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Real options approach: Case study applied to a nursery to produce *Eucalyptus* forest seedlings in Brazil

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Abstract

Aim of study: We checked if an infrastructure investment project for a nursery to produce Eucalyptus forest seedlings using the real options approach was economically viable, in order to verify the influence of the deferral, expansion and abandonment options on the investment project value, as well as their concatenation.

Area of study: Our study was based on technical-economic coefficients of a nursery infrastructure to be installed in the São Paulo's state Midwest region, Brazil.

Materials and methods: The investment was assessed by addressing the uncertainties inherent in the investment project. We used the dynamic model for real option approach and, to determine the volatility of the project, we applied the Monte Carlo simulation method. As real options for the project, we employed deferral, expansion, and abandonment.

Main results: Using the traditional valuation methodology, we obtained a negative static net present value of USD 50,957. When incorporating the real options of the abandonment, deferral and expansion in the form of managerial flexibility to forest managers, we obtained the expanded net present value of USD 216,498, that is, 524.8% of valuation. The traditional method of investment evaluation undervalues the project in infrastructures to produce Eucalyptus forest seedlings nursery, and the increase in managerial flexibility, through the real options for deferral, expansion and abandonment, promotes value to forest managers and enables the feasibility of the project.

Research highlights: Infrastructure investment project for a nursery to produce Eucalyptus forest seedlings is not economically viable through the traditional economic evaluation techniques. However, by incorporating managerial flexibilities, through real options, the investment project was valued and it became economically viable.

Additional key words: geometric Brownian motion; investment decision-making; irreversibility; Monte Carlo; net present value; uncertainty; underlying asset.

Abbreviations used: ADF (augmented Dickey-Fuller); BRL (Brazilian real); CAPEX (capital expenditure); CAPM (capital asset pricing model); CRR (Cox, Ross and Rubinstein); GBM (geometric Brownian motion); GPI-IA (general price index with internal availability); NPV (net present value); ROA (real options approach); USD (American dollar).

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Introduction

The success of a planted *Eucalyptus* forest is based on the seedling quality to be implanted in the field, which is dependent on a production and selection process carried out in forest nurseries. The nursery infrastructure to produce *Eucalyptus* forest seedlings must be able to offer favorable conditions for seedling the development, such as controlled environments, water availability, as well as protection against pests and diseases.

Activities carried out in nursery infrastructures to produce *Eucalyptus* forest seedlings require financial contributions which are undoubtedly irreversible and also cause uncertainties, whether due to failures in the protection against pests and diseases process, or even from nature's weather, productive resources scarcity, market conditions, fluctuations in the price of inputs, among others, which inevitably affect the expected value to forest managers.

Every investment has uncertainties associated with capital recovery and the planned time horizon. Forest managers aware of the risks to which they are exposed, and who assimilate volatility to the estimated economic amounts, gather structured and pertinent information for greater control of the project's future cash flows (Yusuf *et al*., 2014; Whittet *et al*., 2016; Ray *et al*., 2021).

In this perspective, for the improvement of forest management, the investment evaluation must be able to incorporate the managerial flexibilities to which the forest managers are exposed during the planning of a nursery infrastructure to produce *Eucalyptus* forest seedlings, in order to monetize the decisions and changes made in the investment project (Duku-Kaakyire & Nanang, 2004; Mathias *et al*., 2015; Bravo *et al*., 2019; Shukla *et al*., 2019;). Forest managers have the opportunity to change the planning (Munis *et al*., 2022a), maximize profit (Brandão & Dyer, 2005) or, even, minimize damage (Savolainen, 2016).

