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N. 290, SEPT. 2008

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INTEGRATING FIRE RISK INTO THE MANAGEMENT OF FORESTS[*]

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ABSTRACT

In a standard cash-flow data-sheet analysis, the quantification of the impact of exogenous variables and management decisions on the investment's Net Present Value is limited to only a few scenarios. This perspective is insufficient for an efficient risk management in complex business environments. In this work, I present a dynamic programming model that takes into consideration fire risk. Having applied the model to forest management, I conclude that when fire risk increases, it is optimal for the manager to increase the area used per tree and the cut-off weight of stems. Rather than increasing the business Expected Net Present Value (that, with real interest rate of 3%/year, is between 1.5€/m^2 and 2.2€/m^2), the optimal strategy decreases the business risk. Additionally, I conclude from the model that there is no private incentive to carry out fire risk prevention.

KEYWORD: Risk Management; Project Evaluation; Expected Net Present Value

JEL CODES: D81; C61

1. INTRODUCTION

Good management of a business requires quantification of the influence of actions implemented by the manager in the business Net Present Value, *NPV*, so that at each moment the manager may implement the efficient action. Since perfect risk diversification is unfeasible, it is necessary to compute the *NPV* expected value, *ENPV*, plus its variability, *i.e.*, the business risk.

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[*] I acknowledge Aurora Castro Teixeira for her extremely helpful comments and suggestions.

With this requirement in mind, in this work I use a dynamic programming model in the computation both of the investment *ENPV* and *NPV* standard deviation, giving the distribution function of contingencies. This model is closely related to the real option framework where it is understood that "[an] irreversible investment opportunity is much like a financial call option" (Pindyck, 1991: 1111): The landowner has an option either to invest in a forest plantation or to wait (or to sell it). This similarity allows evaluation of this perpetual real option that is almost costless to maintain alive, by using valuation methods developed for financial options. These investment options are named "real options" to distinguish them from "financial options" (see, Kester, 1984 and Brennan and Schwartz, 1985).

The use of a real options framework in forest management is significant, although concentrated mainly in the optimal decision of cutting the stem (to exercise a put option) when prices (*e.g.*, Morck *et al*, 1989; Insley, 2002; Cunha 2003) or growth process are assumed as stochastic (*e.g.*, Shackleton and Sodal, 2006). In the literature the value of the real option is modelled as a "random walk" and the managers decision is to exercise the option, i.e., the determination of the optimal cut-off value, Newman (2002). For a survey of the related literature see Pindyck (1991) and Duku-Kaakyire and Nanang (2004).

The model I set up here is more business oriented than those considered in the literature by considering that stochastic process is imbedded inside the decision model and by assuming that the manager has not just one decision variable (the optimal cut-off value) but several decision variables (primarily the soil area used per tree), i.e., the manager is capable of selecting the put option characteristics. Contrary to the literature, in the presented study I assume future wood prices and trees growth rate are perfectly anticipated being fire risk the only source of risk. This simplification is valid in Mediterranean forests where fire contingency is the major source of risk.

In formal terms, I implement a model similar to Abel (1983) but formalised in recursive form (time discrete) and resolved by Monte-Carlo simulation.

Although, the assumed assumptions are to a certain degree included in the literature (*e.g.*, the decision "wait for the tree to be reborn by itself" when fire occurs is parallel to the Shackleton and Sodal, 2006, decision "wait for a natural recovery" when unfavourable growth path occurs), it results from my model a tailored strategy to manage fire risk and an estimative of the land value for the average Portuguese circumstances.

The example I calibrate and compute is the problem that fire risk imposes to the forest management of a *Eucalyptus globules* plantation (that in Portugal is the most profitable flora species). Nonetheless, the model may easily be extended to other flora species or to other management problems.

