Forest plantations with *Toona ciliata*: impacts of the managerial flexibility on economic viability

Rafaele Almeida Munis[1]
Diego Aparecido Camargo[1]
Danilo Simões[1]

[1] São Paulo State University (UNESP)
School of Agriculture
Department of Forest Science,
Soils and Environment
Botucatu, 18610-034
Brazil

Auteur correspondant / Corresponding author:
Danilo SIMÕES -
danilo.simoes@unesp.br

Photo 1.
Plantation of *Toona ciliata* in Brazil.
Photo R. A. Munis.

Doi : 10.19182/bft2022.353.a36818 – Droit d'auteur © 2022, Bois et Forêts des Tropiques – © Cirad – Date de soumission : 21 novembre 2021 ; date d'acceptation : 23 février 2022 ; date de publication : 1er septembre 2022.

Citer l'article / To cite the article
Munis R. A., Camargo D. A., Simões D., 2022. Forest plantations with *Toona ciliata*: impacts of the managerial flexibility on economic viability. Bois et Forêts des Tropiques, 353: 31-41. Doi : https://doi.org/10.19182/bft2022.353.a36818

RÉSUMÉ

Plantations forestières de *Toona ciliata* : impacts de la gestion flexible sur leur viabilité économique

Les plantations forestières à *Toona ciliata* sont annoncées comme économiquement viables grâce à leur bois qui convient bien aux produits de niche de haute qualité. Cependant, cette étude vérifie si les projets d'investissement dans *T. ciliata* sont économiquement viables en y intégrant une gestion flexible. Nous avons appliqué les coefficients technico-économiques des plantations de *T. ciliata* sur un horizon de planification à 15 ans, en considérant le projet d'investissement comme un actif sous-jacent et le prix du bois comme la seule source d'incertitude. En utilisant la méthode de Monte-Carlo, nous avons modélisé l'incertitude pour obtenir la volatilité du projet, de sorte que, en appliquant la méthode des options réelles, la flexibilité de gestion pour le report, l'expansion et l'abandon s'ajoute aux actifs sous-jacents. En se basant sur la méthodologie traditionnelle d'évaluation économique, nous avons obtenu une valeur actuelle nette statique de 5 075 USD, ce qui indique la viabilité économique du projet d'investissement dans des plantations forestières à *T. ciliata*. En raison de l'incertitude liée aux prix du bois, la volatilité du projet s'établit à 131,7 %. Ensuite, il a été constaté que l'intégration des options de report et d'abandon ajoute une prime de 2 147 USD à la valeur du projet, le redirigeant vers une valeur nette actualisée accrue de 7 223 USD. L'intégration des options réelles de report et d'abandon apporte de la souplesse et une aide à la décision pour la gestion des plantations forestières à *T. ciliata*, ce qui se traduit par une augmentation de 42,3 % de la valeur du projet d'investissement.

Mots-clés : cèdre rouge d'Australie, arbre binomial, actif biologique, modélisation dynamique, investissement forestier, valeur nette actualisée, méthode des options réelles, volatilité.

ABSTRACT

Forest plantations with *Toona ciliata*: impacts of managerial flexibility on economic viability

Forest plantations with *Toona ciliata* are presented as economically viable thanks to the suitability of their wood for high-quality niche products. However, this study verifies whether investment projects in *T. ciliata* plantations are economically viable with the incorporation of managerial flexibility. We apply technical-economic coefficients from *T. ciliata* forest plantations over a 15-year planning horizon, considering the investment project as an underlying asset and the price of wood as the only source of uncertainty. Using the Monte Carlo method, we model uncertainty to obtain project volatility, so that, using the Real Option Approach, managerial flexibility for deferral, expansion and abandonment is added to the underlying assets. Based on the traditional economic valuation methodology, we obtained a static net present value of USD 5,075, which reflects the economic viability of the investment project in *T. ciliata* forest plantations. Due to the uncertainty arising from timber prices, project volatility was 131.7%. Afterwards, it was found that incorporating the deferral and abandonment options added a premium of USD 2,147 to the value of the project, redirecting it towards an expanded net present value of USD 7,223. Incorporation of the real deferral and abandonment options provides flexibility and support for the decision-making process in the management of *T. ciliata* forest plantations, resulting in a 42.3% increase in the value of the investment project.

Keywords: Australian cedar, binomial trees, biological asset, dynamic modelling, forest investment, Net Present Value, Real Option Approach, volatility.

RESUMEN

Plantaciones forestales con *Toona ciliata*: impacto de la flexibilidad de la gestión en su viabilidad económica

Las plantaciones forestales de *Toona ciliata* se presentan como económicamente viables gracias a la idoneidad de su madera para productos del nicho de mercado de alta calidad. Sin embargo, este estudio verifica si los proyectos de inversión en plantaciones de *T. ciliata* son económicamente viables con la incorporación de la flexibilidad de gestión. Aplicamos los coeficientes tecnicoeconómicos de las plantaciones forestales de *T. ciliata* en un horizonte de planificación de 15 años, considerando el proyecto de inversión como activo subyacente y el precio de la madera como única fuente de incertidumbre. Utilizando el método de Montecarlo, modelamos la incertidumbre para obtener la volatilidad del proyecto, de modo que, utilizando el método de las opciones reales, la flexibilidad de la gestión para el aplazamiento, la expansión y el abandono se añade a los activos subyacentes. Basándonos en la metodología de valoración económica tradicional, obtuvimos un valor actual neto estático de 5 075 USD, que refleja la viabilidad económica del proyecto de inversión en plantaciones forestales de *T. ciliata*. Debido a la incertidumbre derivada de los precios de la madera, la volatilidad del proyecto fue del 131,7 %. Posteriormente se comprobó que la incorporación de las opciones de aplazamiento y abandono añadía una prima de 2 147 USD al valor del proyecto, reorientándolo hacia un valor actual neto ampliado de 7 223 USD. La incorporación de las opciones de aplazamiento y abandono real proporciona flexibilidad y apoyo al proceso de toma de decisiones en la gestión de las plantaciones forestales de *T. ciliata*, lo que se traduce en un aumento del 42,3 % del valor del proyecto de inversión.

