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Valuing Forestry Agronomic Potential under Seasonal Mean-Reverting Prices

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Abstract: In the valuation of forest resources, the alternative use of the land is one of the central themes. In most cases it is made without taking into account the uncertainty and the possible flexibility of the alternative use. Within these alternatives, the strategy of shifting to a more profitable and sustainable crop is a well-studied topic in forest research. Although the transformation opportunity could add great value to the project, the valuation of this flexibility is obviated by traditional discounted cashflow criteria (NPV). The application of real options theory (ROT) makes it possible to assess this flexibility based on the uncertainty that the transformation entails. However, the hypotheses that are made about the future evolution of the underlying asset, in this case the value of the new crop, may condition the precision of the result. Usually some researchers model these conversions under the hypothesis of geometric Brownian motion (GBM), hypotheses that are not plausible when the new crop has a strong seasonal component. In this work, an adapted model framework is proposed to evaluate forest transformation opportunity into another crop when land use has both high agronomic potential and high seasonal component, a context in which classic real options framework is not applicable. As a work based on a theoretical model, after methodological motivation, the strawberry crop is chosen as alternative due to its seasonal component. Using private data for this crop, we model through the Ornstein–Uhlenbeck process, with mean-reversion (MR) to a seasonal component, and then we use of Longstaff and Schwartz's algorithm to calculate the option value. The results show that when considering flexibility in option valuation it leads to an increase on the return of more than 4%. Furthermore, robustness analysis evidence shows that option value is very sensitive to seasonal component, reinforcing previous evidence that suggests that the MR process offers a more accurate and appropriate valuation over the traditional GBM in the arena of agronomic potential valuation. Specifically, the result of valuing this transformation through the MR process is between 1.5 and 1.7 times the value of the NPV, which results in approximately a 13% annual return. If GBM had been used, the valuation would have been a 72% annual return, an unrealistic result in this context, due to the non-consideration of the seasonal mean-reverting prices process.

Keywords: land agronomic potential; Ornstein–Uhlenbeck process; real options; sustainable land use

JEL Classification: C15; C32; C53; G13; G31; Q14

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1. Introduction

Forestry investment analysis has always been complex due to, among other reasons, the planning horizon, incorporated uncertainty of the cashflows, and mainly due to the fact that in these types of decisions, flexibility plays a fundamental role. Consequently, the risks of obtaining the expected returns are intrinsically high. In this scenario, traditional methods that deal with the justification of a firm's investment projects, based on discounting cashflows and calculating metrics such as the net present value and the internal rate of return, can hardly be considered adequate. These methods are unable to even consider the possibility of contemplating new opportunities in the forestry investment arena and could be underestimating the full potential of these investment projects [1].

As Amran and Kulatilaka [2] state, the use of discounted cashflow models implies considering only the most relevant outcomes and ignoring management flexibility. Alternatively, real options theory (ROT) arises as an alternative approach to overcome shortcomings and remove the barriers of the traditional capital budgeting methods as "ROT can inform the key tensions that managers face between commitment versus flexibility as well as between competition versus cooperation, and we show how it can uniquely address the fundamental issues in strategy" [3] (p. 1).

Since Myers proposed the original idea in 1977 [4], applying the theory of financial options to the valuation of enterprise assets, this methodology has been widely used to assess investment decisions in different domains, and the spectrum of topics covered by ROT has been manifold [5]. For example, Refs. [6–14], in the evaluation of natural resources and energy sectors, Refs. [15–18] in the scope of investigation and development of biotechnologies and drugs, and [19–23] in the technology sector and emerging markets.

In the field of forestry investment decision, Chaudhari et al. [24] presented a deep analysis of the development of ROT, reviewing eighteen forestry and non-forestry journals, along with significant books on ROT. These authors classified the works into four categories:

1. Firstly, the optimal harvest decision, which includes articles on optimal rotation and decision on variables such as where and how much timber to cut. Chladna [25], Gutherie, and Kumareswaran [26] and Tee et al. [27] used a real options model with uncertain future timber prices. These authors, in a context of carbon credit payment schemes on forest owners, found that the optimal rotation periods vary considerably depending on the type of price process and the way that carbon is defined. In addition, as Insley and Wirjanto [28] and Manley [29] showed, in this valuation, contingent claims versus dynamic programming take high relevance.
2. The works related to the optimum investment timing option. For example, Yin and Newman [30] analyzed the risk of entry or exit in the presence of catastrophic risk on forest investment decisions. Thorsen [31] discussed the optimal investment timing considering the effects of subsidies to the landowners to initiate afforestation. Duku-Kaakyire and Nanang [32] used binomial tree methods to analyze different investment timing options and managerial flexibility. In all referred cases, the author found that depending on the hypotheses regarding the option model valuation, related to if the right to invest can be maintained after the event, the effect of catastrophic risk varies considerably.
3. A third group of works encompasses papers that discuss the optimal value of timber cutting contracts, such as [33–35]. These works used the Black–Scholes model or a more advanced least-square Monte Carlo simulation to determine optimal timber cutting contracts. These works demonstrated that, conditioned by assumptions made about the prices, random timber prices led to higher contract values than traditional approaches such as DCF models, and it reduced their exposure to market risks.
4. Finally, in a fourth group, we find the topic of optimal value from management options switch (conversion) which, according to Chaudhari [24], is the most referenced topic after the optimal harvest decision. With regard to this topic, studies such as [36–40] applied ROT to analyze decisions about optimal process timing conversion to another land use depending on the dynamics of timber prices and amenity values. Kassar and Lasserre [41] emphasized the value of species diversity and how a perfectly substitutable pool of species can create value under an ROT framework. Abildtrup and Strange [42] found higher option value by switching from natural to seminatural forest to Christmas tree production even though there was an irreversible risk of watershed contamination due to fertilization.

Included in the switch options, agricultural conversion arises as an alternative for land uses, showing the high value that this option can incorporate. In this context, ROT has been applied to organic farming [43–45], adoption of precision agriculture [45,46], expansion of agricultural enterprises [46–48], the adoption of genetically modified crops [49], and adaptation to climate change [50–52]. Most of the abovementioned works used a continuous-time stochastic price models in their application of ROT. As Manley and Niquidet [53] stated, the relevance of option valuation is very sensitive to the assumptions of the underlying price model, and the optimal decisions largely depend on price dynamics. Alternatively, Gjolberg, and Guttormsen [54], Insley [55], Insley and Rollins [56], Plantinga [57], Rocha et al. [58], Schmit et al. [59], Schwartz [60], and Tee et al. [27] used a mean-reversion (MR) process. However, no previous studies have analyzed the seasonal pattern of agricultural prices at each specific period of time when valuating conversion options.

Our study, based on a theoretical framework, proposes an adapted theoretical model to value a forest resource with agronomic potential when the selected alternative crop has a strong seasonal component and it is not possible to apply GBM assumptions. Specifically, using information from a eucalyptus forest plantation in southwestern Europe, we value the transformation to a strawberry crop. This crop was selected because the strawberry price incorporates a high uncertainty that can induce changes in land use and it also has an available public market price. However, it does not have to be limited specifically to the cutter. The proposed model can be extended to other crops with a high seasonal component that could include other berries or citrus. Furthermore, although the risk analyzed is limited to variations in the price of the alternative crop (strawberry in this case), this methodology could be extended to cover multiple risks linked to alternative crops, costs and interest rates, probability distributions, or stochastic processes.

For our analysis, we use a larger private forest manager in Spain and one of the leaders in Europe in Eucalyptus pulp production. Because of the land characteristics of its properties, this firm has the implied option to transform the forested areas into a different type of plantation, mainly orange crops and berries crops. This option is identified as an American call option in which the company has the right to transform the eucalyptus crop by paying an exercise price (transformation cost) at any time period. At the study moment, the total area is 73,953 hectares, of which 83% (62,000 ha) are eucalyptus, the rest being brush and Mediterranean forest. The option to transform forested areas into irrigated land depends on their agronomic potential. It involves, for each of the areas selected, consideration of the climatologic, edaphologic, and other inherent factors that could affect the implied value. In the previous phase of this analysis, each of the forested areas are measured and classified, obtaining a total agronomic score. In the second step, a total of nine forested areas are selected, whose agronomic score is ranked in the first quartile. This gives a total of 3,091.24 hectares (the valuation of the agricultural potential of forests is based on the technical report by Almansa [61]).

The rest of this paper is organized as follows. Section 2 describes the methodology to identify the sources of uncertainty and the forest project real options, and we outline the theoretical framework for modeling underlying assets and detail its implementation. Once the theoretical foundation is established, we collect the inputs and parameters necessary for calculating the value of the real option, and in Section 3 we present results. Section 4 includes robustness analysis and Section 5 discuss the results. Section 6 concludes this paper.