2. FOREST MANAGEMENT

Similar to other management problems, the forest uses scarce resources, and its management implies the selection of efficient strategies. In particular, forest uses soil, and its management involves the optimal selection of flora species and agricultural actions. When the investment is perfectly diversifiable, the relevant function that the manager must maximise is the expected present value of all future cash flows subjected to restrictions. As perfect diversification is unachievable, the manager must be able to quantify the risk of his investment, measured, *e.g.*, by the net present value standard deviation.

Since tree growth is a long-term process, *e.g.*, the Cork Oak (*Quercus Suber L.*) economic break-even point is higher than 100 years, the likelihood of fire occurrence becomes the major source of risk. On average, in Portugal forests' fire risk is approximately 3.3% per year: in the time period between 2001 and 2006, from a total of 3400 thousand ha of forest, fire damaged 111 thousand ha per year, DGRF (2006).

In present model, I assume that the manager has five decision variables. The manager decides, through sequential process, the flora species, the soil area used per tree, the agricultural intensity, the cut-off weight and, when the tree is cut, between replanting or waiting one period for the old tree to be reborn. The manager's strategy and exogenous contingencies, fire risk, give rise to the expected value and the variability of the Net Present Value (*NPV*) of the option to invest.

3. ASSUMPTIONS OF THE THEORY

I will formalise the management problem assuming that the only source of risk is the likelihood of a fire event:

A1. The occurrence of a forest fire is a stochastic phenomenon, with z representing the probability that a fire will occur during a certain period (one year).

Adding to this, I will assume that:

A2. The weight of trees increases with time. The tree-weight depends on the age of its root, *Ar,* the age of its stem, *As*, the used soil area, *M*, its species, *S*, and agricultural intensity, *AI*. In formal terms, the weight of the tree is $W(Ar, As, M, S, AI)$.

A3. The cost of planting a tree, *I*, is proportional to the used soil area and increases with agricultural intensity, *AI*. It is also dependent on the species: $I(S, AI)\cdot M$.

A4. The cost of cutting a full-weight tree is a fixed amount, *C*, and the cost of cutting an under developed tree is half that amount.

A5. During trees lifetime there are no maintenance costs.

A6. When a fire occurs, the manager may either replant a new tree or may wait for the tree to be reborn by itself. The proportion of reborn trees is *b*.

A7. The discount rate is *R* per period (one year), real terms.

A8. Time is divided into one-year periods.

A9. Wood price is perfectly anticipated and it is independent of the manager's decision and of the occurrence of fires.

A10. There is no time evolution in the business environment.

A11. The optimal strategy results from the maximisation of the business *ENPV*.

4. FORMALISATION OF THE NET PRESENT VALUE MODEL

The model considers that the manager's decision variables are, without loss of generality, the trees species, *S*, the area of soil used per tree, *M*, agricultural intensity, *AI*, the trees cut-off weight, *Wc,* and to replant new trees or to wait for the trees to be reborn by herself.

The manager's decisions are sequential and rotational with this meaning: First, the manager decides whether the trees weight is optimal to be cut. Second, the manager decides either to plant a new tree or wait for the old one to be reborn. Third, (assuming the decision is to plant a new tree) the manager decides on the species, the area and the agricultural intensity, returning in the next period to the initial decision.

The manager's sequence of decisions is as follows.

First, let us assume that the tree has been cut. If the manager decides to replant a new tree, in the next period the tree root and the tree stem are one year old. As such, the *ENPV*, which at present is unknown, is represented as the function:

$$\text{Replant} = ENPV(1, 1, M, S, AI) \tag{1}$$

If, on the contrary, when the manager decides to wait for the old tree to be reborn, ENPV will be

$$\text{Wait} = ENPV(Ar+1, 1, M, S, AI)\cdot b + ENPV(Ar+1, 0, M, S, AI)\cdot(1-b) \tag{2}$$