The managerial flexibility allows practical assessments associated with uncertainties and opportunities (Gomez-Cunya *et al*., 2020), the incorporation of which is possible through the Real Options Approach (ROA) (Eyvindson *et al*., 2017; Bistline *et al*., 2018). The ROA is a valuable tool in strategic planning, especially when

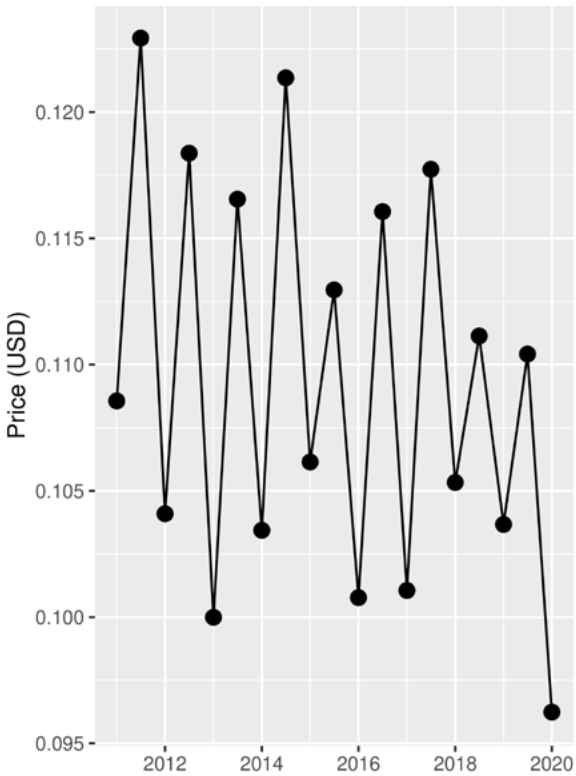

Figure 1. Time series of the semester prices of *Eucalyptus* seedlings.

future modeling is needed (Rout *et al*., 2018), which allows forest managers to assess in real time the evolution of their investment and their effects on the uncertainty's distribution according to the present risks (Peña *et al*., 2018; Heidari *et al*., 2020).

Forest managers can analyze the best investment alternatives considering market uncertainties, flexibilities and fluctuations (Kallio *et al*., 2012; Brandão *et al*., 2018), which will promote the value creation for the forest investment project (Soda & Furlotti, 2017), that is, they provide veracity to the decision-making process (Rocha *et al*., 2006). This method has been recently applied for pine plantations with good results (Martins *et al.,* 2022).

Our hypothesis is that the value of investment projects in nursery infrastructure, with strategic planning associated with the real options approach, is directly related to the volatility captured from project uncertainties and the incorporation of managerial flexibilities. Our objective was to check if an infrastructure investment project for a nursery to produce *Eucalyptus* forest seedlings using the ROA is economically viable, in order to verify the influence of the deferral, expansion and abandonment options on the investment project value, as well as their concatenation.

Material and methods

Infrastructure of the nursery to produce *Eucalyptus* forest seedlings

Our study was based on empirical data of an infrastructure investment project for a nursery to produce *Eucalyptus* forest seedlings to be installed in an area of 20,000 m^2 located in the São Paulo's state Midwest region, Brazil. The infrastructure required to produce seedlings was established through the vegetative propagation technique, sectorized type, with suspended beds and micro sprinkler irrigation system. The effective productive capacity considered was 4 million seedlings per year, with an average productive cycle of 90 days.

The investment project was designed for a 10-year time horizon, with the average unit price of *Eucalyptus* forest seedlings obtained from forestry suppliers, which were traded for USD 0.11. Salaries from the productive, administrative and managerial sector constituted the fixed costs. Acquisition of seedlings, consumption of electricity and forestry inputs, such as substrate, nutrient solution, fungicide and insecticide, were added to the variable costs. Details of direct and indirect costs in our study are provided as Table S1 [suppl].

To simplify the model, we assumed that the price of selling *Eucalyptus* seedlings was the only factor that influenced the investment project value, which assumed the flexibility to defer the initial investment, that is, the Capital Expenditure (CAPEX) of USD 326,414 from year 0 to year 1, abandon the investment project in years 3 and 5, with the bonus of recovering 100.0% of the initial invested capital. In year 5 it was decided to expand 30.0% of the production capacity under favorable market conditions, at a cost of USD 97,924.

Determination of the dynamic evaluation model

The uncertainty arising from the investment project in nursery infrastructures to produce forest seedlings was modeled using the stochastic process Geometric Brownian Motion (GBM) of a first-order linear Stochastic Differential Equation (SDE) consisting of a deterministic component and a stochastic component (Miranda *et al.*, 2017).