Palabras clave: Cedro australiano, árboles binomiales, activo biológico, modelización dinámica, inversión forestal, valor actual neto, método de las opciones reales, volatilidad.

Introduction

In addition to the performance physical and mechanical regarding the wood, the economic aspects must be measured and taken care of, to then define a genus or species for an investment project in planted forests. In Brazil, exotic genus usually stands out, such as *Eucalyptus* and *Pinus*. This genus, after the genetic enhancement, started to show rapid growth and meet physical, mechanical and, in some contexts, economic requirements of the industrial sector.

When quality, physical, and mechanical resistance is accentuated, species such as *Toona ciliata* are incorporated into the list. Native to Australia, *T. ciliata* is a hardwood with excellent workability and mechanical resistance, in addition, its appearance, texture and colour, make it preferable among artisans and furniture plant industries (Forrester, 2013; Li *et al.*, 2015; Castro *et al.*, 2016; Dejene *et al.*, 2017; España *et al.*, 2017).

Thus, as it moves towards intensive production, an understanding of investment and the uncertainties that affect the use of monetary capital becomes essential (Jongrungrot *et al.*, 2014; Rodrigues *et al.*, 2016; Holland, 2017; Mao *et al.*, 2021). Operating with flexible scenarios promotes forest managers primacy in risk management.

Photo 2.
Plantation of *Toona ciliata* in Brazil.
Photo R. A. Munis.

They support the discernment between the acceptance or rejection of the investment in *T. ciliata*. In this context of measuring risks and incorporating uncertainties, the Real Option Approach (ROA) promotes the required accuracy (Phillips and Wright, 2009; Khadka and Vacik, 2012; Lee *et al.*, 2013; Cui and Shibata, 2017; Favato and Vecchiato, 2017; Kozlova, 2017; Tang *et al.*, 2017). ROA emphasizes that many initial investments create relevant opportunities that provide managers, especially forestry, with opportunities, but not obligations to make subsequent investments (Liu and Ronn, 2020; Oh and Yoon, 2020).

Our hypothesis is to certify the economic viability of planted forests with *Toona ciliata*, according to traditional methods of evaluating investment projects, plus the prize for the implementation of managerial flexibility. In view of this, we verified whether investment projects in *T. ciliata* forests are economically viable, when incorporated managerial flexibility.

Material and Methods

Toona ciliata planted forests

With the observance of a planted forest of *T. ciliata* in Brazil, technical-economic coefficients were obtained, considering an area of one hectare, with 816 trees grown in spacing of 3.5 m × 3.5 m. A systematic thinning in the eighth year with the removal of 60% of the trees was considered, therefore, clear cut in the fifteenth year, with an average productivity during the useful life of the forest of 25 m^3/ha/year.

Cash flow from the planted forests investment project with *Toona ciliata*

Cash flow was projected over a 15-year time horizon, therefore, the clear-cut period of the forest. It was considered as unconventional cash flow, as it requires investments intrinsic to silvicultural tracts during this horizon, in addition to the investment necessary for the implantation of the forest at the project's focal date. Considering mechanized areas, the capital expenditure (CAPEX) for the implantation of the planted forest was USD/ha 3,384.

In the eighth year and in the last year after the forest was implanted, the costs of harvesting of wood were assumed. Still, as a non-disbursable cost, the remuneration for the use of the land was estimated, and to attend the investment project in planted forests with *T. ciliata*, administrative expenses were considered. In the years when harvesting of wood was carried out, biological assets were quantified and related to the rate of depletion, following the percentage of systematic thinning, to deduct federal taxes.

The investment project in planted forests with *T. ciliata* was classified as real profit, based on the annual gross revenue of USD 5,399, according to Brasil (1996). A tax rate of 5.0% of the Social Integration Programs and 4.6% of Social Security Financing Contribution were taxed on gross revenue. Were deducted from earnings before interest and Income Tax (IT) 9.0% of Social Contribution on Net Income and 15.0% of IT. Further details regarding direct and indirect costs in our study are provided in the supplementary materials (appendice tables S1 to S3).

Weighted average cost of capital rate

To estimate the minimum attractiveness rate of the investment project in planted forests with *T. ciliata*, discussed from the perspective of the opportunity cost, the weighted average cost of capital rate was estimated. The weighting between the cost of capital of owners and the cost of capital of creditors was estimated, according to equation 1, which was adapted from Brigham and Houston (2018).

$$WACC = K_e\, K_p\, (K_p + K_t)^{-1} + (1 - Ʈ)\, K_d\, K_t\, (K_t + K_p)^{-1} \quad (1)$$

where: $WACC$ is the weighted average cost of capital; K_e is the capital cost of shareholders; K_d is the capital cost of creditors; K_p is the participation of shareholder's capital; K_t is the capital participation of creditors; Ʈ is the corporate tax rate.

