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Forest management decision making based on a real options approach: An application to a case in northeastern Argentina

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Abstract. The Net Present Value (NPV) approach is widely applied to assess forest investments, but this method has serious shortcomings, which we propose to overcome by switching to the assessment through the Real Options Approach (ROA). The model in this paper starts with the simulation of the forest's growth, combined with the projection of the products' prices and valuing the assets using a binomial model. We include an option of postponement, determining the optimal period of felling. We find that ROA is more robust than the NPV approach because it relaxes the assumption of constancy of both the prices and the discount rate, allowing the determination of the optimal time of felling based on the growth rate of either the forest or the prices of its products. Contrary to the traditional NPV approach, the results obtained with ROA exhibit longer harvest turns and consequently higher profits. The key variable in the ROA, the Real Option Value (ROV) can be shown to be less (albeit moderately) sensitive to decreases of the discount rate than NPV. Moreover, ROV is moderately sensitive to decreases in the price of logs and is negligibly affected by rises in the costs of harvesting, loading and transporting rolls.

Key words: real options, binomial model, binomial tree.

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Introduction

The optimal time of felling, i.e. the turn of a plantation, can be determined according to different criteria. For instance, the *biological rotation age* maximizes the volume of production, indicating that stands should be harvested at their highest. On the other hand, the *technical rotation age* prescribes harvesting only when trees have reached certain dimensions that best meet the demands of the markets of final products. Finally, the *economic rotation* criterion determines the turn in terms of the period at which revenue reaches its maximum level (Bettinger *et al.*, 2009). Since the usual motivation for commercial forestry is commercial, any decision has to consider the

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yields of capital as well as the time value of money. Because of this, the economic rotation criterion tends to prevail in the sector. However, analyzing forest investments in this light is complicated by the extension of the planning horizon and the uncertainty related to macroeconomic variables, in particular in highly volatile countries like Argentina (Broz *et al*., 2018). One of the classical approaches in this line is Net Present Valuation (NPV), which is by far the most popular way of implementing the economic criterion. Other classical methods involve the computation of the Internal Rate of Return (IRR) and the Land Value Potential (LVP) of forestry projects. In particular, NPV has been criticized for not reflecting the breadth of economic considerations relevant for decision-making about private land use (Yemshanov *et al*., 2015). Besides, Yin (2001), Milanesi *et al*. (2012) and Broz *et al*. (2014) have shown that NPV fails to capture strategic flexibility in the cases where multiple decisions have to be made. Peltola & Knapp (2001) restrict the applicability of NPV to cases in which risk-neutral rates can be assumed. But in real-world applications, this model works with adjusted-per-risk rates specific for each case and constant for the periods under analysis. Furthermore, past behavior of prices is not considered, being replaced by unrealistic static prescriptions (Milanesi *et al*., 2012; Broz *et al*., 2014).

Unlike classical methods, the Real Options Approach (ROA) considers the strategic flexibility of projects, evaluating potential alternatives (postponement, giving-up, expansion, fusion, *etc*.). Furthermore, it considers contingencies, unlike the deterministic NPV, that only takes into account the profit obtained from the current investment independently of any future events. The Black-Merton-Scholes model (Black & Scholes, 1973; Merton, 1973) provides a well-established foundation to the valuation of options. Originally expressed in the formalism of stochastic differential equations it has been extended to cover, among others, discrete-time applications with simpler stochastic structures. In the latter case, binomial models represent decision-making in most of the ROA applications (Trigeorgis, 1995; Mun, 2002). So, the representation can be simplified to be captured in grids or trees (Brandão *et al*., 2005; Smith, 2005), using either objective or implicit probabilities (Rubinstein, 1994).

In the forest sector, Thomson (1992) and Yin & Newman (1997) studied the optimal time of felling assuming that prices follow a Geometric Brownian process. Platinga (1998) suggested the use of ROV introducing the concept of a premium on the postponement of the harvest date to be compensated by better market prices. Sant'Anna & Nogueira (2010) also recommend ROA for the evaluation of forest projects given its higher realism, since NPV assumes a constant discount rate all along the entire life of the project. Petrasek & Perez-Garcia (2010) assess timber harvesting contracts in a ROA model through Monte Carlo simulations, assuming stochastic prices of wood, harvest flexibility, and the existence of enforceable penalties. Milanesi *et al*. (2012) and Broz *et al*. (2014) present ROA models in which sale prices follow a Geometric Brownian stochastic process and the harvesting decision is made by comparing, at each period, the cash flows at the corresponding nodes of the binomial grid. Yemshanova *et al*. (2015) evaluate changes in land use combining both methods, ROA and NPV. Manley (2013) applied the ROA to the derivation of an emissions trading scheme, concluding that for a planning horizon of 10 to 20 years, taking only into account the price of rolls, ROA improves over Faustmann's model up to a 3 to 7%. If also the value of carbon is included the improvement reaches 27–28%.