We used a time series of the semester prices of *Eucalyptus* seedlings from 2011 to 2020 (Fig. 1). We applied econometric tests in order to validate the adjustment. Using the Jarque Bera test (Jarque & Bera, 1980), we tested the null hypothesis that the data have a normal distribution at the 5.0% significance level that followed the application of the unit root test, that is, verify the null hypothesis that the slope (b) of linear regression (Eq. 1) is equal to 1 (b-1=0).

The modified Dickey-Fuller approach (Dickey & Fuller, 1981), augmented Dickey-Fuller test (ADF), was applied for this purpose, since the trend hypothesis was incorporated into the *Eucalyptus* seedling price series.

$$P_t = a + (b-1)P_{t-1} + c + ɯ \qquad (1)$$

where, P_t is the price of *Eucalyptus* seedlings at time t, P_{t-1} is the price of the *Eucalyptus* seedling at time t-1, a is the linear coefficient of the regression, c it is a trend term, ɯ is the random error.

Once the 10-year historical series was proven to be non-stationary, we modeled the price of the *Eucalyptus* seedling using a GBM (Eq. 2).

$$dP_t = \mu P_t dt + \Omega P_t dw_t \qquad (2)$$

where, μ is the drift parameter, Ω is the standard deviation of the Neperian logarithm of price returns, and dw_t is the standard increment of a Wiener process.

Due to the uncertainties presented in the management of an investment project in nursery infrastructures to produce forest seedlings, it was necessary to choose an investment evaluation model that included the associated managerial flexibilities. We chose a dynamic model for the ROA, based on the binomial tree model developed by Cox *et al.* (1979), also referred to as the Cox, Ross and Rubinstein (CRR) model.

Investment project's cash flow

The currencies were expressed in US dollars (USD), with an exchange rate, in Brazilian Real (BRL), of BRL 4.2469, released by the Banco Central do Brazil (2020) on February 3, 2020.

The CAPEX of USD 326,414 came from all expenses of the nursery's infrastructure for the forest seedlings production, such as the required area acquisition for the physical structure implementation, material for civil construction, electrical installations, labor outsourced for construction of the construction sites, structure maintenance costs, the inputs inherent to the *Eucalyptus* production process of seedlings such as trays, tubes, genetic material, nebulizer, micro sprinkler, plastic filter, reservoir and water pump, micro tractor with cart, scale, sprayer, vibrating table, among others.

The tax framework for the investment project was established based on the National Classification of Economic Activities in force in Brazil, where the economic activity code for the cultivation of seedlings in forest nurseries is 0210-1/06. In line with Brazilian legislation (Brazil, 2006), the deductions were based on the Brazilian Simplified Tax Regime for billing in the order of USD 440,000, the fourth range of that regime was assumed, which considers the rate nominal value of 10.7% and deduction of USD 5,297. Consequently, the effective rate was 9.3% and the amount collected annually was USD 41,782.

We prepared the budget based on cash inflows and outflows that occurred over the planning horizon (Eq. 3).

$$dP_t = \mu P_t dt + \Omega P_t dw_t \qquad (3)$$

where; t are the cash flow periods, CF_t is the cash flow, GR_t is the gross revenue, IT are the taxes based on the Brazilian Simplified Tax Regime, SC_t are the operating, input and maintenance costs, and OC_t are overhead costs.

The equation to determine de value of the project without real options (Eq. 4) estimated the difference between the present value of benefits and the present value of costs, considering the time value of money.

$$NPV = \sum_{j=0}^{n} \frac{CF_t}{(1+i)^t} - CAPEX \qquad (4)$$

where; NPV is the net present value, n is the number of periods, i is the discount rate adjusted to the investment's project risk, and CF_t is the cash inflow at moment *t*.

Discount rate adjusted to the investment's project risk

As a risk-adjusted discount rate for the investment project (k_e) the Capital Asset Pricing Model (CAPM) was considered, determined through Eq. 5, according to Damodaran (2002):