With a percentage *b* of trees reborn, on average, the following results from expression (2):

$$\text{Wait} = ENPV\left(Ar+1, 1, M/b, S, AI\right)\cdot b \tag{3}$$

Although *ENPV* is yet unknown, the model moves one period backwards and the functions (1) and (3) are used in evaluating the choice between replanting or waiting one period for the old tree to be reborn as if it is known (see figure 1, point *C*):

$$ENPV(Ar, 0, M, S, AI) = \max\left\{Replant; Wait\right\}/(1+R) \tag{4}$$

Second, the model moves another step backwards and the choice between cutting or maintaining the tree one more period when fire has not occurred (*nf* means “no fire”) is evaluated (see figure 1, point *B*), with function *V* given by expression (8):

$$\begin{aligned} &ENPVnf(Ar, As, M, S, AI) = \max\left\{\text{Cut; Maintain}\right\} \\ &\qquad \text{Cut} = V\left(Ar, As, M, S, AI, 0\right) + ENPV(Ar, 0, M, S, AI) \\ &\qquad \text{Maintain} = ENPV\left(Ar+1, As+1, M, S, AI\right)/(1+R) \end{aligned} \tag{5}$$

In this same step, when a fire occurs, the tree must be cut (*of* means “a fire occurred”):

$$\begin{aligned} &ENPVof(Ar, As, M, S, AI) = \text{Cut}/(1+R) \\ &\qquad \text{Cut} = V\left(Ar, As, M, S, AI, 1\right) + ENPV(Ar, 0, M, S, AI) \end{aligned} \tag{6}$$

Finally, the model moves another step backwards. Since the occurrence of fire is stochastic, one quantifies the *ENPV* at the beginning of the period by multiplying the pay-off for the probability of fire occurrence:

$$\begin{aligned} &ENPV(Ar, As, M, S, AI) = \\ &\quad ENPVof(Ar, As, M, S, AI)\cdot z + ENPVnf(Ar, As, M, S, AI)\cdot(1-z) \end{aligned} \tag{7}$$

Log tree value is zero when it is lighter than a minimum weight *Wmin*, otherwise it is linear increasing with weight. With *C* as the cost of cutting a full-weight log tree, C/2 the cost of cutting a small log tree, *P* the unitary value of the log tree and *W* its weight, the market value of one log tree that is still located in the forest (net of transportation costs) is computed by the next function where $P(S, Br)$ is the unitary value of the wood and $Br = 1$ means the log is burned:

$$V(Ar, As, M, S, AI, Br) = \begin{cases} -C/2 & W < W\min \\ P(S, Br)\cdot W(Ar, As, M, S, AI) - C & W \geq W\min \end{cases} \tag{8}$$

Now that the model is closed, it is possible, after calibration, to compute the manager's optimal strategy. This strategy consists of selecting the species, S^*, used soil area per tree, M^*, agricultural intensity AI^*, the cut-off weight W^*, and when to replant the tree, Ar^*.

In figure 1, the manager's sequence of decisions is represented. Point *B* represents the choice between cutting or maintaining the tree one additional period when fire has not occurred and point *C* represents the choice between replanting or waiting one period for the old tree to be reborn. Point *A* represents the possibility of fire occurrence and point *D* represents the proportion of tree rebirth.

Although the function *V* that models the log tree cutting and selling appears only once in the model (see fig.1), it is determinant in the computation of *ENPV*.

The Monte Carlo Method repeats simulations that fluctuate with the concretisation of the variable z (which measures the probability of fire occurrence in each period). In this study, I compute the expected value of *NPV* and its variance as the average of 100 000 Monte Carlo simulations for a time span of 200 years.