In estimating the expected return by creditors, the spread for default was estimated due to Brazil's speculative credit rating (BA2). Following the Capital Asset Pricing Model (CAPM) methodology the return demanded by the owners of the investment project in planted forests with *T. ciliata* (equation 2) was estimated.

$$K_e = R_f + \beta\,(R_m - R_f) + \omega_{br} \quad (2)$$

where: R_f is the risk-free rate; β is the systematic risk in the forestry sector; R_m is the expected return by the forest market; $(R_m - R_f)$ is the forest market risk premium; ω_{br} is the country risk premium.

The return required by shareholders at 9.1%, with a risk-free rate of 5.2%. We emphasize that the risk-free rate was based on the historical series provided by the United States Department of the Treasury, since 1962, with a maturity term of ten years.

In obtaining the systematic risk coefficient of the forestry market of 0.5, the return on shares traded at B3 S.A. - Brasil, Bolsa, Balcão (2021), by industries in the wood and cellulose segment, such as Dexco S.A., Eucatex S.A. Indústria e Comércio, Klabin S.A. e Suzano S.A., was considered. The IBOVESPA index was used as a benchmark, as it represents the Brazilian variable income market.

The market risk premium, was assumed as the S&P Global Timber & Forestry index, provided by S&P Dow Jones Indices (2021) for a period of 10 years, resulting in an annualized return of 4.9%. Like the risk-free rate, the 3.9% risk premium for Brazil was the geometric average of debt securities issued by emerging countries since 1994.

Discussed from the perspective of the opportunity cost for the investment project in planted forests with *T. ciliata*, the estimated return expected due to the weighting of the applied capital was 7.3%.

Static net present value

In ROA, one of the inputs of modeling is the static net present value (Brandão and Dyer, 2005). Thus, by updating the annual cash flows at the weighted average cost of capital rate, the static present value of the investment project in planted forests with *T. ciliata* was determined, which, associated with CAPEX, resulted in the net present value (NPV) static (equation 3).

$$NPV = \sum_{n=1}^{N} \frac{CF_t}{(1 + WACC)^t} - I_0$$

where: CF_t is the cash flow in year t; I_0 is the initial investment; n is the number of periods in the planning horizon.

Volatility of the investment project in planted forests with *Toona ciliata*

Corroborated by Cox, Ross and Rubinstein (1979), therefore, the assumption of the Cox-Ross-Rubinstein market model (CRR model), which assumes that the value of an underlying asset follows a process of diffusion of the Geometric Brownian Motion (GBM), the revenue from the commercialization of *T. ciliata* wood was attributed to the GBM distribution.

As we do not have a historical series with regular data on the price of *T. ciliata* wood, corroborated by Black and Scholes (1973) and Lajbcygier and Connor (1997), we assume the simplistic approach that the return of log prices follows a lognormal distribution. Like the authors, the objective was to explore the analytical tractability of the investment project, when uncertainty is modeled using Geometric Brownian Motion.

As advised by O'Hagan *et al.* (2006), Leal *et al.* (2007), Briggs *et al.* (2012), and Simões *et al.* (2018), based on the opinion of forestry experts, a volatility of 30.0% and a drift of 10.0%, both related to the behavior of the price of *T. ciliata* wood, were assumed. Consequently, the Monte Carlo method simulation was performed with 100,000 iterations, with the use of the @Risk Copyright © 2020 software (Palisade Corporation, 2021).

Still, according to Brandão *et al.* (2012), the volatility of the investment project in planted forests with *T. ciliata* was estimated through the standard deviation of the return sample (υ), obtained from the static present value conditioned to the expectations of the present values from the second to the fifteenth year (equation 4).

$$\upsilon = \ln\left[\frac{\sum_{n=2}^{N=15} \frac{CF_t}{(1 + WACC)^{t-1}}}{PV_0}\right]$$

where: PV_0 is the present value of the planted forest investment project with *T. ciliata* at the focal date.

Underlying assets' modeling

Because it allows estimating the real value of underlying assets, ROA was conducted primarily with basic asset models, that is, capot.

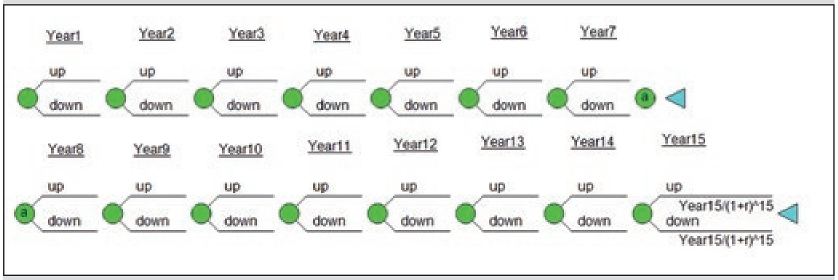

Figure 1.
Modeling of the underlying assets.

Using the DPL software (Syncopation, 2021), the project's volatility parameters (σ), risk-free rate (R_f), increment levels ($u = e^{\sigma}$) or decrease ($d = u^{-1}$ of the project value, risk-neutral probability ($p = (1 + r - d)/(u - d)$) and the complementary probability ($q = 1 - p$), were linked to the static present value (figure 1).

Binomial trees

Nodes, expressing decision of managerial flexibility, were incorporated into asset models, therefore, a binomial tree was generated (figure 2). At the end of the first year, the option of deciding by deferring the initial investment was considered, with the bonus of implementing the investment project in planted forests with *T. ciliata* under favorable conditions or, on the other hand, deciding to abandon it.