$$k_e = r + \beta\,(r_m - r) + \lambda_{Br} \qquad (5)$$

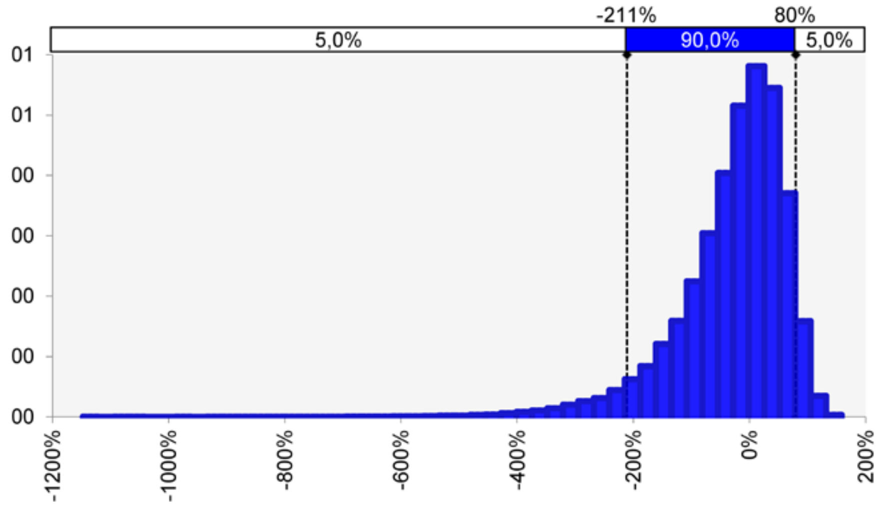

Figure 2. Probability distribution of the investment project profitability.

where; r is the risk-free rate, β is the proxy to the systematic risk of the investment project, r_m is the expected return by the market, (r_m-r) is the market risk premium, λ_{Br} is the country-risk premium.

The 5.42% risk-free rate was based on the geometric average of the Annual Return on Treasury bonds 10Y historical series made available by the U.S. Department of the Treasury (2020) since 1962, with a ten-year maturity. The predilection for longer periods for each variable will result in the absence of any trend over time (Damodaran, 2012). The risk-free rate was geometrically weighted, so that its value was not overestimated due to the long period of data (Damodaran, 2010).

The average systematic risk factor β was the one of the wood and cellulose sectors (we used the beta of the sector as a proxy to the systematic risk of the investment project), for the companies listed on the stock exchange B3 SA (2020)-Dexco S.A., Eucatex S.A. Indústria e Comércio, Klabin S.A. and Suzano S.A.–. The expected market return was assumed to be the S&P Global Timber & Forestry for the 10-year period, which provided an annualized return of 5.4% (S&P Dow Jones, 2020).

As well as the risk-free rate, the 4.0% country risk premium for Brazil was obtained from the geometric average of the historical series started in 1994 and provided through the Emerging Markets Bond Index - JP Morgan made available by Instituto de Pesquisa Econômica Aplicada (IPEA, 2020).

Net present value and project volatility

The net present value (NPV) of the investment project could be estimated by adjusting free cash flow at the risk-adjusted discount rate, that is, the CAPM. This criterion was applied using the traditional valuation methodology, which acted as an input in the dynamic modeling of investment's project NPV (Eq. 6).

$$P_t = P_{t-1}\, exp\left[\left(\alpha - \frac{\sigma^2}{2}\right)\Delta T + \sigma\varepsilon\sqrt{\Delta T}\right] \quad (6)$$

where; σ is series volatility, α is the expected rate of return, obtained with $\alpha = \mu + \frac{\sigma^2}{2}$, with μ being the series drift, ΔT is the increment of time, ε is the random error with standard normal distribution.

To estimate the investment's project volatility, we applied the Monte Carlo simulation method, which is associated with the source of consolidated uncertainty, by a single stochastic process, the GBM (Samuelson, 1965; Munis *et al.*, 2022b). In order to remove the overestimation bias source presented in the traditional Monte Carlo simulation method, we adopted the model proposed by Brandão *et al.* (2012), whereby the investment's project volatility in the first year is conditioned to the expectations of the present values from the second to the tenth year.

The volatility was computed by means of the return samples' standard deviation, which was captured by means of the Monte Carlo simulation, following the GBM probability distribution, with the aid of the software Risk Analysis and Risk Modeling (Palisade, 2020) and the generation of 100,000 pseudo-random numbers.

