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Are short rotation coppices an alternative to traditional agricultural land use in Germany? A real options approach

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Abstract

Short rotation coppice (SRC) is an interesting economic alternative to agricultural land use. Nevertheless, farmers often do not switch to SRC. Thus, it seems like the farmers do not act according to the classical investment theory. A relatively new approach which can help to explain farmers' reluctance is the real options approach (ROA). Compared to the classical investment theory, the investment triggers are shifted upwards. We want to answer the question of whether the ROA is an explanatory approach for farmers' reluctance to invest in SRC. To do so, we develop a model to calculate the investment triggers of the gross margins (GM) of SRC a farmer should switch from rye production to SRC. The results show that the trigger GMs calculated according to the ROA are higher than those of the net present value and a risk-averse farmer invests earlier than a risk-neutral farmer. It can be concluded that a part of famers' reluctance concerning SRC can be explained by the ROA.

Keywords:

Land conversion, short-rotation-coppice, rye, real options approach, net-present-value

1. Introduction

Short-rotation-coppice (SRC) is defined as the plantation of trees on agricultural land. Currently, it is heavily discussed as an alternative energy source in European countries, especially in Germany, Sweden and the UK (Coote, 2005; Larsson and Lindegaard, 2003; Mitchell et al., 1999; SAC, 2008). Other countries such as Canada, New Zealand and the US are interested in SRC, too (Rockwood et al., 2004; Sims et al., 2001). In contrast to annual crops, SRC do not have an annual output. It is harvested several times in a few years interval. SRC often has an expected useful lifetime that exceeds 20 years (Simpson et al., 2009).

One reason why SRC has attracted interest is its higher ecological advantageousness compared to classical agricultural land use. For example, Baum et al. (2009) and Rockwood et al. (2004) describe the ecological advantage of SRC regarding soil and biological diversity. Rockwood et al. (2004) note that it is possible to use contaminated soil and groundwater for SRC and that this type of land use allows a better control on soil erosion. In addition, they state that SRC can be grown on soils with agricultural and industrial wastes and that it is advantageous for wildlife habitats.

From the economic point of view, many studies have shown that SRC has the potential to be more profitable than annual crops. For example, Heaton et al. (1999) specify the economic advantage of SRC for Mid-Wales. Schoenhart (2008) shows that SRC can become a profitable production alternative in Austria. For Germany, Wagner et al. (2009) identify an economic advantage of SRC over the cultivation of malting barley and rye.

The economic advantage of SRC over traditional agricultural land use is the aforementioned option to grow crops in areas with marginal soil qualities because SRC reaches high and stable yields despite poor soil quality (Stolarski et al., 2011). For Germany, Murach et al. (2009) argue that sandy soils are particularly interesting for SRC. They give an example of a plantation on sandy land in the German federal state of Brandenburg. These soils often have high levels of groundwater without much rainfall. Stolarski et al. (2011) note that SRC might be advantageous for land that normally has a very high water content and cannot be harvested by using heavy machinery. Another advantage pointed out by the authors is the ability of SRC to use water reservoirs that other annual cultures simply do not reach.

In Germany, governmental incentives were set to encourage further plantations of SRC. Since 2010, the German federal state of Mecklenburg-Western Pomerania allows farmers to plant SRC on permanent grassland until the total area used for SRC reaches 3,000 hectare (ha) (DGErhVO M-V, 2008). In general, it is not possible to cultivate annual crops on permanent grass land in Germany. Other European countries motivate farmers to plant SRC by paying direct subsidies. In the UK, for example, there has been a general planting grant of 400 British Pounds per hectare for set-aside land and 600 British Pounds per hectare for non-set-aside land. Using the so-called Woodland Grant, the Scottish Forest Commission offered 1,000 British Pounds per hectare for a limited area (Mitchell, 1999 et al.; SAC, 2008).

Even if SRC is becoming a more and more profitable alternative to traditional agricultural land use farmers do not invest in SRC. Up to now, only about 5,000 ha of SRC have been planted in Germany (German Agriculture Publisher, 2011).

In contrast to annual crops, we observe an investment in the case of SRC. Its useful lifetime amounts to more than 20 years and the plantation is expensive. For these decision problems, the classical investment theory is widely used. When applying this approach, decision-makers in general, and farmers in particular, must switch to SRC if the NPV per hectare of SRC is higher than that of any other alternative crop. If farmers do not act in accordance with the classical investment theory, it is necessary to find out the underlying reasons. Does farmers' traditional behavior cause this reluctance? Or are farmers afraid of negative effects of SRC on the land/soil quality (Weih, 2009)? Another reason for farmer's reluctance concerning investments in SRC may be their risk-aversion with respect to problems with the access of technical machineries and missing liquid assets (Weih, 2009).

If farmers convert to SRC, they know that the high costs for the establishment of the plantations are sunk because the conversion is irreversible within the useful lifetime. Moreover, farmers can postpone the investment in SRC. Also, there are uncertain economic variables, such as the prices for the harvested wood chips. The classical investment theory ignores irreversibility, entrepreneurial flexibility and flexibility regarding the time of investment as well as the uncertainty of the investment returns (Trigeorgis, 1996: 1). A relatively new proceeding theory, which takes into account these aspects, is the new investment theory that is also referred to as real options approach (ROA) (Dixit and Pindyck, 1994). With regard to farmers' reluctance to invest in SRC, the aforementioned aspects can be of high importance. The investment triggers calculated by the ROA that induce the investment, are shifted upwards compared to the triggers of the NPV. This effect can be explained, for example, by the reason that the ROA considers opportunity costs over time. In the case of SRC, the investment/conversion triggers at which farmers switch from annual crops to SRC calculated by the ROA can be much higher than those of the NPV.

Some applications of the ROA can be found in agricultural and forestry literature. Behan et al. (2006) mention the optimal time of investing in forest grown on former agricultural land regarding the temporal flexibility of investment implementation. Duku-Kaakyire and Nanang (2002) analyze the utility of the real options theory in order to investigate forest investments. Rocha et al. (2006) evaluate the concession market value of an Amazon natural forest of commercial wood.