One of the main issues in the application of NPV is that the discount rate may not be precisely established. It is usually estimated qualitatively, taking into account different pieces of information, like the opportunity cost of the investment, the risk of the project, the cost of money as well as opinions of different experts. A more precise alternative for the estimation of the adjusted-per-risk rate is the Capital Asset Pricing Model (CAMP), the basis of modern portfolio theory (Fama & French, 2004). Forestry applications of this method can be found in Yao & Mei (2015), Broz *et al*. (2014), Milanesi *et al*. (2012) and Sun & Zhang (2001).

In this work, we extend and improve over some of these previous results. We present a ROA model in which optimal harvesting dates are evaluated based on the risk associated to a portfolio of prices of subproducts subject to stochastic variations. The evaluation is performed on a binomial tree against a risk free investment. These features distinguish our contribution from others in the literature (Yin & Newman, 1997; Duku-Kaakyire & Nanang, 2004; Yemshanov *et al*., 2015, Yao & Mei, 2015). The model is applied to the case of a forest project in Argentina in which sale prices fall while harvest costs rise.

Material and Methods

Forest scenario

We consider a private plantation of *Pinus taeda* L. in northeastern Argentina. We simulate its growth with SisPinus® (Oliveira, 2011) for a range of ages from 6 to 34 years with an initial density of 1,600 trees per hectare and 95% chances of survival. The site index is 22 meters. We consider 2 thinning treatments (on 8 and 10 years old trees) extracting 50% of the population in each intervention, i.e. 149.9 and 182.4 m^3/ha respectively. The first thinning is systematic (line 5 is harvested) and selective (the dominated and bifurcated trees are harvested) and the second thinning is selective. The mean annual increment (MAI) ranges from 9.7 to 20.0 m^3/ha/year. The diameters correspond to the four types demanded by industries in the region: pulpwood (5–15 cm), sawlog -small diameter- (15–20 cm), sawlog -large diameter- (20–30 cm) and veneer log (> 30 cm). The prices in factory (at an average distance of 60 km) – as reported by the local professional association of forest engineers (COIFORM, 2017) – are USD 22.3/t for pulpwood, USD 33.9/t for sawlog -small diameter-, USD 36.1/t for sawlog -large diameter-, and USD 49.3/t for veneer log.

Real Options Approach

A ROA model, with a binomial continuous stochastic process, can be simplified and modeled as a discrete stochastic process. Some requirements need to be fulfilled: 1) the price of the asset S varies at discrete time periods determined by time intervals Δt, $2\Delta t$, $3\Delta t$,…, up to $N\Delta t = T$; 2) if the price of the asset is S^n at $n\Delta t$, then at $(n + 1)\Delta t$ it can only adopt two possible values: $uS^n > S^n$ or $dS^n < S^n$, where u and d are the rise and fall factors, with $0 < d < 1 < u$; 3) u and d are the same for the whole planning horizon; and 4) the probability of a rise and a fall of S are p and $1 – p$ respectively (Trifonov *et al*., 2013). In our setting, some straightforward adaptations ensure that these conditions are fulfilled. So, for instance, 4) implies that the case in which prices remain the same from a period to the next is omitted. In highly volatile context, like the Argentinean, this is an acceptable simplification.

The process starts with the definition of the initial value of the underlying asset S_0. Then the planning horizon T is divided in N steps of length $\Delta t = T/N$. In the first stage, two possible future values are obtained, uS_0 with probability $P(S_1 = s_1^u | S_0 = s_0) = p$ and dS_0 with a probability of $P(S_1 = s_1^d | S_0 = s_0) = (1 – p)$. In a second stage, three possible prices are obtained: u^2S_0, udS_0 and d^2S_0 (Figure 1), and so on until the step N. Bayram & Ganikhodjaev (2013) defined (u, d) as the environment of the binomial tree.

