Approach to Reaching an Optimum Budget for Forest Fire Prevention, and its Application to the Forest Areas of Mediterranean Spain[1]

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Summary

By determining the optimum budget for forest fire prevention in a specific territory, an objective reference is provided of the financial cost, which tends to be high and is frequently the subject of much controversy. This paper proposes not only to establish a cost efficiency function for the fire fighting budget of a region on the basis of previous budgets, the number of fires and the average data on burnt surface area which permit marginal costs to be established; but also, the value of the natural active surface area affected, which may be assessed from two perspectives: that of the owner of the forest land – private value - and that of the public related to the forest land - private value plus public value-; this study proposes to focus on the latter. The final phase consists of comparing the marginal cost of the budget with the value per unit of surface area f the damage caused by the fires. This methodology is proposed for application to Mediterranean forest land in Spain where public values are a substantial part of the total value. As case studies we have used the forest lands of the Autonomous Community of Andalusia and the Community of Valencia.

Introduction

The frequency and intensity of forest fires, particularly in countries with marked periods of drought, have determined an intensive fire-fighting policy. In the case of Spain the situation has reached a catastrophic level, as in recent decades thousands of fires have led to a high toll of human life and incalculable losses, which in many cases are impossible to recover.

Bearing in mind that the recurrence of fires in forested areas has the effect of degrading the environment in terms of: destruction of soil, erosion, loss of native species, game … prevention of these disasters is of the utmost priority for the competent authorities involved.

The Council Regulation (EEC) no. 2158/92 on the prevention of forest fires in

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Community forests established a Community programme for the prevention of forest fires, it has identified the causes of fires, the creation of protection systems, and the improvement of those already in existence, including vigilance. This programme has achieved positive results, such as the financing of specific causality studies which have improved knowledge on the causes of fire, which is essential to the basis of a prevention policy. Nevertheless, this scant provision clearly shows the limited scope preventive efforts have provided so far. This programme was in force until 2001. Since 2003, forest fire prevention has been encapsulated in the Parliament and Council Regulation (EEC) 2152/2003 on the monitoring of forests and environmental interaction in the Community (Forest Focus), which show the characteristics of forest land in its contribution to the development of rural areas – economic and social aspects - and nature conservation, – environmental aspect- .

The European Union Social Fund (EUSF) is also involved through rural development programmes and measures for prevention of forest fires.

The Spanish Forestry Plan proposes to coordinate the plans of the Autonomous Communities (regional governments) and the General State Administration through the Forest Fire Fighting Committee (CLIF). This coordination should be based on the distribution of risk and cost-efficiency criteria, as an essential step in achieving the objective of forest fire prevention and control. (Environment Ministry 2002) The aim is to promote fire prevention measures which reduce the number of fires and limit the impact they have on forested areas.

Society is become increasingly aware that forest lands, in addition to providing a source of raw materials, play an essential part in maintaining balance, particularly in respect of the soil, water systems, climate, fauna y flora; they also provide environmental services and direct amenities. The source function of raw materials refers to private assets – those for which there is rivalry for their consumption and over who shall exploit them : the proprietor : - The rest consist of public assets over which proprietors have no rights- they are made use of by any normal member of the public – and constitute what are known as externals. The value of the forest land is incomplete unless the externals are taken into account, particularly those forest lands with limited productive possibilities.

The cost –efficiency analysis is a useful tool in the field of environmental policy (Azqueta 2002). It involves the rationalisation of a commonplace practice: weighing up the advantages and disadvantages of the decision on how to achieve a goal in the best possible way, in this case it would be the optimum budget for fire-fighting. The novelty of the analysis lies in the incorporation of public assets in order to establish the social cost of the burnt surface area and the enablement of direct comparison with the optimum fire fighting budget.