In this paper, we examine decision-makers' in general, and farmers' in particular, option to switch from traditional agricultural land use to SRC. As it has been already mentioned, SRC provides an economic advantage on marginal soils. Therefore, we observe a plantation on these soils. Since rye is usually cultivated on marginal soils for which other crops are not suitable, we compare SRC to rye production (Bushuk, 2000). We want to determine investment/conversion triggers at which farmers would switch from traditional annual crops to SRC. We compare the conversion triggers of the NPV to the triggers of the ROA. Our calculation should answer the question of whether the ROA can help to explain farmers' reluctance concerning SRC. The model applied for our calculations to determine the conversion triggers is based on stochastic simulations and on parameterization. We consider two variables of uncertainty. Both, the uncertain gross margins (GMs) of SRC and the uncertain GMs of rye are taken into account. In contrast to Duku-Kaakyire and Nanang (2002), we have tested the historical time series of the GMs to analyze stationarity and chose the most suitable stochastic process. In this case, we used an arithmetic Brownian motion (ABM). In order to compare the optimal conversion boundaries according to the degree of risk-aversion, we differentiated between a risk-neutral and a risk-averse farmer. We created an exemplary approach by comparing annual crops with an investment that is characterized by high investment and recultivation costs as well as a lifetime of often more than 20 years. Moreover, uncertainty and entrepreneurial flexibility are considered.

In section 2, the methodological approaches are described. First, the NPV and the ROA are explained in general. Second, the model comparing SRC with rye is specified. In Section 3, the model assumptions and the data used are described. Section 4 illustrates the results of our model. In section 5, we draw some conclusions.

2. Methods

To observe the decision problem a farmer in our model can decide between planting rye and converting to SRC. We want to define the conversion trigger GMs of SRC at which a farmer switches from rye to SRC. In order to implement the influence of different GMs of rye, the GM for rye is varied to determine the optimal conversion boundary. If he/she converts to SRC, he/she is committed to this production for its useful lifetime. He/she has the option to reinvest in SRC or to cultivate rye after the useful lifetime of SRC. According to the ROA, the farmer can postpone the investment in SRC to the future. On the one hand, we compare the optimal conversion boundary following the classical investment theory to the optimal conversion boundary following the ROA. Also, we analyze the difference concerning the optimal conversion boundary between a risk-neutral and a risk-averse farmer. In case of the risk-averse farmer, we use a flexible risk-adjusted interest rate.

2.1. Comparison of net-present-value to real options approach

The Real Options Approach combines uncertainty of investment returns, sunk costs and temporal flexibility with regard to the investment's implementation in a comprehensive dynamic-stochastic model (Dixit and Pindyck 1994). The approach is based on the analogy between financial options and physical investments. The option to invest now or to postpone the investment is similar to American options: The owner of an American option as well as the investor (e.g. the farmer) has the right—but is not obligated—to choose to buy an asset (e.g. the investment in SRC) with an uncertain development (e.g. present value of investment returns) within a certain time period (lifetime of the option).

The classical investment theory analyses a 'now or never' decision. Following the theory, the value of the investment at a time *t* is expressed as the difference between the present value of the returns R_t and the expenditures C_t. The Net-present-value is defined as follows:

$$NPV_t = R_t - C_t \tag{1}$$

Following the classical investment theory, a positive NPV would suggest investing (Hull, 2009: 737).

Regarding the financial options theory, it can be said that the classical NPV, also referred to as intrinsic value, is only a part of the investment option. (Trigeorgis, 1996: 124). Moreover, the investment option has a continuation value, which is defined as the discounted expected value of the investment at the next possible time of investment. If a decision-maker invests now, he/she is earning the intrinsic value but cannot earn the continuation value. A rational investor will only invest immediately if the intrinsic value is greater than the continuation value. The Bellmann equation for this binary decision-making problem is defined as follows (Dixit and Pindyck, 1994: chapter 4):

$$F_t = max(NPV_t; \mu(NPV_{t+dt}) \cdot (1 + i)^{-dt}) \tag{2}$$

F is the value of the investment at time t, i stands for the risk-adjusted interest rate, $\mu(\cdot)$ is the expectation operator and $max(\cdot)$ implies the maximum operator. The classical NPV is the lower limit for the options value F. Referring to equation (2), there is a stopping region, where the intrinsic value exceeds the continuation value, and a continuation region, where the continuation value exceeds the intrinsic value. Under specified regulatory conditions, the two regions are separated from each other by a critical value of the stochastic variable. The critical value is referred to as investment trigger. The regulatory conditions assume that the intrinsic value and the continuation value are monotonous functions of the stochastic variables. Furthermore, the distribution function of the uncertain factors of the stochastic process at the time $t + dt$ has to be shifted to the right (left) as soon as the value in t increases (decreases) (Dixit and Pindyck, 1994: 128).

The solution of equation (2) is not trivial. Analytical solutions only exist for simple valuation or special cases. That implies that the analytical solutions require a variety of restrictions which cannot be fulfilled by complex options. For example, the evaluated investment option must have an indefinite lifetime and a time-continuous opportunity to invest. Furthermore, there should not be interactions between the investment option to evaluate and other options, such as reinvestment options and disinvestment options (McDonald and Siegel 1986). In case of SRC, for example, the investment opportunity is not time-continues because decision-makers can convert only once in a year. Also, it is possible to reinvest at the end of every useful lifetime. In accordance with this, the conditions of an analytical solution are not often met in case of many real options. On that basis, the numerical-approximative options valuation methods, such as the binominal tree or the stochastic simulations must be applied. Hull (2009: chapter 19) provides a number of different numerical option valuation methods.

The advantage of a simulation-based method is that the option value at a given investment strategy can be easily calculated, regardless of the distributions' complexity concerning the stochastic variables. Therefore, the basis of the option valuation method can be the time-discrete version of any stochastic process after the implementation of an open-ended time series analysis. As it is often done in real options applications, it is not necessary to assume a geometric Brownian motion (GBM) to reach an analytical solution (cf. Gjolberg and Guttormsen, 2002: 14). In relation to the GBM, stochastic variables cannot become negative. This does not apply to cash flows or GMs. The disadvantage of stochastic simulation is the absence of optimization algorithms. Therefore, it is only possible to evaluate American options with a limited term, whose optimal investment values are dependent on the remaining lifetime, on the basis of a combination of stochastic simulations with optimization algorithms (cs. Ibanez and Zapatero, 2004). In the case that the investment option can be postponed infinitely, the optimal investment strategy conforms to a constant trigger over the whole lifetime. Referring to this, we suggest conducting the optimal valuation using a stochastic simulation and a parameterization of the triggers. This is only possible in special cases where investment opportunities have an infinite lifetime. In case of a time-constrained lifetime, the trigger values calculated by the ROA converge to the trigger values following the NPV as the lifetime of the investment option comes to its end.