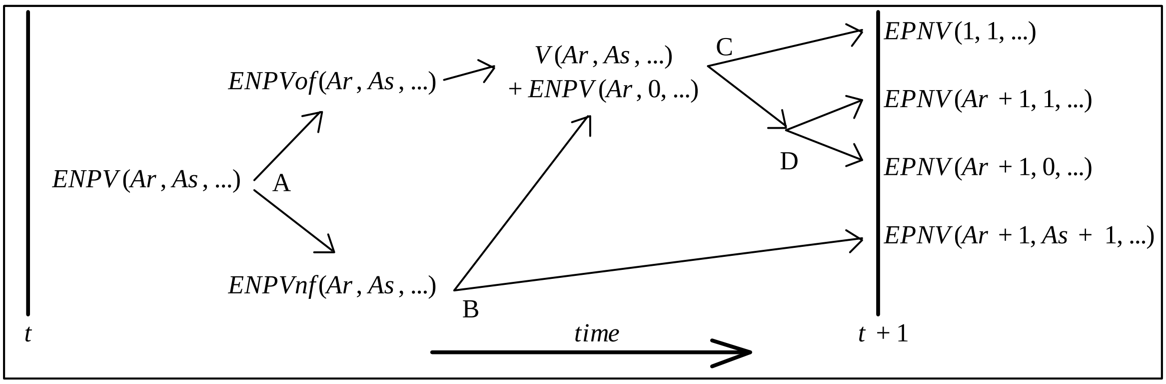

Fig. 1 – Sequence of manager's decisions and contingencies.

5. APPLICATION TO A *EUCALYPTUS GLOBULUS* INVESTMENT

Once the decision model has been built, it is necessary to calibrate it. The major data source I use comes from Gozález-Río *et al* (1997): The optimal strategy, when there is no fire risk, is to use 10 m^2 of soil per tree, cut the stem when it weighs 300 kg and replant the tree when the root age is higher than 25 years.

From the cellulose industry, eucalyptus stem weight must be equal to or higher than 200 kg, the price is 30 Euros per tonne and it loses 30% of its value when burned (it is 45€ per tonne, placed in the industrial unit).

It costs 1 Euro to cut a stem.

Let us assume that the functional form of the log weight is given by expression (9), table 1 and w_0 is 5 *kg per year per* m^2.

$$w(Ar, As, M, S, AI) = w_0(S, AI) \cdot w_1(Ar) \cdot w_2(As) \cdot w_3(M) \tag{9}$$

Ar – years	<5	]5, 20]	]20, 30]	]30, 50]	>50
$w_1(Ar)$	0.6	1.0	0.6	0.3	0.0
As – years	<5	]5, 10]	]10, 15]	]15, 20]	>20
$W_2(As)$	0.6	1.0	0.6	0.3	0.0
M – years	<5	]5, 10]	]10, 20]	]20, 50]	>50
$w_3(M)$	$0.7M$	$1.3 \cdot M - 3$	$0.7 \cdot M + 3$	$0.5 \cdot M + 7$	32

Table 1 – Determinants of the log weight.

The constant w_0 quantifies the maximum potential productivity, *i.e.*, when $Ar = 25$ years, $As = 7$ years and $M = 10\ m^2$.

I assume that rebirth proportion varies with the root age. I assume that rebirth proportion is 100% when root age is less than 15 years; it is 75% when root age is in the time interval]15, 25], and 25% otherwise.

I assume that the discount rate is 3% a year.

I assume that, on average, it costs 0.25 Euros per square metre to plant one tree for the first time and 1/3 of that price to replant it.

6. RESULTS

The simulation produces the result that the economic value of soil, even when there is no fire risk, is much smaller than the value I expect to obtain, i.e., 2.2€/m^2 for the most profitable flora species.

The optimal response to an increase in the fire risk is to increase the soil area used per tree (0.8 m^2/tree per percentual point of risk increase – see fig. 2) and it is to increase the stem cut-off weight (7 kg/tree per percentual point of risk increase – see fig. 3).