2. Materials and Methods

2.1. Identifying Transformations Options of a Forest Company

Forest planning is essential for achieving sustainability in forestry [62] and, according to Gautam et al. [63], the dominating paradigm for planning consists of three stages, namely, strategic, tactical, and operational planning. Strategic planning deals with company-wide questions such as plans for sustainable harvest levels or changes for another variety of plant or crop (e.g., Gunn [64]). Tactical planning (intermediate stage) works as a bridge between the strategic and operational and mainly facilitates the scheduling of what stands (i.e., treatment units) should be harvested in what year in order to fulfil the strategic aims (e.g., Church [65]). Operational planning (the lowest stage) focuses on the day-to-day scheduling of harvest machines and determining how to meet delivery demands (e.g., Epstein et al. [66]). Traditionally, DCF analysis has been used to evaluate the forest planning, including investment in conservation tillage (Stonehouse, [67]), precision agriculture [68,69], technology adoption [70], new crop varieties and rotations [71,72], extension programs [73], and the value of ecosystem services and environmental restoration [74–77].

DCF analysis only considers the opportunity to invest as a now-or-never decision [78] and makes implicit assumptions concerning future cashflow scenarios. Far from reality, it assumes that management is passive regarding an investment strategy planning where a firm starts and completes a project without any contingencies [79]. In reality, an investment may become less risky in the future or the projected cashflows may differ from initial forecasts. Many land use investments have significant time horizons over which decisions may be undertaken and benefits accrued [80,81].

A long time horizon worsens the uncertainty over an investment's costs and benefits [82]. Because of the inability to assess returns to waiting to invest as new information arises, the use of NPV for land use change investments with long time horizons needs a closer look [83]. As a result of these limitations, DCF and NPV calculations have often failed to explain landholder investment responses, often despite favorable NPV valuations [84]. While NPV is a good starting point to analyze investments in land use where there is uncertainty over future cashflows, the DCF models systematically undervalue the benefits of waiting or flexibility [9]. Real options analysis can better capture the value of flexibility and the opportunity to update decisions as new information emerges and consequently may provide better models of land use investment behavior. In the forestry area, if the land has the possibility of converting the plantations (for example, eucalyptus species) into another crop, the DCF model does not incorporate this value into the project. In our case study, to illustrate how to value this transformation using ROT, we consider a company whose geographic location makes it ideal for some varieties of berries. Concretely, we identify the real option of transformation into strawberry crops.

We fixed the starting point to the beginning of the cultivation of an eucalyptus (no specific year) that has a maturity period of 12 years. If the company does not transform the plantation into another crop, it would receive the income corresponding to the cubic meters cut (minus the fixed timber harvesting expenses). Nevertheless, eventually the company could decide to transform its properties into a strawberry plantation at any future moment of time. The decision depends on whether or not the future strawberries cashflow overcomes the eucalyptus earnings.

This trade-off is a direct function of the strawberry market price that we propose modeling as a mean-reverting process in the theoretical model. We evaluate this as an American call option where the underlying free cashflows are discounted from the option's transformation exercise cost. The intrinsic value of this option represents the flexibility value of the forest company with regard to the transformation cost.

2.2. Theoretical Model Framework

The evolution of the commodity price, in our case the price of strawberries in the European market, is rather similar to Lucia and Schwartz [85] (see Appendix B for Matlab implementation). First, there is a deterministic component of the price when modeling the seasonal pattern behavior for each month and each campaign; secondly, there is a stochastic component of the price converging to the seasonal component. Thus, we assume that the dynamics corresponding to the logarithm for the price of strawberries is driven by

$$\ln P_t = f(t) + X_t \tag{1}$$

where $t \geq 0$, $f(t)$ denotes a deterministic function of time, and X_t follows a stochastic mean-reverting process, or Ornstein–Uhlenbeck (OU) process, with a zero long-run mean. This is

$$dX_t = -\kappa X_t dt + \sigma_X dW_X \quad (2)$$

such that $\kappa > 0$ is the mean reverting (or speed of adjustment) parameter, σ_X is the instantaneous volatility, dW_X is the increment of the Wiener process, and the initial condition: $X(0) = X_0$. Since $X_t = \ln P_t - f(t)$, we can rewrite the previous stochastic differential equation (SDE) as

$$d(\ln P_t - f(t)) = -\kappa(\ln P_t - f(t))dt + \sigma_X dW_X \quad (3)$$

The exact solution corresponding to the SDE in (2), see Bergstrom [86], is a discrete stochastic equation (DSE) and, specifically, the following stationary AR (1) process:

$$X_t = \beta X_{t-1} + \xi_t; \;\; \xi_t \sim \text{i.i.d}\, N\left(0, \sigma_\xi^2\right); \;\; \beta = e^{-\kappa}; \; \sigma_\xi = \sigma_X \sqrt{\frac{1 - e^{-2\kappa}}{2\kappa}} \quad (4)$$

where $0 < \beta < 1$. The relationship between the SDE and DSE parameters, i.e., Equations (2) and (4), is given by the following expressions:

$$\kappa = -\ln \beta, \qquad \sigma_X = \sigma_\xi \left(\frac{2 \ln \beta}{\beta^2 - 1} \right) \quad (5)$$