The following steps were used to determine the trigger values of the GMs of SRC and the option values in the stochastic simulation:

1. A certain number of test triggers are chosen. A parameterization range of the stochastic variables (in this case, the GMs of SRC) is divided into equal intervals. For the parameterization range, the minimal and the maximal values of test triggers have to be determined.

2. The option value of each test trigger is calculated. The stochastic simulation is used to determine the development of the stochastic variable, while the option value of the test triggers is estimated for each simulation run. For every run, the initial value of the stochastic variable is varied. The option value that corresponds to the respective test trigger is estimated as the average of all simulation runs. Figure 1 describes the relationship between option value and test trigger. $GM*$ indicates the number of test triggers. F_0 stands for the corresponding average option value.

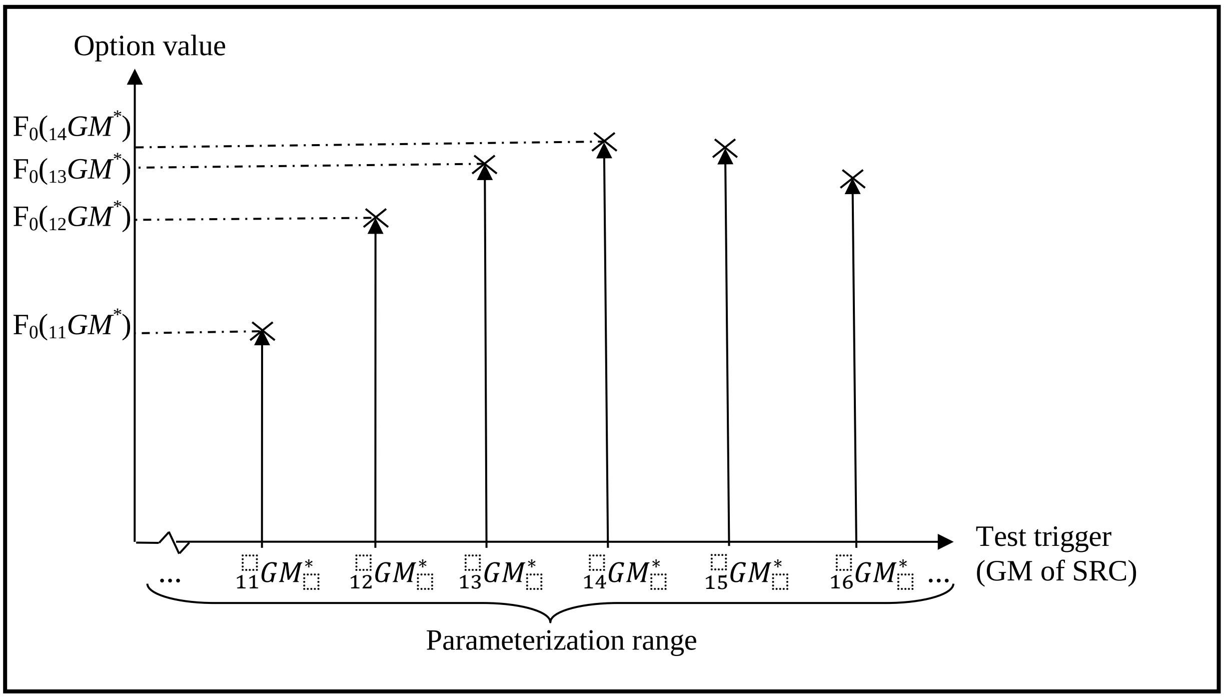

Figure 1. Stylized relationship between the option value and the underlying investment strategy

3. The option value F_0 rises up to the test trigger ${}_{14}GM*$ and decreases after the test trigger ${}_{14}GM*$. Hence, the test trigger ${}_{14}GM*$ is next to the 'true' optimal conversion threshold as it has the highest average option value for all simulation runs.
4. After one simulation is finished, a further simulation to enhance the optimal value of the 'true' conversion threshold starts. Therefore, the values on the left, ${}_{13}GM*$, and on the right, ${}_{15}GM*$, next to the optimal test trigger of the previous simulation ${}_{14}GM*$ define the new parameterization range of the next simulation. The numbers of the test triggers do not change. The parameterization range is divided into equal intervals.
5. Step 4 is repeated until a small range for the critical value is provided leading to the maximal option value.
6. The value of the investment option is defined on the basis of the previous determined optimal investment trigger and of the currently observed value of the stochastic variable.
7. In our model, steps 1 to 6 were repeated for different GMs of the annual crop in order to determine the optimal conversion boundary.

Regarding the results of the option valuation procedure, it has to be mentioned, that the options can be evaluated independently of the risk attitude of decision-makers. This is only possible if a replication portfolio of the assets that corresponds with the stochastic results of the (dis)investment project can be formed (Hull, 2009: 241 ff.; Luenberger, 1998: 251 ff.). This possibility must be proven on a case-by-case basis. With this in mind, the recourse of the risk-neutral valuation principle requires a risk-neutral drift for modeling the stochastic variable and a risk-free interest rate for discounting the payments. If the risk-neutral valuation principle cannot be applied, the results of the option valuation can only be considered for the supposed risk attitude of the decision-makers.