Stochastic modeling by binomial tree

In order to evaluate the investment project plus the managerial flexibilities, we performed the underlying asset modeling through the binomial decision tree construction, according to the CRR model, with the aid of the DPL software (Syncopation, 2020). We modeled the basic asset, that is, the investment project without real options, using the parameters: project volatility (σ), risk-free rate (r), levels of increase ($u=e^{\sigma}$) or decrease (d=1/u) in the project value and risk-neutral probability (p=(1+r-d)/(u-d)). We added

Table 1. Asymptotic critical values of statistics Ʈ from augmented Dickey-Fuller (ADF) test.

Level of significance	1%	5%	10%
Critical values (Ʈ)	-4.4	-3.6	-3.2

decision nodes, containing management flexibilities as real options for the investment project.

Despite the risk-free rate application in the ROA process in the binomial decision tree, we substituted the risk-free rate with the risk-adjusted rate of the investment project to obtain the real probability of the execution of each option, according to Miranda *et al.* (2017).

Underlying asset

The value of the options is a function of maximizing the difference between the value of the underlying asset and the exercise price of the respective option and zero. To determine the value of deferral and expansion options, which are considered call options, we used Eq. 7, according to Guj & Chandra (2019), while for the abandonment option, a put option, we used Eq. 8, according to Benaroch (2001). It should be noted that, as they are American options, the forest manager acquired the right to buy or sell the underlying asset, based on the options, at the exercise price, at any time before the predetermined expiration time. Contrary to European options, which shortens the useful life of the options (Chen *et al*., 2018; Lin *et al*., 2018).

$$\mathrm{ROV} = \max(\mathrm{U} - \mathrm{X}; 0) \tag{7}$$

$$\mathrm{ROV} = \max(\mathrm{X} - \mathrm{U}; 0) \tag{8}$$

where ROV is the real option value, U is the underlying asset value, X is the exercise price of the real option.

Results

Premises for the application of Geometric Brownian Motion

Through the application of the Jarque Bera test, the normality of the data was verified, at the significance level of 5.0%, with a *p*-value of 0.4. With the ADF test application, the existence of the unit root was verified. This is the fundamental assumption for the non-stationary condition of the GBM with the trend increase, since the test's *z.lag.*1 statistic (-1.8) was superior to the critical values (Table 1).

We did not reject the hypothesis that the price of *Eucalyptus* seedlings follows GBM. We obtained a series volatility (Ω) of 18.0% and a drift (µ) of 0.3%.

Net present value and project volatility

The rate of return on risk-adjusted equity obtained with the CAPM was 9.4%. Through the traditional investment appraisal approach, when associating the rate of return to the free cash flow of the investment project, as well as to CAPEX, the return was a deficit of USD 50,957 for NPV.

The Monte Carlo method was applied to the cash flow of the investment project. The expected value of the investment project, at t=1, was USD 225,110, with kurtosis and asymmetry coefficients of 3.29 and 0.39, respectively. The Monte Carlo simulation returned the investment project volatility of 96.0%. Fig. 2 shows the result of the simulation for project profitability (%), with an expected average value of -30.7%.

In order to model the underlying asset without managerial flexibilities, the binomial decision tree was built, according to the CRR model, for which we obtained the parameters shown in Table 2, in addition to the risk-free rate and the investment project volatility.

The investment project NPV without real options is the value of the underlying asset (Fig. S1 [suppl]); as well as in the traditional methodology, it returned the static NPV of the investment project of USD 50,957.

Real option of deferral

The implementation of the nursery to produce forest seedlings under the deferral regime of the initial investment from year 0 to year 1 was part of the forest managers strategy. We assume that if these managers did not carry out the investment at the end of year 1, it would not carry out the investment project implementation, therefore, it would be unfeasible (Fig. S2a [suppl]). The option to defer the initial investment at the end of the first year was exercised with 100.0% probability, which implied an expanded NPV of USD 112,283, *i.e*., USD 163,240 from the deferral option.

As the underlying asset does not pay dividends, the option to invest in a future moment was evaluated as a call option and a call option never exercises before the expiration date. When we consider the CAPEX of the investment project as the cost of the option to invest at a future time

Table 2. Parameters for building the Cox, Ross and Rubinstein (CRR) model.