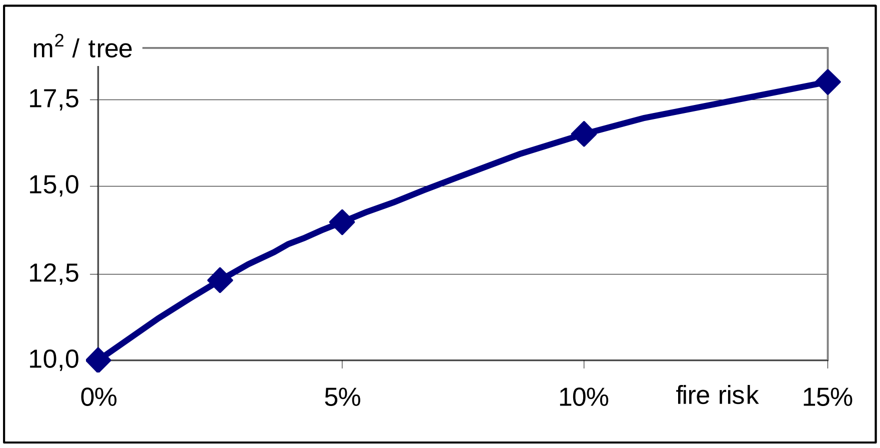

Fig. 2 - Optimal soil area used per tree (*M**)

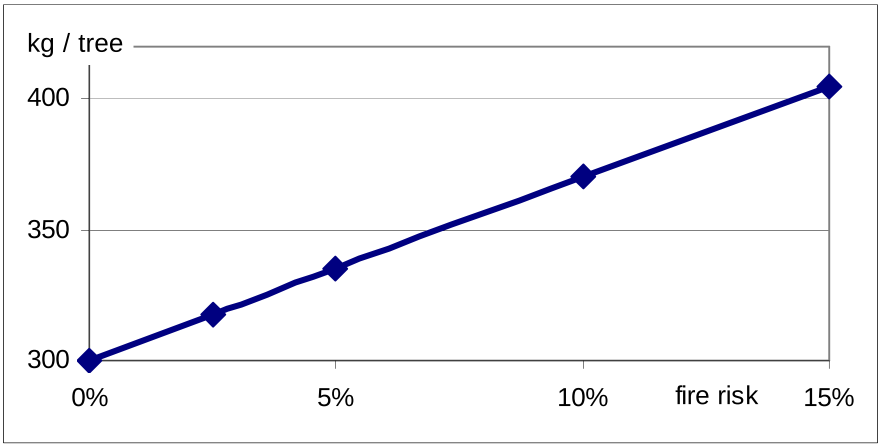

Fig. 3 - Optimal cut-off weight (*W**)

The *ENPV* when the strategy is fixed (as if there were no fire risk) may be compared to the optimal one (fig. 4 and fig. 5). It is important to notice that, in the typical fire risk interval, between 0% and 5%, the optimal strategy does not increase the *ENPV*, but significantly reduces the risk (on average, it reduces the *NPV* standard deviation 0.088€/tree, see fig. 5).

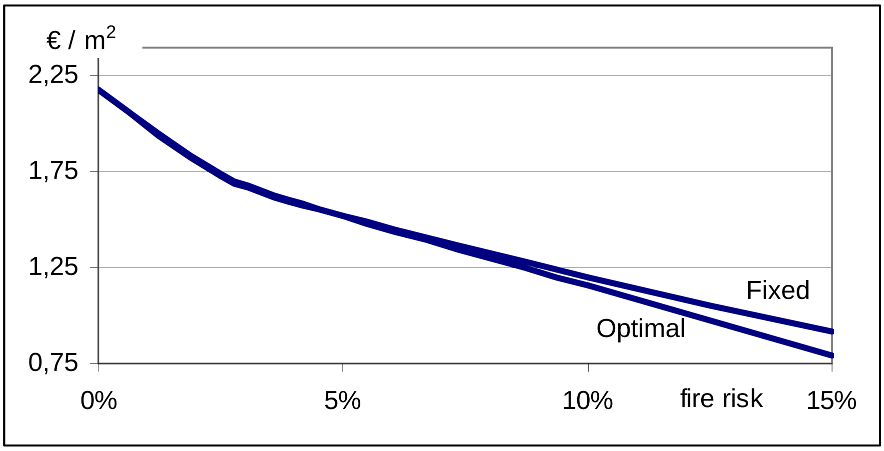

Fig. 4 – Expected net present value (*ENPV*)