2.2. Conversion decision in SRC following the classical investment theory

As mentioned in Section 2.1, the investment decision following the classical investment theory is made if the NPV is positive (cs. (1)). To calculate the gross margins of SRC (GM_t^S), the average yields of the harvest per hectare and year Q is multiplied with the difference of the expected wood price p and the cost of harvesting hc, drying dc and transporting tc. The wood price and the variable costs are defined in € per metric tons of dry material (€ t_{DM}^{-1}). The GM of SRC is defined as follows:

$$GM_t^S = Q \cdot (p - vc) \tag{3}$$

In practice, the first harvest of SRC is lower than the following harvests when the plants are established. Hence, the revenues of the first rotation are lower than the average yields. We assume that the decision-maker who invested in SRC has several cultures with different years of plantation. In the forestry literature, this is described as a “normal forest”. In a normal forest, there is a set of forests with desired age classes. The upper end of the age class is the defined useful lifetime. The advantage of a normal forest is that there are equal time periods between the harvests, as well as relative constant yields per harvest (Bettinger et al., 2009: 199 ff.). Thus, he/she harvests an average volume each year. The present value of the average GM is calculated as follows:

$$GM_0^S = GM_t^S \cdot \frac{1}{i^S} \tag{4}$$

GM_t^S indicates the annual average GM of SRC. To include risk-aversion in terms of a risk-adjusted interest rate we differentiate between the annual the annual target rate of SRC i^S and the annual crop i^{AC}.

The investment costs IC accumulate in the year zero, as well as in each of the following N years. The present value of the investment cost is calculated as follows:

$$IC_0 = IC + IC \cdot \frac{1}{I^S(p = N)} \tag{5}$$

$i(p = N)$ is the adequate target rate for a discount period in the amount of the useful lifetime N of the SRC. The relationship between the annual interest rate i and the interest rate $i(p)$ referring to a time period p in years can be expressed as follows:

$$i^S(p) = (1 + i^S)^p - 1 \tag{6}$$

Moreover, recultivation costs RC must be considered. They accrue in each of the N years, as well as the investment costs. The present value of the recultivation costs equals:

$$RC_0 = RC \cdot \frac{1}{i^S(p = N)} \tag{7}$$

If SRC is planted, it is no longer possible to receive the GMs of the annual crop GM_t^{AC}. The average harvest was multiplied by the difference of the expected price and the sum of the variable costs of the annual crop to calculate the GM of the annual crop. Therefore, we must calculate the present value of the alternative GM of the annual crop as follows:

$$GM_0^{AC} = GM_t^{AC} \cdot \frac{1}{i^{AC}} \tag{8}$$

The NPV equals:

$$NPV_0 = GM_0^S - IC_0 - RC_0 - GM_0^{AC} \tag{9}$$

On the basis of the equations (9), the critical present value of the gross margin GM^{S*M} can be calculated analytically. If the NPV equals zero, the conversion threshold is defined as follows:

$$GM_0^{S*M} = NPV_0 - IC_0 - RC_0 - GM_0^{AC} \tag{10}$$

The parameter M belongs to the investment thresholds that are in context of the NPV often referred to as Marshallian-Triggers.

2.3. Conversion decision in SRC following the real options approach

The conversion option must be valued with a numerical method (cs. section 2.1). In our model, the different volatility of the returns concerning SRC and the annual crop leads to different interest rates. The present value of the future investment/conversion returns R_t can be defined as follows:

$$R_t(GM^{S*}) = \begin{cases} 0, if\ LU_t = 0 \wedge GM_t^S < GM^{S*} \\ -IC \times (1+i^S)^{-t}, if\ LU_t = 0 \wedge GM_t^S \geq GM^{S*} \\ GM_t^S \times (1+i^S)^{-t} - GM_t^{AC} \times (1+i^{AC})^{-t}, if\ LU_t = 1 \wedge N_{jt} < T \cdot \tau \\ (GM_t^S - RC) \times (1+i^S)^{-t} - GM_t^{AC} \times (1+i^{AC})^{-t}, \\ \qquad if\ LU_t = 1 \wedge N_{jt} = T \cdot \tau \wedge GM_t^S < GM^{S*} \\ (GM_t^S - RC - IC) \times (1+i^S)^{-t} - GM_t^{AC} \times (1+i^{AC})^{-t}, \\ \qquad if\ LU_t = 1 \wedge N_{jt} = T \cdot \tau \wedge GM_t^S \geq GM^{S*} \end{cases} \tag{11}$$

The equation can be explained as follows:

1. R_t equals 0 if the GM of SRC is lower than the value of the trigger GM of SRC ($GM_t^S < GM^{S*}$). That means that the land will be used for annual crop production in the next period. The land has been used for annual crop production ($LU_t = 0$) and the decision-maker (farmer) will earn the GM of the annual crop in the next period ($LU_{t+1} = 0$).
2. R_t equals the present value of the investment costs (IC) if the land has so far been used for annual crop production ($LU_t = 0$) and the GM of SRC is higher than the value of the trigger GM of SRC ($GM_t^S \geq GM^{S*}$). The land will be converted to SRC ($LU_{t+1} = 1$). i^S is defined as the interest rate for SRC.
3. R_t corresponds to the present value of the GM of SRC (GM_t^S) minus the present value of the GM of the annual crop (GM_t^{AC}). This is the case if the land is used for SRC ($LU_t = 1$) within the useful lifetime of the same and has not reached the last period of

harvest ($N_{jt} < T \cdot \tau$). The GM of SRC is discounted with the interest rate of SRC (i^S) and the GM of the annual crop with the corresponding interest rate (i^{AC}).

4. R_t corresponds to the present value of the difference between GM of SRC (GM_t^S) and the recultivation costs (RC) minus the present value of the GM of the annual crop (GM_t^{AC}) if ($LU_t = 1$). SRC has reached the last period of harvesting ($N_{jt} = T \cdot \tau$). The prerequisite saying that the trigger GM has to be higher than the GM of SRC ($GM_t^S < GM^{S*}$) must be fulfilled. Accordingly, the land is used for annual crop production in the next period.
5. R_t corresponds to the present value of the difference between GM of SRC (GM_t^S) and the sum of the costs for recultivation (RC), and the following investment costs in SRC (IC) minus the present value of the GM of the annual crop (GM_t^{AC}) if ($LU_t = 1$). SRC has reached the last period of harvesting ($N_{jt} = T \cdot \tau$). The trigger GM has to be lower than the annual GM of SRC ($GM_t^S \geq GM^{S*}$). Accordingly, the land is used for SRC in the next period of the useful lifetime.