In the eighth year, the option to expand the initial area of the investment project in planted forests with *T. ciliata* with an expenditure of USD/ha 2,664 was incorporated by 30.0%. On the other hand, in the same period, under unfavorable conditions, the possibility of abandoning it to the bonus of USD/ha 3,384 was considered, or else, proceeding without incorporating the decision of managerial flexibility.

The risk-free rate was replaced by the risk-adjusted rate of the investment project in planted forests with *T. ciliata* and the probabilities of the occurrence of the related options were estimated. With the return of the expanded net present value, the static net present value was discounted, and the options' premium was obtained, in line with Monjas-Barroso and Balibrea-Iniesta (2013).

Results

The static net present value was USD/ha 5,075. To measure the compensation for incorporating options into the planning horizon of an investment project, it is necessary to capture the volatility of the project. The standard deviation of the return of the present value conditioned to the expectations of the present values from the second to the fifteenth year allowed the inference of an oscillation of 131.7%.

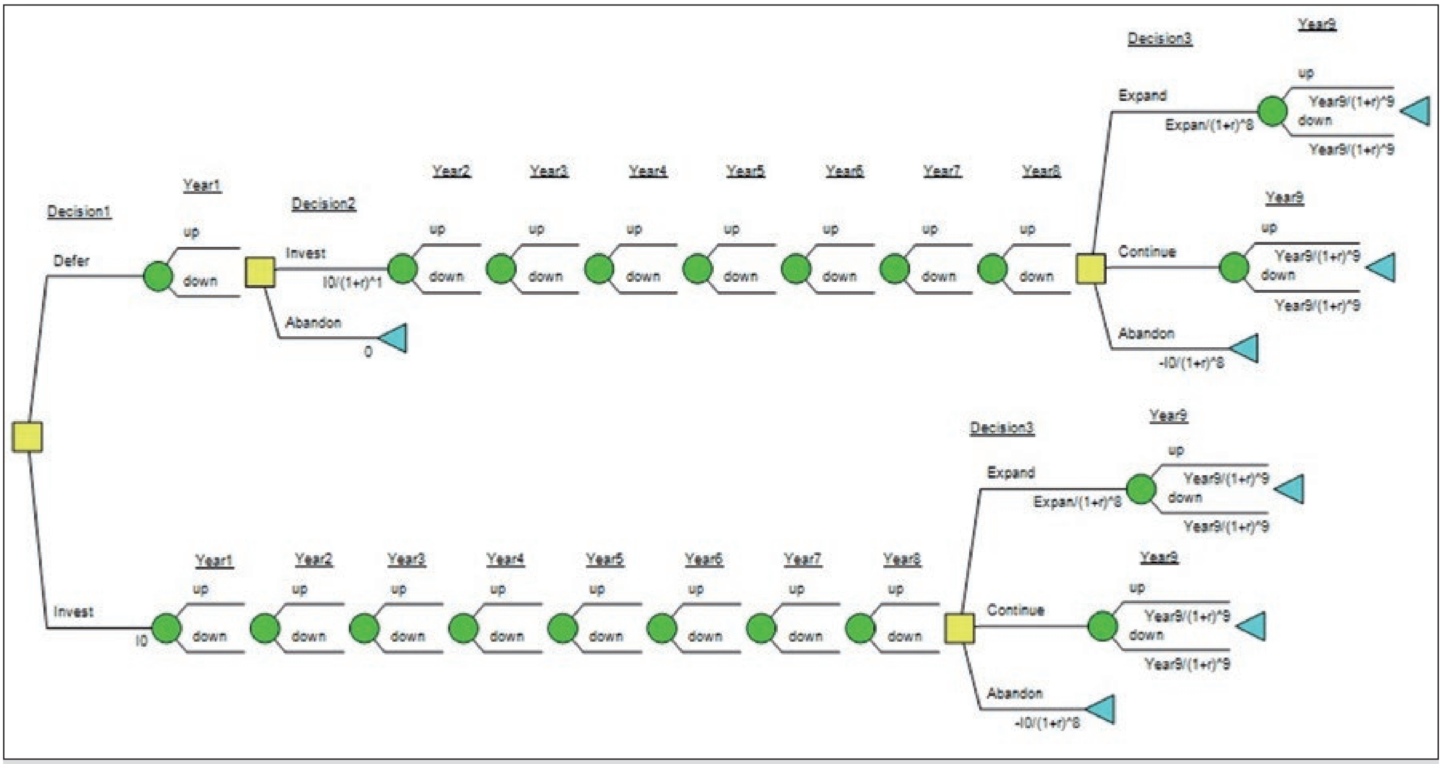

Figure 2.
Binomial trees with the incorporation of real options.