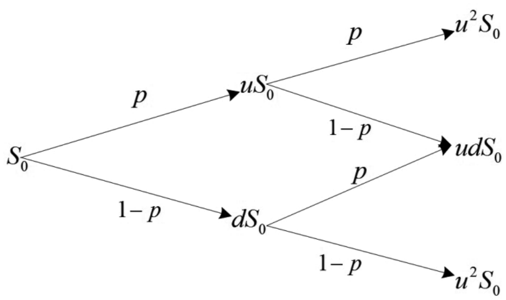

Figure 1. Up and down movement in the binomial tree for n = 2

In our case the underlying asset is the market value of harvesting the forest, which is determined up from the prices of its subproducts. The average and the variability of the prices of subproducts can be obtained applying methods of Modern Portfolio Theory (Markowitz, 1991). So, equation (1) yields the average.

$$P_0 = \sum_i^n x_i P_i \tag{1}$$

Where P_i represents the price of each subproduct i (veneer log, sawlog of both small and large diameter and pulpwood) and x_i the proportion of i in the total production, both at t=0. In turn, the risk associated to this portfolio (σ_c) is given by equation (2), using the historical series of prices:

$$\sigma_c = \sum_{i=1;j=1}^{n} x_i^2\sigma_i^2 + x_j^2\sigma_j^2 + 2(x_i x_j)\rho_{ij}\sigma_i\sigma_j \tag{2}$$

Where x_i y x_j are the participations of two different subproducts in total production; σ_i^2 y σ_j^2 are the variances of their corresponding prices (being σ_i y σ_j their corresponding standard deviation). Finally ρ_{ij} is the correlation coefficient between those prices. The cash flow at period t (FF_t) is calculated with equation (3):

$$FF_t = [P_0 \times vol_t] \times (1 - C_t) \times (1 - I) \tag{3}$$

Where vol_t is the expected production, obtained from simulations run with SisPinus, is the ratio of the fixed and variable production cost over the amount of sales and I is the marginal rate of Income Tax (in Argentina, 35%).

To calculate the adjusted-per-risk rate (k) we use equation (4), where rm is the additional per market risk, which we assume to be 10.94% (the historical average inflation rate in Argentina), σ_c is the risk associated to this portfolio and Δt is again T/n.

$$k = rm \times \left(1 + \sigma_c\sqrt{\Delta t}\right) \tag{4}$$

In equation (5), k is used to calculate the NPV.

$$NPV_t = FF_t \times e^{-kt} \tag{5}$$

To compute the input values for these equations we assume that the prices follow a Geometric Brownian stochastic process. The binomial grid is obtained up from the parameters of the CRR model, i.e. the prices of the underlying assets, the transition probabilities p and (1-p) as well as the objective increase/decrease probabilities q and (1-q) (Cox *et al.*, 1979). The up and down price's movements, u and d, are defined according to equations (6) and (7) (Bayram & Ganikhodjaev, 2013) while the prices of i and j at t at each node (ij) of the grid is generated through equation (8). Thus, the price at each node at t is determined up from the price at the same node at t-1 times f, where f is either u or d.

$$u = e^{\sigma_c\sqrt{\Delta t}} \tag{6}$$
$$d = e^{-\sigma_c\sqrt{\Delta t}} \tag{7}$$
$$P_{ij(t)} = \left[P_{i(t-1)} \times f;\ P_{j(t-1)} \times f\right] \tag{8}$$

Once the prices have been projected, the cash flow for each period (t) and node (ij) is calculated using equation (9), where the product is component-wise:

$$FF_{ij(t)} = \left[P_{ij(t)} \times vol_t\right] \times (1 - C_t) \tag{9}$$

The projected cash flow is compared with its expected value for the following year, obtained through equation (10), where the possible values of the cash flow are weighted by their associated probability $q_{(t+1)}$. The probabilities associated with each node (ij) are given by the equation (11).

$$X_{t+1} = \sum_{i=1;j=1}^{n} FF_{ij(t+1)} \times q_{ij(t+1)} \quad (10)$$

$$q_{ij(t+1)} = \frac{n!}{m!\,(n-m!)} \times [p^m \times (1-p^{n-m})] \quad (11)$$

The successes m correspond to the up movements of the price over the total number of observations. Equation (12) determines the certainty equivalent coefficients p.