2.3. Model Implementation (See Appendix B for Matlab Implementation)

In this study, we collect a series of strawberry prices in the Perpignan market, the principal destination of this type of crop in the south European area. The beginning of the campaign often occurs in late January, lasting until April. Thus, we can work with three months of the year: February, March, and April. Although for some campaigns data such as January and May do exist, these are not consistent over time, making it meaningless to include them in the analysis. Definitively, the deterministic function $f(t)$ in Equation (1) takes the following form:

$$f(t) = \sum_{i=1}^{3} \alpha_i D_{i,t} \;\; \text{where} \;\; D_{i,t} = \begin{cases} 1 \text{ if } t \in i \\ 0 \text{ if } t \notin i \end{cases} \;\; i = \text{February, March and April} \quad (6)$$

We obtain prices data from the Directorate General for Agriculture and Rural Development (February to April 2019) (https://agridata.ec.europa.eu/extensions/DashboardPrice/DashboardMarketPrices.html, accessed on 1 June 2020), and we estimate the following model by using the ordinary least squares (OLS) method:

$$\ln P_t = \alpha_1 D_{1,t} + \alpha_2 D_{2,t} + \alpha_3 D_{3,t} + \beta \ln P_{t-1} + \xi_t \quad (7)$$

where $D_{i,t}$ represents dummy seasonal variables for February, March, and April, respectively. Table 1 exhibits the OLS parameter estimates. It is shown that all explanatory variables are relevant. Indeed, the dummy seasonal variables for March and April are statistically significant at 10% while the February variable at 5%. It is also verified that the February seasonal component is the most important (highest parameter value), followed by March and April. As can be seen in Table 1, the multiple linear regression for the strawberry price (in logarithm) is well fitted since its adjusted coefficient of determination is very high.

Table 1. Coefficient estimations for strawberry prices.

Variable	Coefficients	Standard Error	Statistical t	*p*-Value
D_1	0.1282	0.0650	1.9719	0.0496
D_2	0.0693	0.0361	1.9203	0.0558
D_3	0.0265	0.0238	1.1139	0.0663
$\ln P_{T\text{-}1}$	0.8752	0.0520	1.6839	0.0000
R^2	0.8701	Standard error regression		0.1543
R^2 adjusted	0.8688	Statistical Durbin–Watson		1.6711

Finally, given the estimated coefficients in (7), we can generate the paths for the strawberry prices, i.e., $P_t = \exp(f(t) + X_t)$ by recovering the OU estimated parameters in (2) from the discrete model parameter estimated in Table 1 according to (5). As a starting point in the generation of the paths, we take the average price of the first months of the year and run a 10,000-trial Monte Carlo simulation. Each trial consists of a period of 12 years, which is the average time it takes an eucalyptus tree to mature, and, therefore, our temporary horizon for the valuation of real options (for model implementation and parameters calibration, we use MathWorks, Financial Instruments Toolbox).

2.4. Data and Parameters

2.4.1. Input Data of a Eucalyptus Cycle Production

This section describes all the necessary information and data of a forest company and its operation cycle. It was handily collected with the collaboration of the company. For instance, operation management is divided into three areas; forestry (basic activity of the company producing eucalyptus timber), agroforestry (activities on the sustainable development that transcend the production of wood), and silviculture (reforestation work and forestry treatments). This division is distinguished between silvicultural costs (expenses needed to run the plantations) and exploitation costs (related to the harvest and transport of the obtained wood). This case study is focused on the land valuation in which a high agronomic potential exits. The agronomic potential score is ranked based on the land nutrients quality, climate conditions, and the transformation potential into irrigated plantations (see Tables A1 and A2 in Appendix A for more details). From the 23 forested areas analyzed, a total of 9 were selected, around 3091 hectares. From the average of three years (2016–2019), we collected the following data concerning forestry activity:

- Total of m^3 per hectare: Average production is 200 m^3/ha. Nevertheless, according to the historical data provided by the company, the volume of wood produced by one hectare can vary depending on various factors (precipitation, temperatures, frosts, etc.) between 180 and 220 m^3/ha.
- Total cost of forestry per hectare: From an internal cost study it has an average amount of 41.78 EUR/ha, ranging between 41.19 and 42.36 EUR/ha.
- Total cost of repopulation per hectare: The company estimated an average cost of 1185.62 EUR/ha, ranging between 1052.54 and 1318.70 EUR/ha.
- Price of wood: On average, the historical prices equals 67.36 EUR/m^3, varying between 62.36 and 72.36 EUR/m^3.