The option value of the conversion opportunity of the following objective function F_0 has to be maximized to determine the critical gross margin of SRC GM^{S*}.

$$F_0 = \sum_{t=0}^{\infty} R_t(GM^{S*}) \rightarrow \max_{GM^*}! \qquad (12)$$

The option value is calculated by summing up the present value of the future investment returns S_t obtained when using an/the optimal conversion boundary during the planting period ($t = 0, 1, \dots, \infty$). Concerning the optimal conversion boundary, we differentiate between a risk-neutral and a risk-averse decision-maker (farmer).

The maximizing problem of equation (12) corresponds with the determination of the value of an American option with an infinite lifetime.

3. Model assumptions

Our model compares the production of rye with SRC on soils with marginal qualities. For SRC, poplar plantation is assumed because poplar is one of the most promising wood energy trees and has high yields and low input requirements (Nassi o di Nasso et al., 2009). In addition, we presume a sandy soil (30 of 100 possible index points of German soil quality) and a groundwater level of up to 4 meters. There is an average rainfall of 480 millimeter each year, while the average annual temperature is 8.5 °C. Considering these conditions, we anticipate an annual average yield of about 10 tons of dry material per hectare (t_{DM} ha^{-1}) (Murach et al., 2009; Simpson et al., 2009).

3.1. Planning assumptions for SRC

In the literature, many different values concerning the costs of SRC production can be found (Dallemand et al., 2007; Kroeber et al., 2010). Therefore, we conducted a literature research and interviewed experts to gather the data needed to determine the values of the costs. Consequently, the following costs of investment and production are average values.

First of all, it is necessary to plow the land in autumn and to inject a total herbicide before planting. The soil is harrowed in order to prepare SRC planting. Costs for plowing, herbicide injection and harrowing amount to approximately 238 € per hectare (€ ha^{-1}). Planting is carried out using a planter for vegetables. The costs of each poplar tree including planting are about 0.24 €. In practice, often 10,000 trees per hectare are cultivated (Simpson et al., 2009). Consequently, average investment costs amount to about 2,736 € ha^{-1} including possible necessary caring in the first year after planting. In case of poplar, fertilizer is not needed (Roedl, 2010). If the plantation is harvested, costs for harvesting, drying and transport are about 32 € (€ t_{DM}^{-1}). It is very difficult to sell the SRC harvest without drying. The water content of the material after harvesting is about 50% and can be reduced in the process of drying to 30% (Caslin et al., 2010). After each useful lifetime, it is necessary to recultivate the land so that it can be used for a new SRC plantation or other crops. The recultivation costs amount to about 1,120 € ha^{-1}. We suppose that a SRC cultivator has no possibility to switch from the production of SRC to rye within the useful lifetime of SRC. This is based on the assumption that the cultivator has agreed to contracts for SRC harvest. These contracts continue throughout the whole useful lifetime of SRC. Apart from that, the investment (sunk costs) and recultivation of SRC is very expensive.

An expected useful lifetime of 21 years is supposed. Since Nassi o di Nasso et al. (2009) have shown that a 3-year harvest frequency guarantees high net energy yields, we assume a time period between the harvests of about 3 years. In practice, the first harvest is lower than the following ones when the plantations are established. As mentioned in section 2.2, we anticipate that the farmer has several cultures which were planted in different years, so called "normal forest". Hence, the farmer would receive an annual harvest with an average yield volume.

To calculate the revenues of SRC, the metric tons of dry material were multiplied by the price for the harvested material of SRC. The price for the harvested material of SRC was connected to the heating oil price. Therefore, the inflation-adjusted price of oil per liter from 1970 to 2009 was divided by the heating value of oil and multiplied by the average heating value of wood chips (Fuel trading 2011; Hawliczek 2001, IWO 2011). In relation to the heating value, the observed oil prices were higher than the wood chips prices. Therefore, we compared the mean of the oil prices from 2003 to 2009 with the mean of the wood chips prices from 2003 to 2009 of the C.A.R.M.E.N e. V. Here, it becomes clear that the price of oil is on average 2.337 times higher than the price of wood. Hence, the annual prices for oil in relation to the heating value of wood chips were divided by 2.337. To calculate the GMs, the costs of harvesting, drying and transport were subtracted from the revenues.

Figure 2 shows the stochastic GMs of SRC from 1970 to 2009.

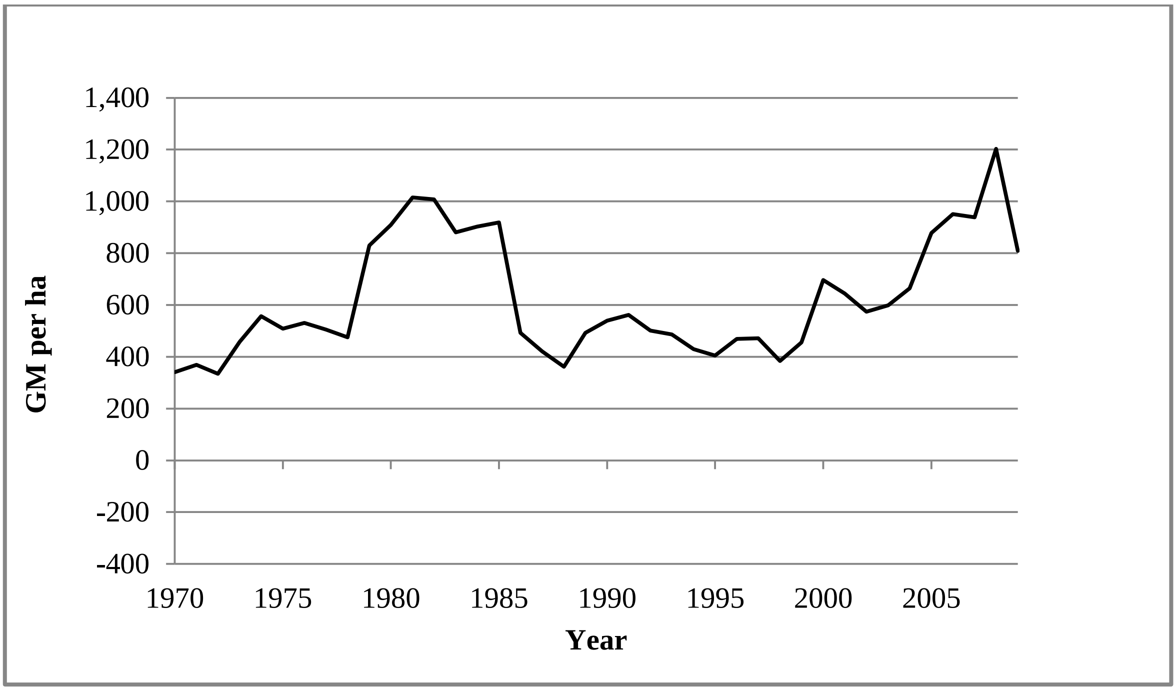

Figure 2. GMs of SRC (in € ha^{-1})