$$p = \frac{(1+r)^{\Delta t} - d}{u-d} \quad (12)$$

Where r represents the risk-free rate and u and d are the rising and falling movements of equation (6) and (7). Feenstra & Taylor (2007) and Caprio (2012) indicate that the risk-free rate r, for forest projects, should be obtained using the Interest Rate Parity Theory. For the case analyzed in this paper, we take the interest rate to be the ratio between the average inflation rate of Argentina and the average inflation rate of USA (both values calculated for the period between 1999 and 2011), multiplied by the interest rate of the US Treasury bonds, as indicated by equation (13). Contrary to Feenstra & Taylor (2007) and Caprio (2012), we work with the average inflation rate because in high inflation settings, like the Argentinean, the average value is a better representative along the planning horizon.

$$r = \frac{(1+TI_A)}{(1+TI_{USA})} \times (1 + i_{USA\,bonds}) - 1 \quad (13)$$

Where TI_A is the average inflation rate of Argentina, TI_{USA} is the average inflation rate in the USA and $i_{USA\,bonds}$ is the interest rate of American bonds.

If we want to determine the optimal time of felling, we compare at each period the value corresponding to each node ($FF_{ij(t)}$) with the expected value for the following year ($X_{t+1} \times e^{-r\Delta t}$), according to equation (14), which yields the final cash flow of the corresponding subproducts. If $FF_{ij(t)} > X_{t+1} \times e^{-r\Delta t}$ the stand is harvested. Otherwise it is kept for another period.

$$V_{ij(t)} = \begin{cases} FF_{ij(t)}, & if\ FF_{ij(t)} > X_{t+1} \times e^{-r\Delta t} \\ 0, & otherwise \end{cases} \quad (14)$$

To obtain the value of the alternative at the initial moment ($t = 0$), we use the recursive procedure to obtain equation (15) (Milanesi, 2012).

$$V_{0t} = \sum_{i=1;j=1;t}^{n} \{V_{ij(t)} \times q_{i;j(t)}\} \times e^{-r\Delta t} \quad (15)$$

Where V_{0t} is the current value of the alternative of felling at the moment t.

Results

We analyze the binomial ROA model in the real-world context described in **Forest scenario**. The projected scenario is compared to the discounted average of the scenarios at the next period (Plantinga, 1998) according (14). To obtain the value of the alternative at the initial moment we apply (15).

In the next subsections we evaluate the effects of the risk-free rate, the sale price and the cost of harvesting on the decisions about forest turns.

Sensitivity to variations of the risk-free rate *r*

We consider risk-free rates varying arbitrarily between 5% and 10%, as well as the one derived from (13).

$$r = \frac{(1+0.097)}{(1+0.024)} \times (1+0{,}029) - 1 = 10.24\%$$

We depict all the potential paths of the real options value (ROV) along the planning horizon in Figure 2. The results obtain applying a recursive process over the binomial grid for given values of the risk free rate (equation 15). Each point on the curve

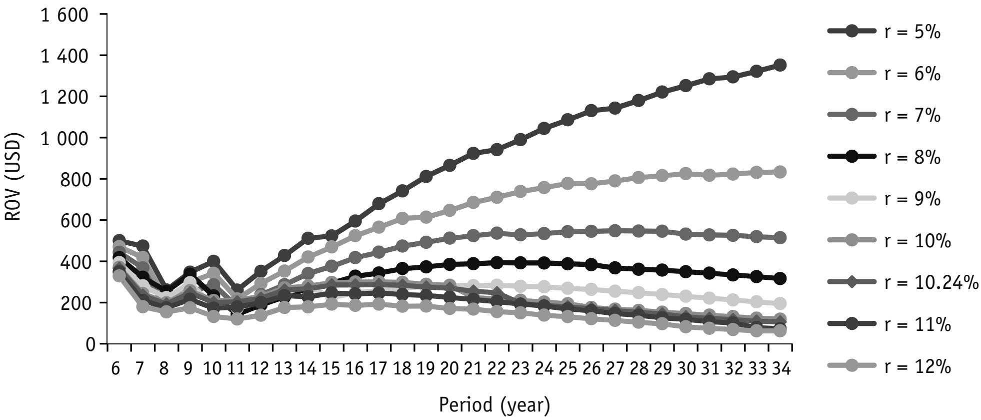

Figure 2. Evolution of the ROV (Real Options Value) for values of the rate *r* (risk-free rate) between 5 and 10%.

represents the current value of the option of harvesting at period *t* for a given value of *r*. Unless $FF_{ij(t)} > X_{t+1} \times e^{-r\Delta t}$, the harvest is postponed to next period (equation 14).