For a CAPEX (capital expenditures necessary for operations discounted at the initial moment) of EUR 32 million and EUR 43 million operating cashflow, the IR is 6.48%. NPV equals EUR 10 million and payback of 23 years for the eucalyptus plantation (approximately two exploiting cycles). Using Monte Carlo simulation of 10,000 trials, certainty is 90.07% from NPV equals EUR 9.2 million. Minimum value of NPV is EUR 8 million and maximum value is EUR 13 million (more details of eucalyptus return plantation can be found in Toscano [87] and Toscano and García-Machado [88]).

2.4.2. Input Data of a Strawberry Crops

– Implementation Cost

In Table 2, the necessary investment to transform an eucalyptus plantation into one of strawberries is quantified. It should be noted that this cost includes the cost of opportunity for the land which could be sold on the land market (internal firm data). The total cost is the average of different campaigns and can vary depending on the land analyzed; however, it is a value that can be easily replaced in the adapted theoretical model proposed.

Table 2. Investment cost for transforming to a strawberry crop (EUR/ha).

Land treatment and preparation	360.61
Stripping and burning	120.20
Irrigation installation	97.35
Plastic arch-protection	3000.00
Water rights community participation quota	2404.05
Land price	12,000.00
Total investment	17,982.21
Working capital	1798.22

– Cashflow for Strawberries

We model free cashflow (FCF) as a random variable at moment t, as follows:

$$FCF_t = (Rev_t - \text{Operations Cost}_t - \text{Interests}]\,(1 - t) + \text{Depreciation} \quad (8)$$

where Rev_t represents the price of the strawberry in the market for each period, and Operation $Cost_t$ the operating expenses that include depreciation. The value of depreciation is EUR 775 annually and the average cost of the debt for the forestry company is 6.5%. A hectare of strawberries produces, on average, 20,000 kg/campaign. In Table 3, we report the average operating expenses for one period and the depreciation (internal firm data). Strawberry price modeling described in the above section refers to the model implementation.

Table 3. Operating expenses for a strawberry crop (EUR/ha.).

Terrain preparation	4329.49
Plantation	4524.97
Cultures	7071.19
Harvesting	10,720.71
Harvesting the culture	601.00
Costs of commercialization	11,040.00
Total operating expenses	38,287.36

– Discount Rate

We use the weighted average cost of capital (WACC). For cost of equity we use the CAPM (Capital Asset Pricing Model) market model and one-year Spanish Treasury bills (2 January 2019) for risk-free rate. For beta estimation in the CAPM we use market relative from Madrid Stock Exchange, ENCE, which is the closer comparable for cellulose firm. We consider for leverage by adjusting the beta of the comparable firm. For a capital structure of 35% equity and 65% debt, we obtain 5.15% discount rate.

3. Results

Table 4 shows the results for valuing the transformation. The initial project column considers traditional valuation for different discount rate (cost of capital). In the column project with flexibility, the value of transformation is incorporated depending on strawberries' price evolution, and the column option value shows the implied option value, calculated by difference project with flexibility less initial project value. To calculate the option value, firstly, we simulate strawberry prices with mean-reversion and parameters calibration of the seasonal model (see Matlab implementation in Appendix B.1). The underlying asset paths (strawberry cashflow) are generated for a total of 72 data of prices (24 per month). Then, each price is multiplied by the total of the commercialized production, 61,820,000 kg. After that, operating cost, interest, and taxes are subtracted. By using simulation, we run 10,000 values of discounted cashflows, each one representing the value of the project for each one of the paths. If the discounted cashflow value is greater than the exercise price, the option has an intrinsic value that corresponds to the flexibility value. Otherwise, the opportunity of transformation does not incorporate any value, meaning that the cost of transformation is higher than the expected strawberry cashflows. The American call option value is calculated using the least-squares Monte Carlo algorithm by Longstaff and Schwartz algorithm [89] with 10 intermediate steps (Matlab implementation code in Appendix B.2). As the option exercise price, we use the cost of transforming the eucalyptus plantation into strawberry crops. This cost includes the initial investment required and the preparation of the land after stripping the trees, multiplied by the total hectares.

Table 4. Valuation of transformation.