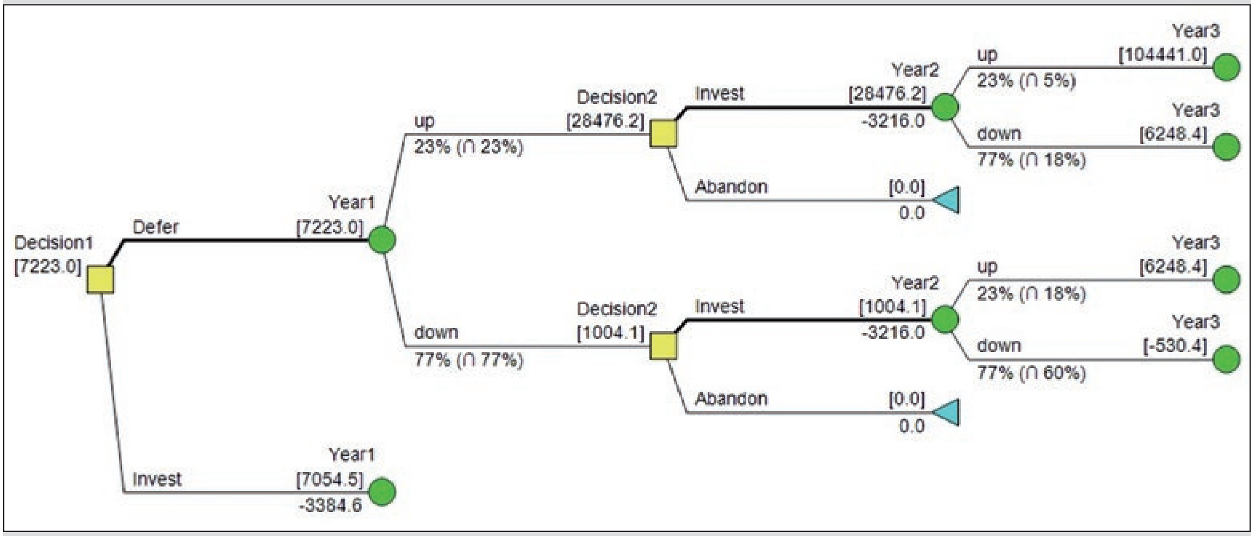

Figure 3.
Optimal policy tree.

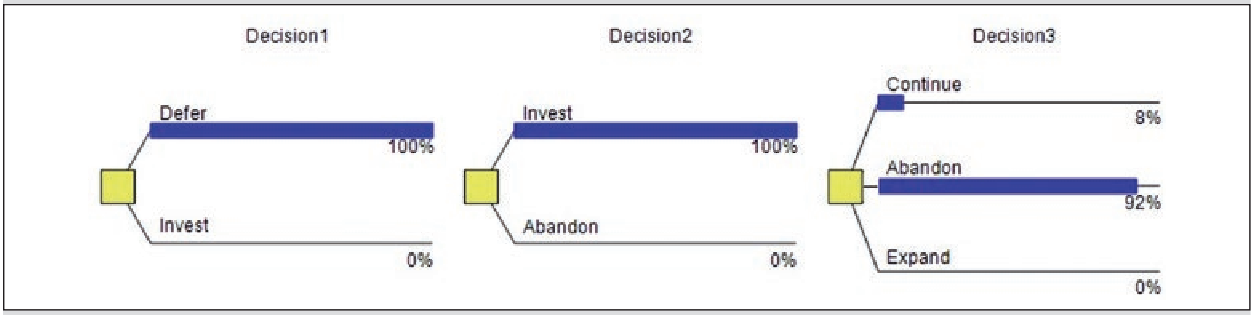

Figure 4.
Probabilities of occurrence of the combined options.

After incorporating volatility and decision of managerial flexibility, into the underlying assets, an expanded net present value of USD/ha 7,223 was estimated (figure 3). Accordingly, the difference shows a premium of USD/ha 2,147 for options weighted together.

The notoriety of the impact of the options on the investment project in planted forests with *T. ciliata*, is reflected in its probabilities of occurrence (figure 4). The deferral was assumed in 100.0% of the scenarios. On the other hand, the expansion resulted in 0.0% of the odds diverging from 92.0% abandonment and 8.0% continuity.

Discussion

From an economic point of view, obtaining a static net present value greater than zero resulted in the economic viability of the investment project in planted forests with *T. ciliata*, as highlighted by Torres and Fullana (2019). According to Runsheng (2001), the conventional forest investment assessment has difficulty dealing with multiple decisions and capturing the operational flexibility involved in timber production.

Compared to other investment possibilities, its potential can be underestimated, which requires alignment of the companies' investment strategy to the environments in which they find themselves, as corroborated by Soda and Furlotti (2017). With ROA and acting in order to maximize the value of an investment project, it was possible to expose the scope that decision of managerial flexibility provided in monetary form.

The ROA revealed the expectation of the future value, as approached by Runsheng and Newman (1996) and Tiwana *et al.* (2007). The volatility expressed the variation that the investment project in planted forests with *T. ciliata*, free of decision of managerial flexibility, suffered over time.

According to Moon and Baran (2018), volatility is an essential property in asset models. In this study, volatility was introduced to represent the change in revenue generated after cutting the planted forests with *T. ciliata*. Volatility was represented through the statistical standard deviation of a sequence of simulations of possible scenarios for the evolution of the investment project from the generated revenue.

According to Luan *et al.* (2019), the larger the sample of simulation performed, the results become increasingly more reliable. This result is consistent with the law of large numbers (Hastings, 1970), also observed in the study by Caporin *et al.* (2017) and Miranda *et al.* (2017).

It should be noted that investment projects in planted forests with *T. ciliata* reflect its economic viability, as pointed out by Dordel *et al.* (2010). Biological assets have synergies between price estimates with environmental conditions and are therefore affected by several other factors, such as those studied by Pirovani *et al.* (2018) and Nohro and Jayakumar (2020). It was explained how the decision of managerial flexibility could express the monetary reach of the value of investment projects in planted forests with *T. ciliata*, after the uncertainties were captured as volatility.

However, the standard deviation, which can be considered high (USD 39.562), was obtained from the Monte Carlo simulation and led to high volatility (131.7%). The volatility indicated the uncertainty produced through the returns of the static present values conditioned to the present values of the second to the fifteenth year of the investment project in planted forests with *T. ciliata*.

This volatility approach produced an inflated number, as corroborated by Smith (2005). However, Nicholls *et al.* (2015) found from different methods that the volatility of the project is always significantly higher than the volatility of the source of uncertainty, which is the main limitation of ROA.