Binomial tree parameters	
up (*u*)	2.6
down (*d*)	0.4
Risk neutral probability (*p*)	30.0%
Present value (*PV*)	USD 275,457
Investment (*t*=0)	USD 326,414

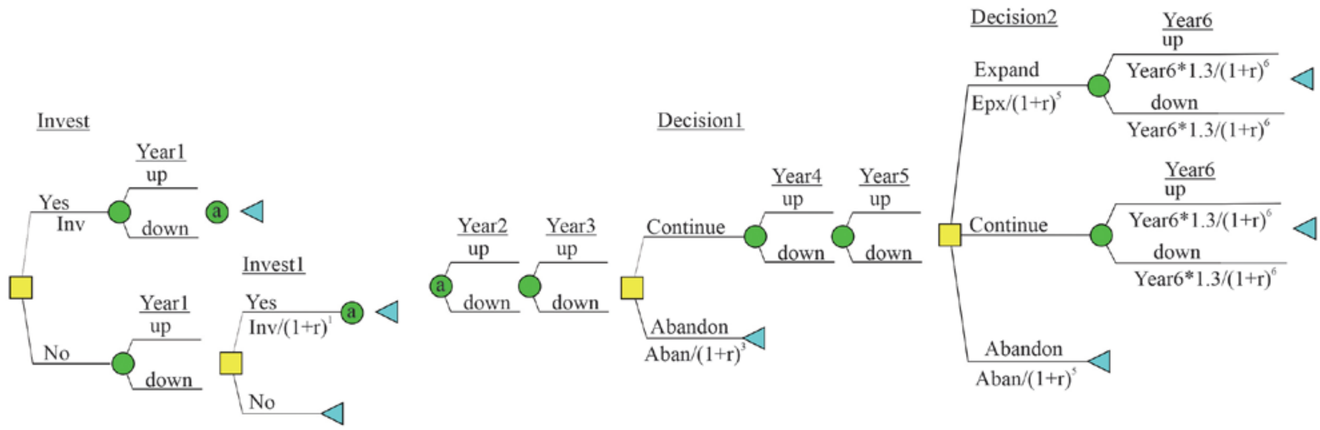

Figure 3. Combined real options: deferral, abandonment, and expansion.

and compare it with the present value of the investment at t = 0, we consider the correction of the value over time, discounted by the risk-free rate.

Real option of abandonment

Likewise, it was part of the strategy of forest managers to consider the option of abandoning the investment project in year 3 or year 5, since in unfavorable market conditions, the continuity would result in greater losses (Fig. S2b [suppl]). When considering the abandonment option, the forest managers considered the recovery of 100.0% of the initial capital invested. The results showed that in year 3 the option was exercised with 76.0% and in year 5, 10.0%. It reflected an expanded NPV of USD 138,587, *i.e.*, USD 189,544 from the abandonment option.

The abandonment value was determined by adding up all the costs incurred to implement the system and it was discounted at the risk-free rate. However, optimal policy of an American put option evaluates its immediate exercise value versus the continuation, so the immediate exercise reflected a greater value than expected by the continuation.

Recognizing the flexibility of incorporating the option of abandonment in two moments of the planned horizon configured a pseudo-American option strategy. As the European put option is simply a special case of an American put option, with only one exercise limit, the pseudo-American option strategy presupposes exercise on the date when the highest value occurs.

Real option of expansion

Finally, in a favorable market condition, the strategy of forest managers was to consider the option of expanding 30.0% of the productive capacities by the end of year 5 (Fig. S2c [suppl]), thus, the exercise price of the option was 30% of the CAPEX. From the value of the underlying asset, that is, the deterministic present value used as input in the ROA, the results showed that the option was assumed with a 19.0% probability, resulting in an expanded NPV of USD 10,405, that is, USD 61,362 exclusive of the option to expand.

Combined real options

As the forestry market is uncertain, the strategic planning associated with the range of possible options to be assumed during the investment project useful life (Fig. 3) favors the creation of value for forestry managers. This fact is reflected in the expanded NPV of USD 216,498, resulting from the association of deferral, abandonment and expansion options.

In this scenario of combined options, the forest managers could exercise the option of deferring the initial investment with a 100.0% probability at the end of the first year. For the abandonment options, the execution probabilities were 76.0% for the third year and 10.0% for the fifth year. Note that in the fifth year a decision is not necessary with a probability of 76.0%, due to the abandonment of the investment project occurring previously. And for the expansion, the probability of execution was 14.0% (Fig. 4).