Panel A. Total Value (EUR Thousand)	**Discount Rate**	**Initial Project**	**Project w Flexibility**	**Option Value**
	6.00	213,900	334,850	120,950
	5.15	221,400	365,090	143,690
	4.00	232,310	411,350	179,040
Panel B. Total Return (Percentage)	**Discount Rate**	**Initial Project**	**Project w Flexibility**	**Option Value**
	6.00	171.57	325.13	153.56
	5.15	181.09	363.52	182.43
	4.00	194.94	422.25	227.31
Panel C. Annual Return (Percentage)	**Discount Rate**	**Initial Project**	**Project w Flexibility**	**Option Value**
	6.00	8.68	12.82	4.14
	5.15	8.99	13.63	4.64
	4.00	9.43	14.77	5.34

Table 4-Panel A shows the result in absolute terms (EUR thousand), Panel B shows this result over the total amount invested in percentage, and Panel C, in the annual return. The company would obtain an NPV of EUR tens of million on its forestry projects, which, in relative terms, is equivalents to 6.48%, which is 1.33% net. If agronomic potential does exist, the manager may consider transforming the eucalyptus plantation at the initial moment of valuation. The results show that by using a 5.15% discount rate, a value equals EUR 221 million considering agronomics potential, but not the flexibility, close to 9% annual return. It means an increase in return more than three percentage points with respect to basic forest plantations. However, this value does not consider the value of the flexibility of transformation depending on underlying prices evolution. Including this, EUR 365 thousand million is obtained. The increment is EUR 143 thousand million and equals the value of the opportunity of transformation anytime. In relative terms, it means an increase of more than 4% in return that corresponds to the value of deciding whether or not to transform crops under prices uncertainty. The range value for the option is between 4.1 and 5.3% of the annual return.

4. Sensitivity Analysis

This section describes the sensitivity analysis of random variables and parameters estimated in the model. Thus, for each of them, we consider differentials of ten percent. We recalculate the options value generated by 10,000 simulations. The values of the projects in Table 5 are expressed in EUR thousand, while returns are in annual percentage. In the last column of the table, the effect on the option value of a ten percent variation for each parameter is reported, with the rest remaining constant. Sensitivity analysis reveals that the most relevant variable is the discount rate and the intermediate steps for computing (in line with García-Machado, de la Vega, and Toscano [90]). Concerning OU parameters, the seasonal component February (θ_1) has the highest incidence on the option value (in percentage), followed by the lower component March (θ_2) and the even lower April (θ_3), as we anticipate from Table 1 estimation coefficients. This result is consistent with strawberry prices in the market, throughout a campaign. Thus, at the campaign starting point, the volume traded is low, and the demand is high, reaching auction prices' highest levels. Therefore, a variation in this parameter greatly influences the flexibility value of the project. For example, poor results attributable to very low prices reached in the auctions at the beginning of the campaign usually persist through it and are difficult to compensate during subsequent production periods.

Table 5. Sensitivity analysis of the option valuation.

Parameters	Initial	Project w Flexibility	Option Value	Return Initial	Return w Flexibility	Option Value (%)	Dif.
WACC (%)							
6.00	213,900	334,850	120,950	8.68%	12.82%	4.14%	−0.50%
5.15	221,400	365,090	143,690	8.99%	13.63%	4.64%	
4.00	232,310	411,350	179,040	9.43%	14.77%	5.34%	0.70%
κ							
0.1466	206,390	339,220	132,830	8.36%	12.94%	4.58%	−0.06%
0.1333	221,400	365,090	143,690	8.99%	13.63%	4.64%	
0.1200	238,100	393,910	155,810	9.66%	14.36%	4.70%	0.06%
θ_1							
1.1299	248,560	392,700	144,140	10.05%	14.33%	4.28%	−0.36%
1.0272	221,400	365,090	143,690	8.99%	13.63%	4.64%	
0.9245	195,810	338,810	143,000	7.88%	12.93%	5.04%	0.40%
θ_2							
0.6112	230,640	374,510	143,870	9.37%	13.87%	4.51%	−0.13%
0.5556	221,400	365,090	143,690	8.99%	13.63%	4.64%	
0.5000	212,460	356,050	143,590	8.62%	13.40%	4.78%	0.14%
θ_3							
0.2339	224,800	368,670	143,870	9.13%	13.73%	4.59%	−0.05%
0.2126	221,400	365,090	143,690	8.99%	13.63%	4.64%	
0.1913	217,960	361,680	143,720	8.85%	13.54%	4.69%	0.05%
σ							
0.1697	229,030	400,150	171,120	9.30%	14.50%	5.20%	0.56%
0.1543	221,400	365,090	143,690	8.99%	13.63%	4.64%	
0.1389	214,560	331,280	116,720	8.71%	12.72%	4.01%	−0.63%
Exercise Price (EUR/ha)							
21,758.47	221,400	357,790	136,390	8.99%	13.44%	4.45%	−0.19%
19,780.43	221,400	365,090	143,690	8.99%	13.63%	4.64%	
17,802.39	221,400	372,370	150,970	8.99%	13.82%	4.83%	0.19%
Steps							
5	221,400	405,290	183,890	8.99%	14.63%	5.63%	0.99%
10	221,400	365,090	143,690	8.99%	13.63%	4.64%	
15	221,400	332,310	110,910	8.99%	12.75%	3.75%	3.75%