Conclusion

Investment projects in planted forests with *Toona ciliata* are economically viable and with the Real Option Approach, there is an increase of 42.3% in the value of the investment project, resulting exclusively from managerial flexibility.

The incorporation of the real deferral and abandonment options gives investment projects flexibility, supporting the decision-making process for managing planted forests with *T. ciliata.*

Relating the real options of deferral, expansion and abandonment as managerial flexibility decisions makes it possible to increase the net present value of the investment project by simulating the strategy that the forest manager naturally exercises over the planned horizon.

Acknowledgment
The authors thank the company Bela Vista and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data access
Our data can be accessed at:
Munis, Rafaele Almeida; Camargo, Diego Aparecido; Simões, Danilo, 2022. Cash Flow Components. Demo Dataverse, V1. Available in: https://demo.dataverse.org/file.xhtml?persistentId=doi:10.70122/FK2/OVQHBD/EQUGCM&version=2.0.

Conflict of Interest
The authors declare that they have no conflict of interest.

References

Brasil, 1996. Constitution. Law N° 9.430, of December 27, 1996. Lex: Federal Tax Legislation. Brasília, Presidência da República, Casa Civil, Subchefia para Assuntos Jurídicos. http://www.planalto.gov.br/ccivil_03/LEIS/L9430.htm

B3 S.A. - Brasil Bolsa Balcão, 2021. Cotações históricas. [B3 S.A.]

Black F., Scholes M., 1973. The pricing of options and corporate liabilities. Chicago Journals, 81: 637-654. [JSTOR]

Brandão L. E., Dyer J. S., 2005. Decision Analysis and Real Options: A Discrete Time Approach to Real Option Valuation. Annals of Operations Research, 135: 21-39. [Crossref]

Brandão L. E., Dyer J. S., Hahn W. J., 2012. Volatility estimation for stochastic project value models. European Journal of Operational Research, 220: 642-648. [Crossref]

Briggs A. H., Weinstein M. C., Fenwick E. A. L., Karnon J., Sculpher M. J., Paltiel D., 2012. Model Parameter Estimation and Uncertainty: A Report of the ISPOR-SMDM Modeling Good Research Practices Task Force-6. Value in Health, 15: 835-842. [Crossref]

Brigham E. F., Houston J. F., 2018. Fundamentals of Financial Management. Boston, MA, USA, Cengage Learning, 832 p.

Caporin M., Rossi E., Magistris P. S., 2017. Chasing volatility: A persistent multiplicative error model with jumps. Journal of Econometrics, 198: 122-145. [Crossref]

Castro C. A. O., Resende R. T., Bhering L. L., Cruz C. D., 2016. Brief history of *Eucalyptus* breeding in Brazil under perspective of biometric advances. Ciência Rural, 46: 1585-1593. [Crossref]

Cox J. C., Ross S. A., Rubinstein M., 1979. Option pricing: a simplified approach. Journal of Financial Economics, 7: 229-263. [Crossref]

Cui X., Shibata T., 2017. Investment strategies, reversibility, and asymmetric information. European Journal of Operational Research, 263: 1109-1122. [Crossref]

Dejene T., Rueda J. A. O., Pinto P. M., 2017. Fungal diversity and succession under *Eucalyptus grandis* plantations in Ethiopia. Forest Ecology and Management, 405: 179-187. [Crossref]

Dordel J., Simard S. W., Bauhus J., Seely B., Pozas L. J., Prescott C., *et al.*, 2010. Trade-offs among establishment success, stem morphology and productivity of underplanted *Toona ciliata*: Effects of nurse-species and thinning density. Forest Ecology and Management, 259: 1846-1855. [Crossref]

España M. D., Arboleda J. W., Ribeiro J. A., Abdelnur P. V., Guzman J. D., 2017. *Eucalyptus* leaf byproduct inhibits the anthracnose-causing fungus Colletotrichum gloeosporioides. Industrial Crops & Products, 108: 793-797. [Crossref]

Favato G., Vecchiato R., 2017. Embedding real options in scenario planning: A new methodological approach. Technological Forecasting & Social Change, 124: 135-149. [Crossref]

Forrester D. I., 2013. Growth responses to thinning, pruning and fertiliser application in *Eucalyptus* plantations: A review of their production ecology and interactions. Forest Ecology and Management, 310: 336-347. [Crossref]

Hastings W. K., 1970. Monte Carlo sampling methods using Markov chains and their applications. Biometrika, 57: 97-109. [Crossref]

Holland S. B., 2017. Firm investment in human health capital. Journal of Corporate Finance, 46: 374-390. [Crossref]

Jongrungrot V., Thungwa S., Snoeck D., 2014. Tree-crop diversification in rubber plantations to diversify sources of income for small-scale rubber farmers in Southern Thailand. Bois et Forêts des Tropiques, 321 (3): 21-32. [Crossref]

Khadka C., Vacik H., 2012. Use of multi-criteria analysis (MCA) for supporting community forest management. iForest - Biogeosciences and Forestry, 5: 60-71. [Crossref]

Kozlova M., 2017. Real option valuation in renewable energy literature: Research focus, trends and design. Renewable and Sustainable Energy Reviews, 80: 180-196. [Crossref]

Lajbcygier P. R., Connor J. T., 1997. Improved Option Pricing Using. International Journal of Neural Systems, 8: 457-471. [Crossref]

Leal J., Wordsworth S., Legood R., Blair E., 2007. Eliciting expert opinion for economic Models: An applied example. Value in Health, 10: 195-203. [Crossref]