Fire-fighting has been centred almost exclusively on fire suppression, where important advances have been made in rate of effectiveness. Conversely, prevention and adequate forest planning within the framework of efficient land management has largely been forgotten. Unfortunately, the global budget details available cover suppression and prevention, thus a joint marginal cost has been estimated. Given this fact, it is not possible in this study to make any inference regarding the proportion of these chapters in the budget.

The results merely provide an initial approach, due to the fact that we have only been able to obtain overall data, and because it must be assumed that the efficiency of budgets in respect of prevention and suppression are different, and the overall optimum budget will be proportionally different for these parts.

Objectives

The main objective is to determine an ideal budget, required for prevention of forest fires in each of the Autonomous Communities mentioned in this study, from the point of view of society overall and not merely from the point of view of private assets.

Secondary objectives are as follows:

- Demarcation of the area of validity of the optimum in function of the other explanatory variables of the cost-efficiency function – analysis of sensitivity-.
- Establishment of the distance existing between the budgetary amounts awarded by the Autonomous Communities studied and the optimum budget established. It would also be interesting to see whether the situation is similar in both cases.
- To determine the social cost per hectare burnt, bearing in mind the natural regeneration occurring in the Mediterranean area.

Materials and methods

Basic data to estimate the cost-efficiency function

The period studied is from 1991–2002, in two autonomous communities: the Autonomous Community of Andalusia (ACA) and the Community of Valencia (CV). The data noted for each of the years within the period are contained in *table 1* : Autonomous Community, year, number of fires, total surface area burned, budget for the year updated to Euros 2003 and Birot's index.

The capacity of a fire prevention budget to reduce the surface area burned within a given period is influenced by the meteorological conditions of that period. Meteorology has been included in the cost-efficiency function using the Birot index calculated with yearly data according to the following formula:

$$IB = N \times Pa / Tm$$

With IB being the value of the index, N the number of days of annual rainfall Pa annual precipitation in millimetres and Tm average annual temperature. The number of fires was not used ultimately because the total surface area burnt was used to measure efficiency within the cost-efficiency functions, instead of average surface area per fire which initially had appeared more appropriate. The reason is that prevention measures include public awareness campaigns which have led to a declining trend in the number of fires.

Table 1—*Basic data for estimation of the cost-efficiency function*

Autonomous Community	Year	Number of fires	Burned Area (hectares)	Birot Index	Prevention budget (per thousand € 2003)
ACA[1]	1991	2.110	65.252,8	9,6	34.936,1
ACA	1993	1.288	17.342,3	11,2	52.554,1
ACA	1994	1.671	36.134,0	7,8	56.720,8
ACA	1995	1.389	12.971,5	9,8	52.438,5
ACA	1996	739	1.257,9	35,7	50.669,3
ACA	1997	750	2.951,2	24,5	36.725,3
ACA	1998	1.137	5.241,5	7,6	61.643,2
ACA	1999	892	6.627,2	9,8	69.193,4
ACA	2000	938	5.411,3	14,2	78.361,3
ACA	2001	961	7.351,4	16,3	56.276,2
ACA	2002	1.181	10.640,7	14,9	63.773,6
ACV[2]	1991	869	44.426,3	20,1	10.329,4
ACV	1992	769	26.188,5	13,8	29.307,7
ACV	1993	715	25.966,7	11,5	26.482,1
ACV[3]	1994	751	138.404,5	8,1	44.278,8
ACV	1995	467	2.220,4	6,8	57.106,8
ACV	1996	383	765,1	16,1	59.598,2
ACV	1997	348	898,2	14,9	59.139,0
ACV	1998	546	1.967,3	8,8	67.661,8
ACV	1999	579	6.356,5	5,7	65.075,8
ACV	2000	606	6.547,8	11,2	66.656,3
ACV	2001	442	4.792,8	13,6	70.175,5
ACV	2002	321	1.202,1	16,3	68.663,5

Source: Modified from the Junta de Andalucía, the Generalitat Valenciana (regional governments) and the National Meteorological Institute
[1] Autonomous Community of Andalusia
[2] Community of Valencia
[3] The figure for this year is considered to be atypical and was not taken into account in the regression model

The budgets in pesetas have been converted to Euros using the official exchange rate of 166,386 peseta/€, and every year up to 2003 they have been updated with coefficients and methods supplied by the National Institute of Statistics (INE 2003).