5. Discussion

When assessing the transformation potential of forest plantations, the hypothesis regarding the evolution of the prices of the alternative crop becomes essential. This work demonstrates how the consideration of the seasonal component of the underlying asset, in our case strawberry prices, has a strong impact on the option value estimation and it can be decisive in assessing flexibility. The proposed adaptation of the Lucia and Schwartz model [85] to the transformation of a forest plantation into an agricultural crop solves the lack of appropriate methodology in this specific context when the option value depends on the evolution of prices with a strong seasonal component.

As we referenced in the introduction, the current literature focuses on the application of ROT in the forestry field, specifically in land conversion, but in most cases it models the evolution of the underlying asset as a GBM process. The hypotheses that are made in these stochastic processes are far from being similar to those that we observe in the prices of agricultural products. Thus, as Sorensen [91] and Banás [92] evidence, these types of agricultural assets present a strong seasonal behavior that, if it is not considered, would lead to biased valuations.

As Mei and Clutter [34] warn, the proper choice of the stochastic process should be cautiously made, otherwise we may have puzzling results. Thus, if in the valuation of alternative land uses we have underlying assets with seasonal characteristics that revert in the long term, this aspect must be included in the valuation (Mei et al. [93] and Schwartz [60]). Contrary, if this long-term reversion does not occur, the use of a random walk or the GBM assumptions could be right. The difference, as Rocha et al. [58] highlighted, could reach eight times with respect to the NPV in the case of using GBM, far from the 1.5 times in the case of using mean-reverting. Insley and Lei [94], Schmit et al. [59], or Tee et al. [29] also found the same results and recommended the MR process in the valuation of natural resources that involve a longer-term management. These authors stated that the MR process is more realistic for commodity prices.

In the adapted theoretical model proposed in this work, we took into consideration this previous evidence and we tried to cover the absence of any work where option valuation includes an agrarian asset. Our results are aligned with the literature that applies the MR process in similar contexts. We can observe that the project value, including the option valuation, through our model is between 1.5 and 1.7 times the value of the transformation with regard to the NPV. If we had modeled the option following a GBM, the value of the project with flexibility, according to the literature, would have been EUR 1777 million compared to EUR 365 million calculated by the MR process. In terms of annual profitability, it would have been 72% compared to 13%, as we calculated in Panel C of Table 4. This overvaluation of the GBM leads the decision-maker to make inflated decisions, compared to the most realistic solution estimated with the MR model, as is proposed in this work.

This work, similar to all research work, has its limitations. The transformation valuation includes many other land use factors that could be considered. Among them, perhaps the most relevant is the use of water and other environmental implications that the transformation could have. For example, Ginbon et al. [95] analyzes the decision to invest considering the adaptation and mitigation of climate change from the perspective of real options and examines how risk preferences and strategic interactions condition the decision. In future work, it would be interesting to delve into the effect that the use of water has on the value of the transformation option.

6. Conclusions

This paper contributes to the quantitative valuation of a forest resource with agronomic potential by proposing an adapted theoretical model when the GBM hypothesis is not plausible. By selecting the strawberry as an alternative crop that has a strong seasonal component, we find new evidence that demonstrates the necessity of adapting previous valuation methodologies that lead to a more realistic valuation of forest resources.

Hypothesis assumed by traditional ROT results in overestimation of the flexibility. The model proposed in this study that considers the seasonal MR process leads to a more prudent valuation than the one carried out by the GBM process and non-seasonal models. Additionally, the flexibility of the transformation and its valuation through the ROT entails a return premium that is far from the estimated that would be found using the GBM process.

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Appendix A

Table A1. Agronomics potential scores description.