The future development of the GMs of SRC is modeled by a stochastic process. These kinds of processes imply that assumptions about the probability evolution of the value of a stochastic variable are made over time (Hull 2009: 271). Using time series analysis, we gather distribution information of the time series and identify the best fitting stochastic process for the given data. To analyze stationarity, the time series was tested using the Augmented-Dickey-Fuller Test (Dickey and Fuller, 1981; Enders, 2003: 76 ff.) and the Variance-Ratio-Test (Campbell et al., 1997). The historical GMs of SRC shown in Figure 2 were taken as an input. The results of both tests show that historical GMs of SRC follow a random walk with a probability of error of 5%.

For modeling the time series of the GMs of SRC, we used the stochastic process of an arithmetic Brownian motion (ABM). In contrast to the geometric Brownian motion (GBM), the stochastic variable of the ABM can adopt negative values. Accordingly, ABM is frequently-used for developments of non-stationary cash flows and GMs which can reach values under zero (Dixit and Pindyck, 1994: 65 ff.). The formula of the ABM can be expressed as follows:

$$GM_t^m = GM_{t-\Delta t} + \alpha \cdot \Delta t + \sigma \cdot \sqrt{\Delta t} \cdot \varepsilon_t, with\ m = S, R \tag{13}$$

The parameter GM_t indicates the gross margin at time t. The parameter α is the drift rate and σ the standard deviation of the absolute changes of the values. The standard deviation is multiplied by a Wiener process ($\sqrt{\Delta t} \cdot \varepsilon_t$). ε_t describes the standard normally distributed random number. A t-test revealed that the drift parameter of an ABM α is not different from zero at a significance level of 5% (p-value = 0.74; two-tailed t-test), meaning that the expected value of the future GMs of SRC is equal to its current value. The standard deviation σ of the ABM of SRC is 142.10 € ha^{-1}.

3.2.Planning assumptions for rye

In case of the annual rye production neither investment costs nor recultivation costs have to be considered. We used the approximate values of the variable costs for rye of the year 2011 of the German federal state of Lower Saxony in the center of Germany (Approximate values of gross margins, 2011) as variable production costs. We used time series of rye prices in Ontario from 1970 to 2009 because the rye prices in the European Union (EU) and in particular in Germany were influenced by political interventions (such as the interventions in the rye market by the EU between 2004 and 2005) (Agriculture and Agri-Food Canada, 2006). The inflation of the time series of rye prices is adjusted. The GMs of rye per hectare for a typical land with marginal soil qualities were calculated on the basis of average yields in Germany from 1970 to 2009. The trend of the time series has been adjusted.

Figure 3 depicts stochastic GMs of rye for the years 1995 to 2009.

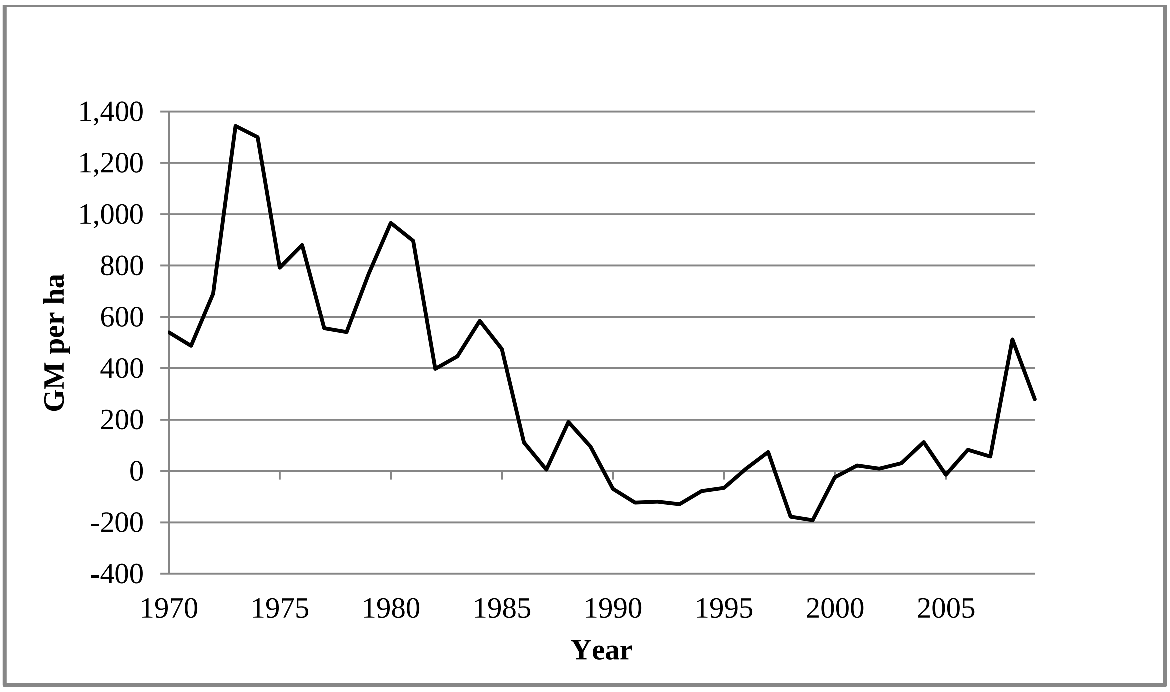

Figure 3. GMs of rye (in € ha^{-1})

The time series of the GMs of rye were also tested using the Augmented-Dickey-Fuller Test (Dickey and Fuller, 1981; Enders, 2003: 76 ff.) and the Variance-Ratio-Test (Campbell et al., 1997) for stationarity. The historical GMs of rye shown in Figure 3 were taken as an input. The tests confirmed non-stationarity (significance level of 5%). For modeling the time series of the GM of rye, we also used the ABM. Based on a t-test, the drift parameter of an ABM α are not different from zero at a significance level of 5% (p-value = 0.88; two-tailed t-test). The standard deviation σ of the ABM of rye is 219.95 € ha^{-1}.