There was no budget data available for 1992 en Andalusia.

1994, was the worst year for forest fires in Spain in recent decades, 92 large-scale fires accounted for 76.63 % of the surface area burned that year in Spain. In ACV it was a particularly bad year with eight large fires of over 5,000 hectares which caused 115,986 hectares burned. This year was considered atypical and was not taken into account when making the regression.

Evaluation data

The ACA and the AVC evaluation data was obtained from land models created by the Junta de Andalucía and the Generalitat Valenciana, (regional governments) which take into account the public as well as private assets which generate forest eco-systems. The results for large areas are contained in *table 2*.

Table 2—*Total economic value by forest area in each of the regions*

Type	Autonomous Community of Andalusia			Autonomous Community of Valencia		
	Area (ha)	PV[1] (euros/ha)	TEV[2] (euros/ha)	Area (ha)	PV[1] (euros/ha)	TEV[2] (euros/ha)
Conifers	625.673	1.554	7.656	278.270	644	5.877
Broadleaved	933.718	2.050	5.979	21.680	674	7.950
Mixed stands	626.598	1.714	6.585	328.329	668	7.147
Shrubs	1.896.953	745	4.312	574.518	446	4.236
Pasture	322.173	892	4.420	12.280	909	5.351
Total	4.082.942	1.285	5.554	1.215.078	560	5.476

Source: Modified from the Junta de Andalucía and the Generalitat Valenciana
[1] Productive value, is the value of woodland as exclusive generator of private assets
[2] Total economic value is the value of woodland as generator of private and public assets

The dates of reference for the models are: 2000 for ACA and 2001 for the ACV. Consequently the values have been updated to 2003 with the same methods used for the budgets.

The evaluation of the ACA forest land takes into account the following private elements: wood, pine nuts, cork, chestnut, pasture, game, wind; and public elements: recreational areas, landscape, CO_2 fixing and non-use.

The ACV evaluation incorporates as private assets: wood, truffles, pasture, game, fishing and wind; as public: recreational areas, landscape, CO_2 fixing replenishment of water sources, flood protection and non-use.

The ACA model has been adjusted to incorporate environmental elements from the ACV and which were not included at the time due to lack of quantitative information; the following specific elements have been added: replenishment of water sources and flood protection.

Value lost through forest fires

Initially, the value of natural stock lost when a hectare of woodland is burned is the total economic value (TEV) of that hectare. If working with regional averages, the values should be for each forested area in each of the Autonomous Communities, those contained in the columns for TEV in *table 2*. Nevertheless, not all the value of the burned surface area is lost, since part of it will regenerate naturally.

In the case of small fires natural regeneration of 100 % is assumed; conversely regeneration in extensive fires is only partial.

In order to attempt to estimate the value recovered through natural regeneration in large-scale forest fires, firstly the concept of regeneration period must be defined (PRG). This is the period of time within which, with a high level of probability, the new mass growth substituting the burnt area may be considered as established; or to put it another way, the years an area will take before it produces viable seeds or re-growth (Bond and Wilgen 1996). From an economic point of view, the mass is not considered completely recovered until it reaches the same fully functioning level it had prior to the fire, this second concept is known as the period of recovery (PRE); it may be affirmed that from this point on the ecosystem will once again generate an infinite flow – estimated with the hypothesis of a sustainable situation— of annual income equal to that lost prior to the fire. In the period between the PRG and PRE, it is assumed that the income grows in a linear manner with the passage of time. F*igure 1* illustrates this point