When combining the options for deferral, abandonment and expansion in the same investment project, we consider the flexibility in the hierarchy of relationships. The deferral tolerated the exercise consisting of successive options, abandonment or expansion. The predilection for the pseudo-American option of abandoning in the third or fifth year does not tolerate the feasibility of the expansion option, as it is an exclusive option.

Discussion

To assess the viability of an investment project in nursery infrastructures to produce *Eucalyptus* forest seedlings, we considered the managerial flexibility of forest managers to exercise the options of differing, expanding, and

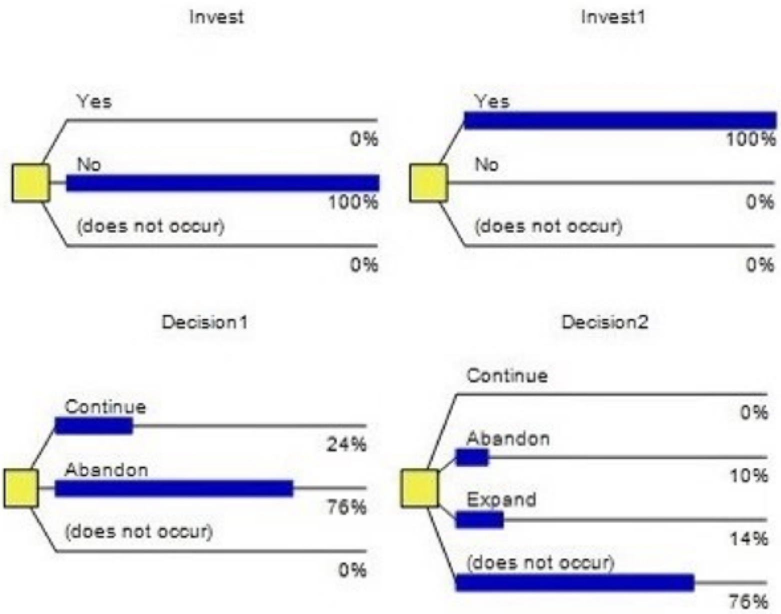

Figure 4. Real probabilities of options execution.

abandoning. This occurred because in the base scenario, that is, the scenario that involves the traditional approach (Miranda *et al.*, 2017), the NPV was negative, which is an indicator of the unfeasibility of carrying out the investment project, since it was lower to zero (Hanafizadeh & Latif, 2011; Žižlavský, 2014; Knoke *et al.*, 2020).

Therefore, the traditional economic valuations – which are based on deterministic values – undervalue investment projects, making them unviable (Fleten *et al.*, 2016). This occurs because these methods are insensitive to the stochastic volatility that is present in a decision analysis (Moon & Baran, 2018), which conditions more accurate descriptions of the return dynamics (Caporin *et al.*, 2017).

All scenarios that involved capturing managerial flexibility, were able to identify the uncertainty of the investment project and transform it into economic contributions, which increased the value to forest managers. It means that with the application of the ROA, it was possible to perceive the inference that forest managers exercise in the planning horizon of forest nurseries, and that in practice they are not accounted, since traditional techniques are limited and do not include such derivations.

Considering the scenarios with the incorporation of one option at a time, the option to abandon the investment project returned the largest expanded NPV, followed by the option to defer and, finally, to expand. The abandonment option was assumed to be the most valuable option, due to what was exposed by Guedes & Santos (2016) and Kim *et al.* (2017), that this option allows management to close investment projects in adverse scenarios, such as failures in any of the execution phases or falls in the price of forest seedlings, avoiding the total investment irreversibility.

Due to the configuration of the investment project for forest managers, the abandonment option was the only one considered as a pseudo-American option. According to Geske & Johnson (1984), from the perspective of unknown future value, the flexibility to determine them at any time for all future dates before expiration promotes the time dependence of the trajectory that separates the exercise region from the non-exercise region in order to maximize the value of the American put option.