In average levels we can see that ROV for *r* = 5% is USD 824/ha while for *r* = 12% is USD 145/ha, i.e. 5.6 times smaller. At the beginning, the behaviors of the different trajectories of ROV are uncorrelated. This is an artifact of the Geometric Brownian process assumed to be followed by prices, were up and down price's movements are defined by equations 6 and 7. But afterwards the values seem to be at an inverse relation with the risk-free rates, but the impact of the latter decreases with larger values of *r*: the sensitivity of ROV to changes in *r* decreases.

Apart from that, we present a sensitivity analysis of the NPV to the adjusted-per-risk rate *k*, varying between 3% and 15% (Figure 3). This will help to contrast the use of NPV with the ROA model. The interest rate *k* is understood as embodying the riskiness of the project. Then, a higher *k* amounts to a larger risk, and thus the profits deemed satisfactory by the investors must be also larger. We take *k* = *r* + *pr*, where *pr* is the risk premium of the project. Considering a *pr* varying between 1% and 10% and *r* varying from 5% to 10%, we can obtain many possible values for the rate *k*. For the sake of brevity, we only consider integer levels from 6% to 15%. These values are already standard in the literature on the Argentinean forest sector (Chidiak *et al*., 2003; Monicault & Delvalle, 2009; Colcombet *et al*., 2010). Figure 3 shows the evolution of NPV for those values as well as the CAPM (Capital Asset Pricing Model) rate of 10.93%.

We can see that for *k* = 6, the optimal harvesting period (indicated by straight line) is at twenty-one years, yielding a NPV of USD 1,520/ha. In contrast, for *k* = 14, the optimal time of felling is fifteen years, with an NPV of USD 383/ha. In general, we can see that the lower the rate, the felling period is further in the future and higher the profit.

The harvesting periods, as determined by ROV are longer than those obtained through NPV. This is so because prices are assumed variable and the expected value of the forest at *t*+1 is conditioned by their evolution (equation 10). This feature makes decision-making more flexible, allowing to wait for better market conditions, as for instance an increase in the value of wood. For *r* = 5 and 6% the felling time is of 34 years because of the period of analysis considered here, even if the maximum ROV

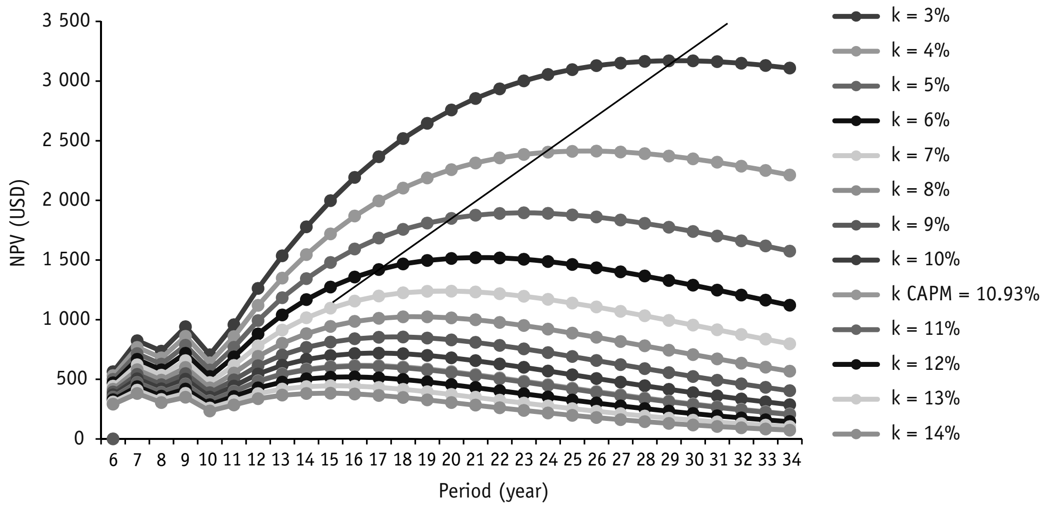

Figure 3. Evolution of the NPV (Net Present Valuation) for values of k (adjusted-per-risk rate) between 6% and 15% and the CAPM (Capital Asset Pricing Model) rate k = 10.93%.

exceeds that time. For r between 10 and 12% the turnover is of 17 years. In the NPV case, up from k = 3%, the turnover is of 29 years, while for k = 4% it is of 26 years and so on until reaching the shorter turnover period of 15 years for k = 13 and 14%.