Lee H., Park T., Kim B., Kim K., Kim H., 2013. A real option-based model for promoting sustainable energy projects under the clean development mechanism. Energy Policy, 54: 360-368. [Crossref]

Li P., Zhan X., Que Q., Qu W., Liu M., Ouyang K., *et al.*, 2015. Genetic Diversity and Population Structure of *Toona Ciliata* Roem. Based on Sequence-Related Amplified Polymorphism (SRAP) Markers. Forests, 6 (4): 1094-1106. [Crossref]

Liu X., Ronn E. I., 2020. Using the Binomial Model for the Valuation of Real Options in Computing Optimal Subsidies for Chinese Renewable Energy Investments. Energy Economics, 87. [Crossref]

Luan S., Chen X., Su, Y., Dong Z., Ma X., 2019. Modeling travel time volatility using copula-based Monte Carlo simulation method for probabilistic traffic prediction. Transportmetrica A: Transport Science, 18: 54-77. [Crossref]

Mao W., Song H., Li Y., Wang Y., Lin H., Yao C., *et al.*, 2021. Efficient plant regeneration and genetic transformation system of the precious fast-growing tree *Toona ciliata*. Industrial Crops and Products, 172: 114015. [Crossref]

Miranda O. R., Brandão L. E., Lazo J. G. L., 2017. A dynamic model for valuing flexible mining exploration projects under uncertainty. Resources Policy, 52: 393-404. [Crossref]

Monjas-Barroso M., Balibrea-Iniesta J., 2013. Valuation of projects for power generation with renewable energy: A comparative study based on real regulatory options. Energy Policy, 55: 335-352. [Crossref]

Moon Y., Baran M., 2018. Economic analysis of a residential PV system from the timing perspective: A real option model. Renewable Energy, 125: 783-795. [Crossref]

Nicholls G. M., Lewis N. A., Zhang L., Jiang Z., 2015. Breakeven Volatility for Real Option Valuation. Engineering Management Journal, 26: 49-61. [Crossref]

Nohro S., Jayakumar S., 2020. Tree species diversity and composition of the Pala Wetland Reserve Forest, Mizoram, Indo-Burma hotspot, India. Biocatalysis and Agricultural Biotechnology, 23. [Crossref]

O'Hagan A., Buck C. E., Daneshkhah A., Eiser J. R., Garthwaite P. H., Jenkinson D. J., *et al.*, 2006. Uncertain Judgements: Eliciting Experts' Probabilities. Wiley, 340 p. [Crossref]

Oh H., Yoon C., 2020. Time to build and the real-options channel of residential investment. Journal of Financial Economics, 135: 255-269. [Crossref]

Palisade Corporation, 2021. @Risk. Newfield: Palisade Corporation. version 7.5. Palisade, website. [Palisade]

Phillips P. A., Wright C., 2009. E-business's impact on organizational flexibility. Journal of Business Research, 62: 1071-1080. [Crossref]

Pirovani D. B., Pezzopane J. E. M., Xavier A. C., Pezzopane J. R. M., Jesus Júnior W. C., Machuca M. A. H., *et al.*, 2018. Climate change impacts on the aptitude area of forest species. Ecological Indicators, 95: 405-416. [Crossref]

Rodrigues L. C. A., Castro E. M., Pereira F. J., Maluleque I. F., Barbosa J. P. R. A. D., Rosado S. C. S., 2016. Effects of paclobutrazol on leaf anatomy and gas exchange of *Toona ciliata* clones. Australian Forestry, 79: 241-247. [Crossref]

Runsheng Y., 2001. Combining Forest-Level Analysis with Options Valuation Approach: A New Perspective for Forestry Investment Assessment. Forest Science, 47, 4: 475-483. [ResearchGate]

Runsheng Y., Newman D. H. 1996. A Timber Producer's Entry, Exit, and Other Decisions under Market Uncertainty. Journal of Forest Economics, 5 (2): 305-320.

Simões D., Dinardi A. J., Silva M. R., 2018. Investment Uncertainty Analysis in *Eucalyptus* Bole Biomass Production in Brazil. Forests, 9: 384-397. [Crossref]

S&P Dow Jones indices, 2021. S&P Global Timber & Forestry Index – Overview. S&P Dow Jones indices, website. [S&P Dow Jones indices]

Smith J. E., 2005. Alternative approaches for solving real-options problems. Decision Analysis, 2 (2): 89-102. [Crossref]

Soda G., Furlotti M., 2017. Bringing Tasks Back In: An Organizational Theory of Resource Complementarity and Partner Selection. Journal of Management, 43: 348-375. [Crossref]

Syncopation software, 2021. DPL – Decision Programming Language. Syncopation Software. Version 9.00. [Syncoptation]

Tang B. J., Zhou H. L., Chen H., Wang K., Cao H., 2017. Investment opportunity in China's overseas oil project: An empirical analysis based on real option approach. Energy Policy, 105: 17-26. [Crossref]

Tiwana A., Wang J., Keil M., Ahluwalia P., 2007. The bounded rationality bias in managerial valuation of real options: Theory and evidence from IT projects. Decision Sciences, 38: 157-181. [Crossref]

Torres I. L., Fullana C. B., 2019. Dimensionless numbers for the net present value and the perpetual value of sustainable timber harvests from a monospecific uneven-aged forest. iForest - Biogeosciences and Forestry, 12: 35-42. [Crossref]

Munis *et al.* – Author's contributions

Contributor role	Contributor names
Conceptualization	D. Simões
Data Curation	R. A. Munis
Formal Analysis	D. A. Camargo
Investigation	D. A. Camargo, R. A. Munis
Methodology	D. A. Camargo
Resources	D. A. Camargo, R. A. Munis
Supervision	D. Simões
Validation	D. Simões, R. A. Munis
Visualization	D. Simões, R. A. Munis
Writing – Original Draft Preparation	D. A. Camargo, R. A. Munis
Writing – Review & Editing	D. A. Camargo, R. A. Munis

Cirad - Campus international de Baillarguet,
34398 Montpellier Cedex 5, France
Contact : bft@cirad.fr - ISSN : L-0006-579X

Appendice 1.
Tables of direct and indirect costs.