3.3.Risk-adjusted interest rate

Anderson (1974) noted that risk plays an important role in the adoption of new production technologies in agriculture. We therefore analyzed the difference between a risk-averse and a risk-neutral farmer concerning the optimal conversion boundary. Because of the difficulties in determining the risk premium of decision-makers in general (Hudson et al., 2005), the risk premium is often parameterized (Berg, 2003; Gebremedhin and Gebrelul, 1992). The risk-adjusted interest rate i^j is calculated as follows:

$$i^m = rf + \rho, with\, m = S, R \tag{14}$$

rf indicates the risk-free interest rate and ρ the extra amount for the risk premium. Following this, we determine the extra amount for the risk premium ρ.

First of all, a risk utility function must be determined to define the decision-makers' risk-aversion. In our model, a power risk utility function is adopted which has a declining absolute risk-aversion and a constant relative risk-aversion (Holt and Laury, 2002):

$$U(Z) = Z^{1-\theta} \tag{15}$$

U indicates the utility, Z is the command variable, e.g. the GM for SRC, and θ stands for the coefficient of risk-aversion. If the value of θ equals zero the decision-maker is risk-neutral. Although, we use the state-continues version of the ABM in our model, for simplicity reasons, we assume the state-discrete version of the ABM in order to calculate the risk-adjusted interest rate. Accordingly, we estimate the expected utility of the alternative as follows:

$$E[U(Z)] = 0.5 \cdot U(Z^-) + 0.5 \cdot U(Z^+) \tag{16}$$

We assume that the probability of occurrence is equal to 0.5. Z^- is the expected value of the alternative minus the standard deviation. Z^+ is defined as the expected value plus the standard deviation. For example, relating to SRC, Z^- is the expected GM minus the standard deviation σ of SRC.

To include the degree of risk-aversion in the model, we can use the certain equivalent with adoption of the risk-free interest rate instead of the uncertain investment returns. For the risk-averse decision-maker, the certain equivalent has the same utility as the expected value of an uncertain alternative. The coefficient of risk-aversion can be used to calculate a subjective certain equivalent. It is calculated as follows:

$$Z[E(U(Z))] = E[U(Z)]^{\frac{1}{1-\theta}} = CE \tag{17}$$

The determination of the certain equivalent is required to calculate the risk premium RP. The risk premium is defined as the difference between the expected value and the certain equivalent (cs. formula 18). It is the amount of money, the decision-maker demands for making a decision in favour of the uncertain alternative.

$$RP = E(Z) - CE \tag{18}$$

E(Z) is the expected value of the commanded variable, which, in this case, is the expected value of the GM of SRC and rye. The following formula is commonly used to calculate the extra amount ρ:

$$[E(Z_N) - RP_N] \cdot (1+i)^{-N} = E(Z_N) \cdot (1+i+\rho)^{-N} \tag{19}$$

$$\rho = (1+rf) \cdot \left[\left(\frac{E(Z_N)}{E(Z_N) - RP_N} \right)^{\frac{1}{N}} - 1 \right] \tag{20}$$

N is the discount period. For simplicity reasons, we assume that N is equal to 1.The interest rate for the risk-averse farmer was calculated following formula (14).

To determine the risk-free interest rate for a risk neutral decision-maker, the mean of the nominal return of the German federal bonds with a residual lifetime of 15 to 30 years from 1988 to 2009 of 5.92% per year (German Central Bank, 2011) was used. The inflation rate of the same period was approximately 1.98% per year (German Chamber of Industry and Commerce, 2010). Consequently, the corresponding real interest rate we used as the risk-free interest rate was about 3.87% per year. To calculate the risk-adjusted interest rate, we considered a risk-aversion coefficient of θ=0.4. The risk-adjusted interest rate is flexible and depends on the standard deviation and the expected value of the GM of SRC and rye (cs. 3.3).

3.4.Summarized model assumptions

Table 1 summarizes all assumptions of the model.

Table 1. Overview of the assumed model parameters [a)]

Investment costs for SRC IC:	2,736 € ha^{-1}
The total cost of harvesting, drying transportation vc:	32 € t_{DM}^{-1}
Rotation period τ:	3 years
Number of rotation periods T:	7
Useful lifetime of a SRC N:	21 years
Average annual output of the SRC Q:	10 t_{DM} ha^{-1}
Recultivation costs for a SRC RC:	1,120 € ha^{-1}
Potential implementation period for the conversion:	∞ (annual implementation right and reinvestment opportunity in SRC)
Risk-free interest rate rf:	3.78% a^{-1}
Risk premium ρ:	0% a^{-1} (risk-neutral decision-maker)
Stochastic process for the GMs:	Arithmetic Brownian motion (ABM)
Process parameters[b)] Drift rate α: Standard deviation (Rye) σ: Standard deviation (SRC) σ:	 0% a^{-1} 219.95 € a^{-1} 142.10 € a^{-1}
Expected gross margin of rye GM_t^S:	Changes from 0 € ha^{-1} to 550 € ha^{-1} with an interval of 50 € ha^{-1} to calculate the corresponding trigger GM of SRC
Expected gross margin of SRC GM_t^{AC}:	Random number between 142,10 € ha^{-1} and 750 € ha^{-1}

a) In variant calculations the sensitivity of the results is examined with regard to the amount of the risk premium ρ.

b) The correlation between the GMs of SRC and rye is about 0.19 and is adjusted.

In order to determine the optimal conversion boundary, we calculated the corresponding conversion trigger GMs of SRC for the expected GMs of rye from 250 € ha^{-1} to 550 € ha^{-1}. The intervals between the expected GMs of rye which were chosen to determine the corresponding conversion trigger GMs of SRC are about 50 € ha^{-1}. The expected GMs of

SRC were newly selected for each simulation run as a random number between 142.10 € ha^{-1} (cs. σ of rye) and 750 € ha^{-1}. Because there is no trend the expected GMs of SRC and rye are the initial values of our stochastic processes.