Assuming that pr = 2%, for r = 5% we get k = 7% (according to $k = r + pr$) and NPV 0.4%, higher than ROV, while for r = 6%, NPV is 10.8% higher than ROV. Similarly, for r = 7% NPV is 20.4% higher than ROV, and so until we reach r = 12%, the case at which NPV is 34.1% larger. This means that at increasing values of r the forest becomes more and more overpriced. Contrary to our expectations, ROV is more variable than NPV.

Sensitivity to variations of the selling price of logs

For this analysis, we consider four scenarios, a base case and three variations. These variations correspond to a price reduction of 10%, 20% and 30% (Table 1). In all the cases, the adjusted-per-risk rate k is 10.93 and the risk-free rate r is 10.24. Figures 4 and 5 show the behavior of ROV and NPV, respectively, at each scenario.

Table 1. Sales price (USD/t) of forest rolls in the province of Misiones, Argentina.

Products	Base case	-10%	-20%	-30%
Pulpwood (5–15 cm)	22.3	20.07	17.84	15.61
Sawlog -small diameter- (15–20 cm)	33.9	30.51	27.12	23.73
Sawlog -large diameter- (20–30 cm)	36.1	32.49	28.88	25.27
Veneer log (> 30 cm)	49.3	44.37	39.44	34.51

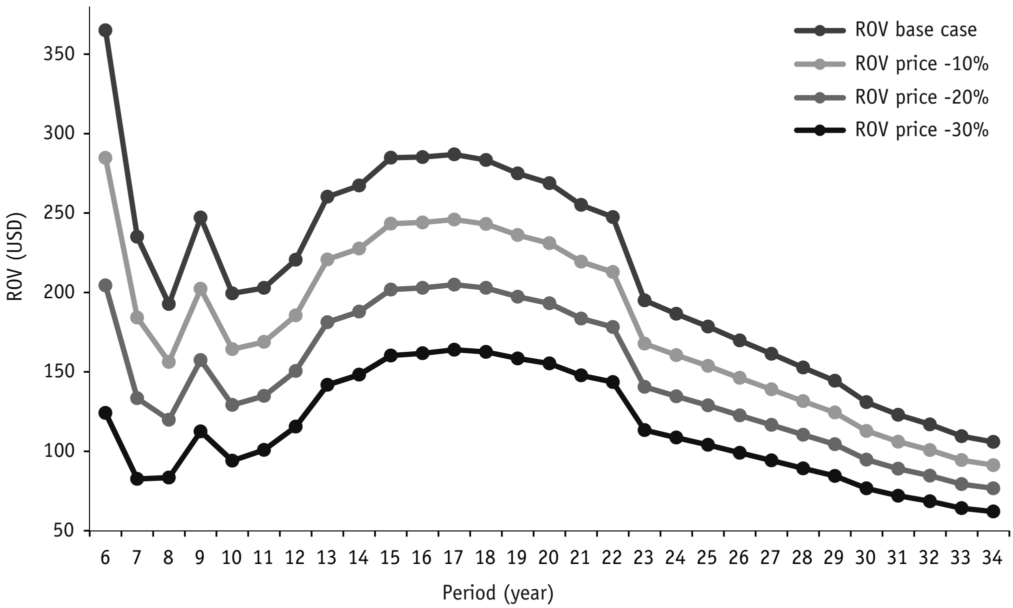

Figure 4. Variation of ROV (Real Options Value) at the three scenarios of decreasing prices.