S1.

Deterministic assumptions	Value
Average unleveraged beta	0.36
Current liabilities	819 124.0
Non-current liabilities	381 200.0
Onerous liabilities	1 200 324.0
Total assets	2 651 952.0
The proportion of debt financed assets	45.26%
The proportion of the asset financed by the owners	54.74%
Tax levied (Income Tax + Social Contribution on Net Income)	34.00%
Beta leverage	1.30
Beta re-leveraged	0.47
r_f is the rate of return on a risk-free asset (10-year rate on Treasury bonds)	5.24%
r_m is the expected rate of return for the market portfolio (S&P Global Timber and Forestry Index - 10 years)	4.90%
α_{Br} - country risk premium (Emerging Markets Bonds Index - EMBI+Br)	3.99%
$(r_m - r_f)$ is the premium for risk in the market	-0.34%
K_s is the cost of ordinary capital	9.07%
Spread (BA2)	2.65%
k_b is the creditor's cost of capital	7.89%
WACC	7.32%

Bois et Forêts des Tropiques – ISSN: L-0006-579X
Volume 353 – 3rd quarter – October 2022 – p. 31-41

S2.

Cash Flow Components	Unit	Year of occurrence	Values
Planted area	ha	-	1.00
Spacing - 3,5m x 3,5m	m	-	12.25
Total individuals	ha	0	816
Thinning	-	8	510
Clear cut	-	15	306
Recipe - Thinning	USD	8	11 497.08
Recipe - Clear cut	USD	15	68 503.45
Investment - acquisition of the 1 ha	USD/ha	0	3 384.56
Investment in deployment and maintenance	USD/ha	1	2 403.61
Investment in deployment and maintenance	USD/ha	2	777.80
Investment in deployment and maintenance	USD/ha	3	445.20
Investment in deployment and maintenance	USD/ha	4	510.29
Investment in deployment and maintenance	USD/ha	5	299.40
Investment in deployment and maintenance	USD/ha	6	348.87
Investment in deployment and maintenance	USD/ha	7	361.89
Investment in deployment and maintenance	USD/ha	8	348.87
Investment in deployment and maintenance	USD/ha	9	195.26
Investment in deployment and maintenance	USD/ha	10	244.73
Investment in deployment and maintenance	USD/ha	11	257.75
Investment in deployment and maintenance	USD/ha	12	244.73
Investment in deployment and maintenance	USD/ha	13	244.73
Investment in deployment and maintenance	USD/ha	14	195.26
Investment in deployment and maintenance	USD/ha	15	7 029.39
Timber Harvesting cost	USD/ha	8	937.26
Timber Harvesting cost	USD/ha	15	4 061.47
Remuneration for the use of land	USD/ha	1 at 15	247.77
Administrative costs	USD/ha	1 at 15	15.62
Exhaustion	%	8	62.48%
Exhaustion	%	15	37.49%
Tax rate: Social Integration Programs and Social Security Financing Contribution	%	5	9.64%
Tax levied (Income Tax + Social Contribution on Net Income)	%	1 at 15	34.00%

S3.

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Operating income	-	-	-	-	-	-	-	-	11 497.08	-	-	-	-	-	-	68 503.45
Deductions	-	-	-	-	-	-	-	-	(1 108.32)	-	-	-	-	-	-	(6 603.73)
Timber Harvesting cost			-						(937.26)							(4 061.47)
Liquid revenue of sales	-	-	-	-	-	-	-	-	9 451.50	-	-	-	-	-	-	57 838.25
Administrative costs	-	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)	(15.62)
Remuneration for the use of land	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	(247.77)	
EBITDA	**-**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**9 188.11**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**57 574.85**
Exhaustion	-	-	-	-	-	-	-	-	(3 433.58)	-	-	-	-	-	-	(5 026.96)
EBIT	**-**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**5 754.53**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**52 547.90**
Tax levied	-	-	-	-	-	-	-	-	(1 956.54)	-	-	-	-	-	-	(17 866.29)
Net Operating Profit After Taxes	**-**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**3 797.99**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**(263.39)**	**34 681.61**
Exhaustion	-	-	-	-	-	-	-	-	3 433.58	-	-	-	-	-	-	5 026.96
Remuneration for the use of land	-	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77	247.77
Investments	(3 384.56)	(2 403.61)	(777.80)	(445.20)	(510.29)	(299.40)	(348.87)	(361.89)	(1 286.13)	(195.26)	(244.73)	(257.75)	(244.73)	(244.73)	(195.26)	(11 090.86)
Free Cash Flow	**(3 384.56)**	**(2 419.23)**	**(793.42)**	**(460.82)**	**(525.91)**	**(315.02)**	**(364.49)**	**(377.51)**	**6 193.21**	**(210.88)**	**(260.35)**	**(273.37)**	**(260.35)**	**(260.35)**	**(210.88)**	**28 865.49**
Deterministic Results																
Present Value	8 460.11															
Net Present Value	5 075.56															