The abandonment option is determinant for achieving the objective of reducing the risk of losses in companies, acting directly in the unprofitable phases of the projects (Copeland & Antikarov, 2005; Mintah *et al.*, 2018; Odetayo *et al.*, 2018). The right to exercise the option of abandonment is characterized as a put option on the value of the project, in which the exercise price is defined as the residual value of the assets and capital goods, discounting the costs inherent to the abandonment (Mei & Clutter, 2015; Cruz Rambaud & Sánchez Pérez, 2016).

By deferring the initial investment project in one year, one of the fundamental characteristics for a decision analysis was created. This means that forest managers - when undecided - were contemplated to leave options open, as a cautious conclusion until opportune later moment (Bhatia & Mullett, 2016; Gerasimou & Papi, 2018).

With the deferral option, the objective is to reduce uncertainty by acquiring new and better information about the market, with the intention that this information reduces the risk of the decision on the investment project (Brach, 2003; Padhy & Sahu, 2011). Therefore, postponing investment decisions is a possibility that creates a call option, in which managers have the right, but not the obligation, to execute the investment project at some future time, when positive market signals appear (Hubbard, 1994; Miller & Arikan, 2004; Cheng *et al.*, 2017). Otherwise, if future conditions are unfavorable, the manager will let the option expire and the project will not be implemented (Pringles *et al*., 2015).With the incorporation of the option to expand the productive capacity of the *Eucalyptus* forest seedling nursery, as well as with the other options, a corporate value was added; the investment was made viable since the capacity expansion model reflected the favorable market return (Hach *et al.*, 2016). Budget allocation can be optimized to increase the adjustment capacities of the productive sector, assuming an adequate cost function as a parameter (Chow & Regan, 2011; Masiero *et al.*, 2016).

In order to react to market conditions, the expansion option uses managerial flexibility to change the project's capacity (Brach, 2003) when the market presents better conditions than expected (Mei & Clutter, 2015; Olsson *et al.,* 2011). In ROA, expansion options are valued as call options and, together with options to abandon and defer, it is one of the most used real options in business (Agliardi, 2007; Cruz Rambaud & Sánchez Pérez, 2016).

According to Pizzirani *et al.* (2019) the best economic returns can be achieved by combining scenarios. Therefore, the scenario that reflected the largest expanded NPV was the one that concatenated the real options, due to the increased complexity of the system and, consequently, the increase in uncertainties in the investment project. Forest managers, especially those who work in seedling production nurseries, need to develop flexible systems and management practices to proactively deal with uncertainty, in order to more effectively manage and exercise their corporate real options (Ioulianou *et al.*, 2017).

In combined options, the exercise of one option leads to the gain of another option. According to Arasteh (2016), most sequential investments can be analyzed as combined options, since investing in one period gives the company the option to continue to the next period.

The result when considering the incorporation of different options in the same project at different times is not the same as when adding the results of the options separately. According to Bowe & Lee (2004) and Schachter & Mancarella (2016), interactions between options can be negative or positive and do not occur linearly depending on the types of options and exercise dates. Investments analysis based on real options are empirical tasks that need to be frequently tested to validate the predictions of the theory.

Conclusions

This study assesses the economic benefits associated with the incorporation of managerial flexibility in decision making by forest managers in nurseries producing *Eucalyptus* seedlings. Flexibility is assumed through the incorporation of three real options: deferral, expansion and abandonment. These options are related given the pre-established needs of forest managers in situations that require the undertaking of actions, since it is not possible to reach reasoned conclusions based on the calculation of the traditional net present value (NPV).

It is observed, for example, that through the traditional NPV, the conclusion that we would obtain is that the project for investment in nursery infrastructures to produce *Eucalyptus* forest seedlings is not feasible under the conditions of the study. However, by adding a minimum of flexibility to the decision-making process of forest managers, the viability of the investment project is achieved with the highest expanded NPV being equalized for the abandonment option, followed by deferral and then expansion. However, the best economic return can be achieved by concatenating the three real options into a single investment project.

This assessment clearly demonstrates the importance of strategically considering the real options of the investment project for management and, therefore, decision-making in a nursery to produce forest seedlings. In this way, the real options approach proved its potential as an ally of managers in the nursery forest sector, which demonstrates the importance of its use and diffusion in the practical environment as a more efficient alternative to traditional techniques.

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Authors' contributions

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