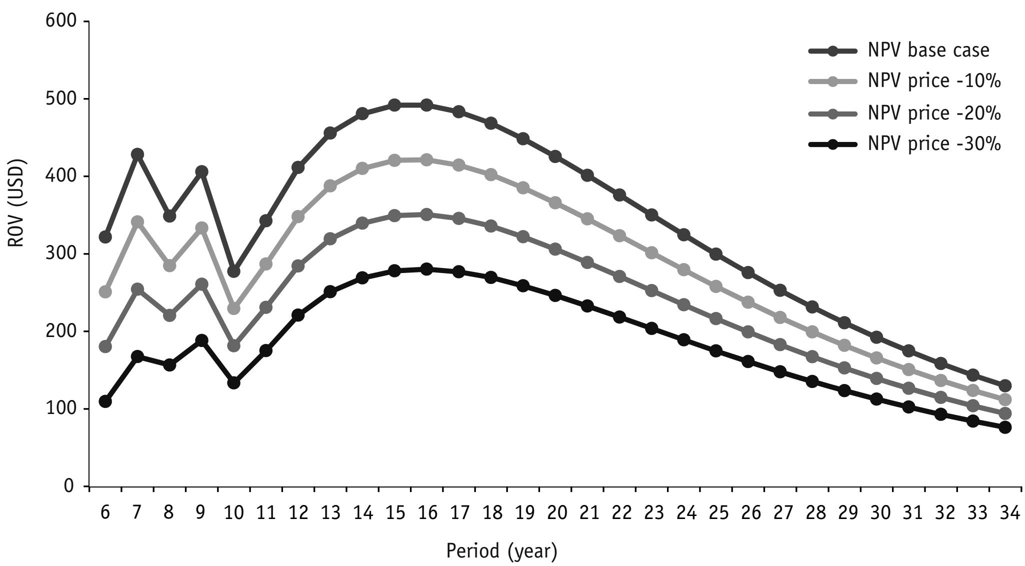

Figure 5. Variation of NPV (Net Present Valuation) at the three scenarios of decreasing prices. ROV – Real Options Value.

Optimal turnover periods are shorter since the lower price affects the expected value, being this reduction compensated by the increase of the underlying due to the growth of the forestry mass. Since the alternative of felling is discarded for stands of less than 10 years old, with diameters below the minimal requirements of the industry, a decade is the minimum age at which we run comparisons. The average ROV from 6 to 34 years old is USD 212.1/ha in the base scenario. The reductions of 10%, 20% and 30% of the price induce a reduction of the ROV of 15.5%, 30.0% and 46.5% respectively. In all these cases, the maximum ROV is achieved at age 17, indicating that prices do not affect the optimal turnover period, despite having a large impact on income. On the other hand, the average NPV from 6 to 34 years old is USD 338/ha in the base scenario. The price reductions induce a corresponding reduction of NPV of 15.2%, 30.4% and 45.6%. The highest NPV is obtained at age 16, defining the optimal turn under NPV criterion. In those scenarios, ROV postpones the harvest for one year.

Sensitivity to variations of the harvest cost

We analyze now the behavior of ROV respect to the cost of harvesting in three scenarios, shown in Table 2. Figures 6 and 7 show the response of ROV and NPV to different cost structures.

Table 2. Cost of harvesting, loading trucks and transporting forest products in four scenarios.

	Base scenario	10%	20%	30%
Transport cost (USD/km)	2.63	2.89	3.15	3.41
Harvesting cost (USD/t)	11.9	13.09	14.28	15.47
Loading truck cost (USD/t)	1.75	1.93	2.10	2.28

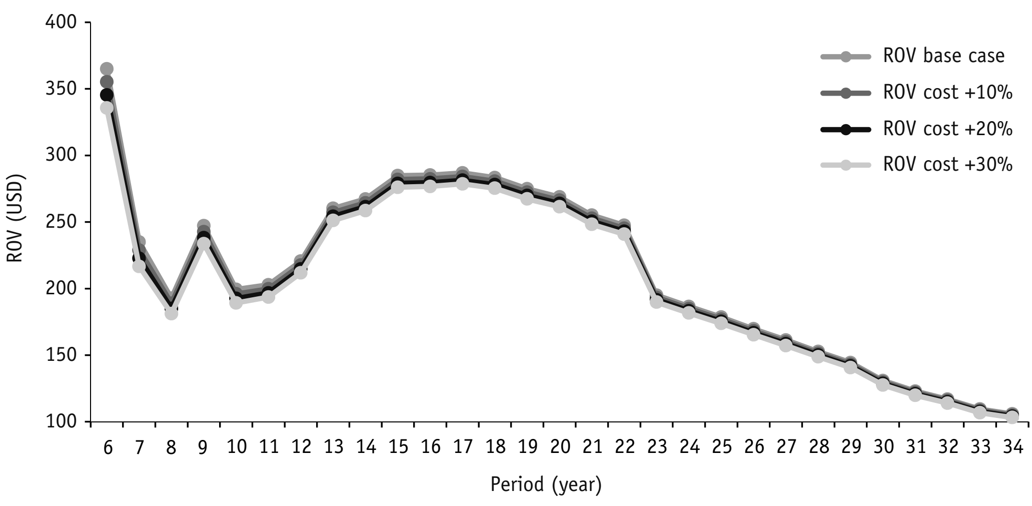

Figure 6. Evolution of ROV (Real Options Value) for different costs of harvesting.