Panel A. (Rank)	**Soil Scale**
5	Sandy or sandy loam soils, deep, well drained, and with a flat or slightly hilly topography.
4	Sandy or sandy loam soils, well drained, not as deep, with a hilly topography and locally sloped.
3	Sandy soils with reduced contact, with layers of clays–silts or clayey slates, resulting in bad infiltration and drainage conditions.
2	Clayey soils, shallow, heavy, generated from slates and with infiltration problems.
1	Poorly developed soils, shallow, with outcrops of metamorphic rocks and almost no agricultural capacity.
Panel B. (Rank)	**Climatology Scale**
5	Zones of coastal influence, mild conditions, without frost, suitable for extra-early agriculture.
4	Zones with mild conditions, without frost, suitable for early agriculture.
3	Zones with mild conditions, low frost probability, requiring crop protection systems.
2	Zones with harsh conditions and medium frost probability.
1	Zones with extreme conditions and high frost probability, not suited for agricultural activities.
Panel C. (Rank)	**Irrigation Potential**
5	Farms with direct water supply.
4	Farms belonging to the irrigation community, working infrastructure, and future expansion plans.
3	Farms in the surroundings of the irrigation community.
2	Farms not belonging to the irrigation community and far from its perimeter.
1	Farms with low probabilities of obtaining irrigation.

Table A2. Agronomic potential rating.

Estate	Soil	Climatologic	Irrigation	Total Score
302	5	4	3	12
303	2	4	2	8
305	5	4	3	12
322	4	5	5	14
326	4	4	4	12
341	4	4	3	11
343	3	4	3	10
355	2	4	2	8
376	4	4	4	12
471	5	4	3	12
473	2	3	3	8
474	1	2	1	4
475	1	2	1	4
476	3	4	2	9
477	5	4	4	13
481	4	4	4	12
316	5	3	2	10
335	5	2	2	9
344	5	4	4	13
454	2	1	3	6
478	5	3	3	11
497	5	2	2	9
504	5	3	3	11

For confidential purposes, Table A2 does not show the estate name for the selected company. Only the estates with high agronomics potential (>12 in total score) are selected for study analysis.

Appendix B. Matlab Implementation Section

Appendix B.1. Simulating Strawberry Prices with Mean-Reversion and Parameters Calibration for the Seasonal Model [85]

```
% Load the strawberries prices.
load('electricity_prices.mat');
PriceDates = datetime(PriceDates,'ConvertFrom','datenum');

% Calibrate parameters for the seasonality model.
seasonMatrix = @(t) [sin(2.*pi.*t) cos(2.*pi.*t) sin(4.*pi.*t)
... cos(4.*pi.*t) t ones(size(t, 1), 1)];
C = seasonMatrix(PriceTimes);
seasonParam = C\logPrices;

% calibrate the stochastic part of the model for Pt
% Prices at t, X(t).
Pt = X(2:end);

% Prices at t-1, X(t-1).
Pt_1 = X(1:end-1);
```

```
% Discretization for the daily prices.
dt = 1/365;

% PDF for the discretized model.
mrjpdf = @(Pt, a, phi, mu_J, sigmaSq, sigmaSq_J, lambda) ...
    lambda.*exp((-(Pt-a-phi.*Pt_1-mu_J).^2)./ ...
    (2.*(sigmaSq+sigmaSq_J))).*
(1/sqrt(2.*pi.*(sigmaSq+sigmaSq_J))) + ...
    (1-lambda).*exp((-(Pt-a-phi.*Pt_1).^2)/(2.*sigmaSq)).* ...
    (1/sqrt(2.*pi.*sigmaSq));

% Constraints:
% phi < 1 (k > 0)
% sigmaSq > 0
% sigmaSq_J > 0
% 0 <= lambda <= 1
lb = [-Inf -Inf -Inf 0 0 0];
ub = [Inf 1 Inf Inf Inf 1];

% Initial values.


x0 = [0 0 0 var(X) var(X) 0.5];

% Solve the maximum likelihood.
params =
mle(Pt,'pdf',mrjpdf,'start',x0,'lowerbound',lb,'upperbound',ub,..
.
    'optimfun','fmincon');

% Obtain the calibrated parameters.
alpha = params(1)/dt
kappa = (1-params(2))/dt
mu_J = params(3)
sigma = sqrt(params(4)/dt);
sigma_J = sqrt(params(5))
lambda = params(6)/dt

end
```

Appendix B.2. Least-Squares Monte Carlo (LSM) in Pricing American Input Options Using Matlab

```
% Payoff:
payoff=max(Stock_Path(:,tn)-K,0);
for k=tn-1:-1:2
payoff=payoff*exp(-rate*Dt);
%holding value
EV=max(Stock_Path(:,k)-K,0);
%exercise value at tn
index=find(EV>0);
Stock_Path(index,k);
payoff(index);
regression=polyfit(Stock_Path(index,k),payoff(index),2);
EHV=polyval(regression,Stock_Path(index,k));
%continuation value
si=size(index);
for j=1:si(1)
if EHV(j)< EV(index(j))
payoff(index(j))=EV(index(j));
end
```

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