Applying the simulation-based options valuation method to determine the threshold for the conversion boundary from rye to SRC, an infinite period must be approximated through a finite value as it has been done in all numerical valuation procedures. In the model, a time period of 500 years is observed. The resulting approximation error is not significant and therefore can be neglected. For example, the present value of 100,000 € with an interest rate of 3.87% received within 500 years is less than 1 cent. The parameterization range of the conversion triggers is 10 € ha^{-1}. Even though Haug (1998: 140) suggested 10,000 simulation runs in the past we, decided to carry out 50,000 simulation runs.

4. Results

Table 2 depicts the conversion trigger GMs for a risk-neutral and a risk-averse farmer.

Table 22. Trigger GMs of conversion to SRC dependent on the degree of risk-aversion

Degree of risk-aversion	**Expected GM of rye (€ ha^{-1})**	**250**	**350**	**450**	**550**
Neutral (θ = 0.0)	**NPV (€ ha^{-1})**	478	578	678	778
	ROA (€ ha^{-1})	798	898	998	1,098
	Difference from ROA to NPV	320	320	320	320
Averse (θ = 0.4)	**NPV (€ ha^{-1})**	343	445	547	657
	ROA (€ ha^{-1})	492	772	892	1,039
	Difference from ROA to NPV	149	327	345	382
Difference between risk-averse and risk-neutral	**NPV (€ ha^{-1})**	-135	-133	-131	-121
Difference between risk-averse and risk-neutral	**ROA (€ ha^{-1})**	-306	-126	-106	-59

Following the NPV, a risk-neutral farmer, at a given expected GM for rye of approximately 250 € ha^{-1} switches from rye to SRC if the GM of SRC is higher than 478 € ha^{-1}. In comparison, a risk neutral farmer following the ROA changes from rye production to SRC at a higher trigger GM. If the expected GM of rye increases, the trigger GMs calculated by the two theories rise as well. However, the difference between the trigger GMs of the ROA and NPV stays constant at a value of 320 € ha^{-1} because the interest rate is equal. Following this, the ROA can partially explain farmers' reluctance.

For a risk-averse farmer, the trigger GM of SRC at an expected GM of rye of 250 € ha^{-1} is up to 343 € ha^{-1}. Compared to the corresponding trigger GM of the ROA it is approximately 149

€ ha^{-1} lower. As well as the trigger GMs of the risk-neutral farmer, the trigger GMs of a risk-averse farmer of both approaches rise due to an increasing GM for rye. In contrast to the risk-neutral farmer, the difference between the trigger GMs of the risk-averse farmer of the two theories does not remain constant. It rises up to 382 € ha^{-1} at an expected GM of 550 € ha^{-1} for rye.
Comparing the trigger GMs of the NPV of the risk-neutral farmer with that of the risk-averse farmer, the trigger GMs of the risk-averse farmer is approximately 135 € ha^{-1} lower. The distance declines with an increasing expected GM for rye to approximately 121 € ha^{-1}. This is reasonable because in case of the risk-averse farmer the interest rates for rye is higher than the interest rate of SRC.
Due to the ROA the distance between the trigger GMs of the risk-neutral farmer and the risk-averse famer is up to 306 € ha^{-1} at an expected GM of 250 € ha^{-1}. With an increasing GM of rye the trigger GMs of the risk-averse farmer converge to the trigger GMs of the risk-neutral farmer. This is justified by the flexible risk-adjusted interest rate which was used for the calculations of the risk-averse farmer (cf. section 3.3). With increasing expected GM for rye the value of the risk-adjusted interest rate decreases and converges to the interest rate of a risk-neutral farmer. This is reasonable because the risk premium which, amongst others, depends on the relationship between the expected value and the standard deviation of the GMs.

5. Conclusiones

In the case of SRC, many studies have shown that it has the potential to be more profitable than annual crops. Moreover, financial incentives and privileges towards other crops are supposed to promote the cultivation of SRC. Nevertheless, the share of SRC in the total agricultural land use has not increased significantly. Decision-makers in general, and farmers in particular, do not follow the NPV rule when investing in SRC. Therefore, we investigated if the new investment theory can explain the observed behavior of farmers regarding investments in SRC. The ROA considers aspects such as the irreversibility of the investment, the temporal and entrepreneurial flexibility of the investment, as well as the uncertainty regarding the investments' revenues. In the model used in this study, the production of SRC was compared to the production of rye on marginal soils. We developed a numerical real options model to define conversion triggers in the form of the GMs of SRC at which a farmer should switch from rye production to SRC. For the uncertain GMs of SRC and rye, the stochastic process of an arithmetic Brownian motion was used. The conversion triggers were calculated for different expected GMs of rye in order to find an optimal conversion boundary. When determining the optimal conversion boundary, we also differentiated between a risk-neutral and a risk-averse farmer. Therefore, a flexible risk-adjusted interest rate was estimated.

The calculations have shown that the trigger GMs according to the ROA are higher than the values of the NPV. In case of the risk-neutral farmer, the difference between the values according to the two theories stays constant when the GM of rye increases. In contrast to a risk-neutral farmer, a risk-averse farmer has lower trigger GMs. This holds for both theories. It can be explained with the lower standard deviation of the GMs of SRC compared to rye. Therefore, the risk-adjusted interest rate of rye was higher than the risk-adjusted interest rate of SRC.

It can be assumed that the ROA can help to explain the reluctance of farmers to cultivating SRC. Our model provides guidance for decision-makers, such as farmers, with regard to the evaluation of new investment alternatives. Moreover, policy-makers can learn that decision-makers often do not decide in accordance with the classical investment theory. We have shown that not only the economical aspects such as the value of the revenues are crucial. A further aspect is flexibility with regard to the investment timing. If the share of SRC in the total agricultural land use should increase significantly, policy-makers can first set higher incentives, e.g. subsidies concerning the plantation or annual land subsidies for SRC to increase the economical effectiveness of SRC. Secondly, they need to understand that endless amounts of subsidies do not have an effect on temporal flexibility. To reduce this effect, it is possible to create temporally limited planting subsidies. As a result, opportunity costs will decline over time and the conversion triggers following the ROA approximate the trigger values determined by the NPV.

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