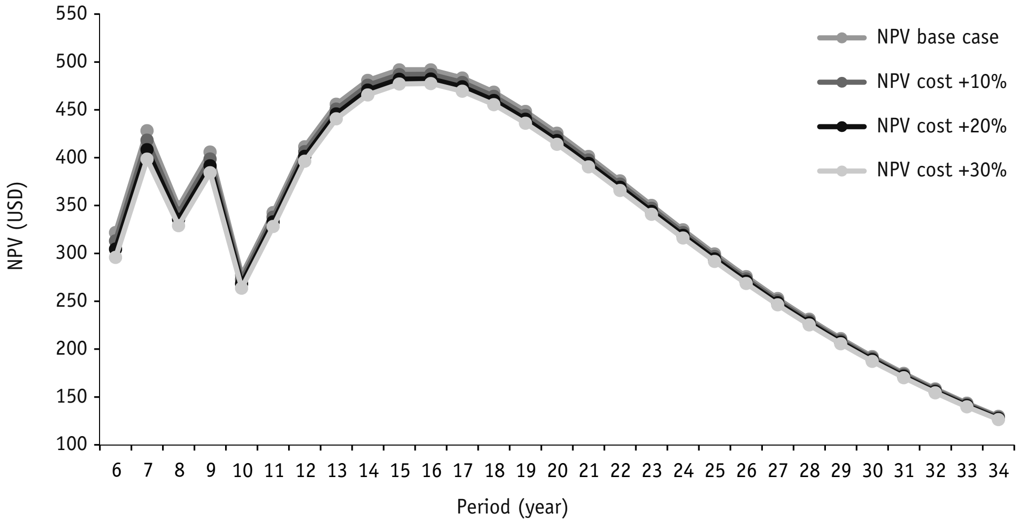

Figure 7. Evolution of NPV (Net Present Valuation) for different costs of harvesting.

Cost increases of 10%, 20% and 30% generate a reduction of ROV of 1.2%, 2.5% and 3.7%, respectively, and of NPV of 1.2%, 2.3%, 3.5%, respectively. This indicates that overall production costs do not seem to have a significant influence over ROV and NPV, which both have an average variation of 2.3%. As in the previous subsection, the turnover period remains the same in all the scenarios. The optimal turnover time for NPV is 16 years with USD 484.6, while for ROV is 17 years with a lower amount, USD 282.7.

Discussion

In principle, ROV shows to be a sound alternative for the determination of the optimal turnover period in the forestry sector. Its advantage is that incorporates strategic flexibility, given by the comparison of the expected forest mass at t+1 to the potential value of harvesting at period t. In contrast, NPV is fundamentally based only on risk-adjusted rates and constant prices.

We compared ROV and NPV under different scenarios in which the rate, prices and costs vary. ROV was tested varying the risk-free rate (r) while for NPV the variation was on the adjusted-per-risk rate (k). This rate k obtains as r plus the risk of the project, *pr*. In both cases, at lower levels of the rate (r and k) the turnover period becomes longer. In the case of ROV this is due to the inherent positive asymmetry of the expected values. This makes the decision more flexible and yields potentially better contexts to exert the option. Besides, ROV is more sensitive to r than NPV to k. The values of NPV are higher than those of ROV, particularly for higher rates.

Finally, even if ROV and NPV are very sensitive to changes in the price of the raw materials, ROV was slightly more responsive to that. For both assessment methods, the turnover period remained constant, although ROV takes one period longer than NPV. The same is true for the cost of harvesting.

In general, ROV is more complex than NPV, due to the need to build binomial grids to project prices. However, if the economic context is volatile, as in Argentina and similar emerging economies, with a high degree of uncertainty, the extra effort of implementing ROV pays off.

Conclusions

In this paper, we presented a discrete time model based in the Real Option Approach (ROA) on a binomial grid for the determination, among of other questions, the optimal harvest period. The binomial grid setting in discrete time allows deriving the Black-Scholes-Merton specification, avoiding the difficult calculations associated to contexts that are more complex. The ROA seems to be a more robust tool than the traditional approaches to decision-making in forestry because it assumes a stochastic projection of prices and incorporating strategic flexibility, seen in the possibility of postponing the harvest time.

Both models are highly sensitive to the discount rates, yielding lower values for ROV than for NPV, but the turnover periods are longer for the former than for the latter. The longer time for harvesting under ROV is an artifact of the option structure. Even so, the possibility of postponing the felling turn endows ROV a richer strategic flexibility, i.e. the ability to wait until the right market conditions arise. This is contrary to NPV that focuses only on the mass of the forest, independently of the market.

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