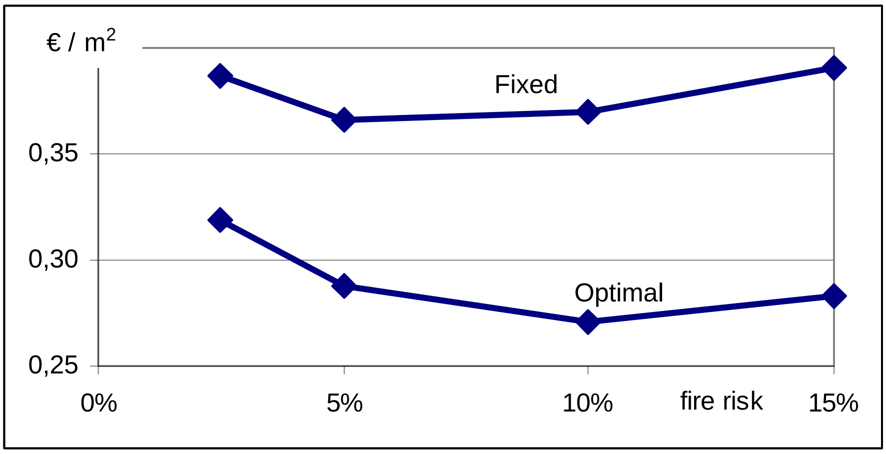

Fig. 5 – *NPV* standard deviation

The increase in the soil area used per tree when there is an increase in fire risk is intuitive: a greater area implies that the stem grows quickly, attaining the minimum acceptable weight more rapidly (the *Wmin*). It is optimal to increase the cut-off weight because when the stem weight is smaller than *Wmin* and a fire occurs, its economic value is zero. As such, the increase in the cut-off weight reduces the period when the stem value is zero, compensating the assumed 30% loss caused by a fire when the weight is higher than *Wmin*.

Finally, the model is applicable in evaluating the pertinence of reducing fire risk by performing precautionary maintenance. Let us assume that the fire risk is 10% and that it is possible to reduce the fire risk ten-fold by performing precautionary maintenance that costs 0.025 per square metre per year. Even though this dramatic reduction is an optimistic situation, the investment performance declines. The reduction of an initial fire risk of 10% to

1% causes *ENPV* to decrease from 1.18 €/m^2 to 0.98 €/m^2 and *NPV* standard dispersion to increase from 0.29 €/m^2 to 0.40 €/m^2.

7. CONCLUSION AND LIMITATIONS

In this work, I compute the optimal management strategy of a forest investment when there is fire risk. I conclude that the economic value of the land is small (for the most profitable flora species it is between 1.5€/m^2 and 2.2€/m^2) and that when fire risk increases, it is optimal to increase the soil area used per tree and the cut-off weight of stems. The optimal strategy causes a significantly decreases in the investment risk.

I simulated the existence of precautionary maintenance and I conclude that, although an optimistic ten-fold reduction in fire probability is assumed, there is no private incentive to perform forest protection.

In the calibration of the model, I assume that the future price of wood is constant and independent of the occurrence of fires. Although in the last 20 years data corroborates this assumption - price has being constant (45 € / tonne, placed in the industrial unit), the future tendency, related to an increase in Chinese or Indian paper consumption or related to an increase in Indonesian or Brazilian wood production, is unpredictable.

The VB Code used in the simulation is available upon request and may be downloaded from www.fep.up.pt/docentes/pcosme/forest-fire-risk.zip

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