 50,000 simulation runs over the infinite period under consideration, which is approximated by $T =$ 100 years. For each simulation run, the demand heat μ_t is used to calculate the farms' investment volumes according to equation (7). Following the model assumptions of section 4, the investments are determined by sorting the farms according to the investment trigger price level, starting with the lowest. The farm with the lowest investment trigger price invests to the extent of its maximum output capacity of wood chips, followed by the farm with the second lowest trigger price, etc. until a last farm, whose investment trigger price is equal to the expected wood chip price of the next period, invests. The model ensures that there always is one farm out of the $N = 50$ farms which invests last. The investment volume of a farm n yields the total production output of wood chips corresponding to equation (6) and subsequently, the wood chip price following the demand function of heat defined by equation (1). With these values, the options value per farm according to equation (8) is calculated for the respective simulation run. The determination of the options value per farm is carried out as arithmetic mean of the options values over all simulation runs with a given population of investment trigger prices and an initial demand parameter μ_0 = 1,000 and an initial wood chip supply X_0 = 300 t_{DM}. Since all 50 farms are able to produce X_{cap} = 20 t_{DM} the maximum wood chip supply is 1,000 t_{DM} of wood chips. The maximum wood chip demand of the biomass heating station X_{max} equals 661 t_{DM}.
3. In the third step, the fitness of the farms' strategies is determined. The options values, calculated in the previous step, give information about the "quality" of the

respective genomes: The higher the options value of an investment trigger prices, the higher the fitness of the genome. Therefore, the investment trigger prices are sorted according to their respective options values, starting with the highest. A number of genomes with the highest fitness are adopted for the following generation. The relatively less fit genomes are replaced with better ones which are doubled (selection and replication). Also, it is necessary to create new genomes with investment trigger prices, because the more fit ones of the previous generation are often not the optimal genomes (recombination and mutation). The operators of the GA (selection, replication, recombination and mutation) are used to determine the genomes for the next generation. The parameters of the GA are shown in Table A1.

4. Steps 2 and 3 are repeated until the investment trigger price is homogenous and stable over many generations.
5. Due to the fact that GA is a heuristic search method, it is not guaranteed that the global optimum is found in each particular search run. Therefore, various search runs with different genomes in order to determine optimal and stable investment trigger price have been started.

Table A1

Model parameters

Number of farms N	50
Maximum output capacity of wood chips X_{cap}	20 output units per farm
Period under consideration T	Infinite, approximated by 100 years
Investment outlay I	273.60 €/t_{DM}
Useful lifetime of SRC	Infinite
Annual average yield of SRC	10 t_{DM}
Risk-free time-continuous interest rate r	3.69%
Capital costs of investment k	10.10 €/t_{DM}
Variable costs of producing wood chips Cv_F	32 €/t_{DM}
Annual fix costs of the biomass heating station C_f	53,779 €/year
Variable costs for generating heat out of wood chips Cv_B	42 €/t_{DM}
Maximal annual production capacity of the biomass heating station X_{max}	661 t_{DM}/year
Initial supply of wood chips in the year zero X_0	300 t_{DM}
Stochastic process of the demand parameter of wood chips μ_t	Geometric Brownian motion (GBM)
Demand parameter of wood chips in year zero μ_0	1,000
Parameters of the stochastic process	
Drift rate α	0%
Volatility σ	6.77%
Time step length Δt	1.00
Price elasticity of demand η	-0.32
Investment subsidy s	0%, 100%, 200%, 300% of k
Price floor $k + c$	80%, 95% of $k + c$
Simulation runs S	50,000
GA operators	
Selection rule	Quadruplicate the five fittest genomes, triplicate the next five, duplicate the next five, reproduce the next five, delete the remaining 30
Rekombination rule	Starting with the ninth fittest genome after Selection, the arithmetic mean of a genome with its foregoing neighbor is calculated with 5% recombination rate
Mutation rule	Starting with the ninth fittest genomes after Rekombination, a random number from the range between -2% and 2% is added to a genome with 20% mutation rate

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Die Wurzeln der **Fakultät für Agrarwissenschaften** reichen in das 19. Jahrhundert zurück. Mit Ausgang des Wintersemesters 1951/52 wurde sie als siebente Fakultät an der Georgia-Augusta-Universität durch Ausgliederung bereits existierender landwirtschaftlicher Disziplinen aus der Mathematisch-Naturwissenschaftlichen Fakultät etabliert.

1969/70 wurde durch Zusammenschluss mehrerer bis dahin selbständiger Institute das **Institut für Agrarökonomie** gegründet. Im Jahr 2006 wurden das Institut für Agrarökonomie und das Institut für Rurale Entwicklung zum heutigen **Department für Agrarökonomie und Rurale Entwicklung** zusammengeführt.

Das Department für Agrarökonomie und Rurale Entwicklung besteht aus insgesamt neun Lehrstühlen zu den folgenden Themenschwerpunkten:

- Agrarpolitik
- Betriebswirtschaftslehre des Agribusiness
- Internationale Agrarökonomie
- Landwirtschaftliche Betriebslehre
- Landwirtschaftliche Marktlehre
- Marketing für Lebensmittel und Agrarprodukte
- Soziologie Ländlicher Räume
- Umwelt- und Ressourcenökonomik
- Welternährung und rurale Entwicklung

In der Lehre ist das Department für Agrarökonomie und Rurale Entwicklung führend für die Studienrichtung Wirtschafts- und Sozialwissenschaften des Landbaus sowie maßgeblich eingebunden in die Studienrichtungen Agribusiness und Ressourcenmanagement. Das Forschungsspektrum des Departments ist breit gefächert. Schwerpunkte liegen sowohl in der Grundlagenforschung als auch in angewandten Forschungsbereichen. Das Department bildet heute eine schlagkräftige Einheit mit international beachteten Forschungsleistungen.

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