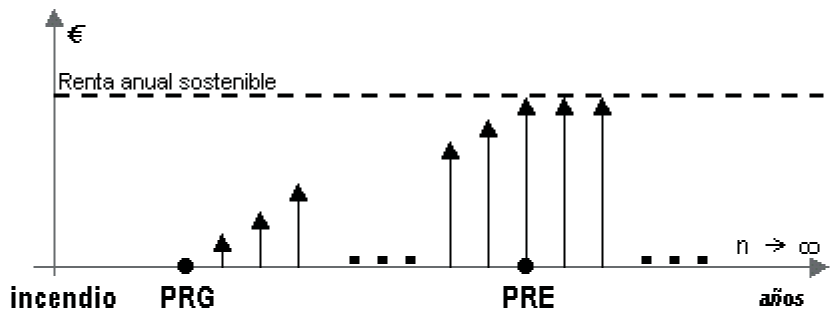

Figure 1—Flow of funds recovered by the regeneration of the mass following an extensive fire.

In large-scale fires —of more than 500 hectares— for each of the large forest areas, the percentage of regenerated surface (RGI) , the PRG and the PRE have been estimated, considering the data for each type of vegetation with the surface area of each dominant species pursuant to the Second Forest Inventory (Ministry of the Environment 1998).

With respect to conifers, *Pinus halepensis* presents the greatest level of regeneration following fire, due to its wide dissemination, aided by high temperatures and low germination requirements of the pine cone. Conversely, other species of the *Pinus* genus tend towards low germination, due undoubtedly to their early dissemination, pre-summer and the sensitivity of the cones at moderately elevated temperatures (Rey et al 2003). As an approximation, INFOMED (Mediterranean Forestry Institute) detected in the ACV that more than 78 % of the forest surface area of adult *Pinus halepensis* burned had regenerated in a natural manner. Nevertheless, in those other pine woods which had not reached maturity the results were very different, and only 2 % of the surface area was regenerated (Gómez 1998). Other studies have assigned a figure of 7% to the masses of *Pinus nigra* and *Pinus sylvestris* —which are typical of northern and Central European woods—since these practically disappear following a forest fire. (Habronk 2001).

For broad-leaved masses**,** the regenerated surface areas rises to 60 % as shown in simulations carried out in the great fire of 1994 in Bages and Bergueda in Cataluña (Habronk 2001) and that of 1995 in Mercadal in Illes Balears (Hugel 2001). *Quercus ilex* is capable of re-growth following felling and fire, which presupposes good adaptation to low intensity fires. Nevertheless, following high intensity fires its ability to grow from the stand disappears, due to destruction of the stumps. The percentage of regenerated undergrowth and brush rises to 80 % (Rey et al 2003). It is estimated that pasture areas may reach the same levels as the underbrush of up to 80%.

In an analysis of the recurrence of fires, the age at which areas of *Pinus* become established is that in which the trees are able to produce viable pine cones – between 7 and 15 years (Bond and Wilgen 1996)—. On the other hand in the case of oaks, the PRG rises to up to 25 years (Díaz–Delgado 2003). The PRG considered for other types of terrain such as brush wood and pasture is 4 to 2 years respectively. Finally, the PRE of the vegetation types was taken as the state of maturity, as defined by a panel of experts, which is the criterion used in the integral evaluation of forest lands of the Community of Madrid (Castellano et al 1999).

The capacity for the regeneration of flora may be modified by a series of factors which are extraneous to the nature of the plant species such as: size and recurrence of fire, type of terrain, height, gradient, exposure… (Bond 1996, Habronk 2001). Consequently the values shown in *table 3* are only general average figures estimated solely for the purpose of correcting the loss of value suffered by the natural stock**.**

Table 3— Regeneration data and total economic value lost in large-scale fires

Vegetation type	Conifers	Broadleaves	Mixed	Brush	Pasture	Total
RGI[1] (pct)	25	60	50	80	80	
PRG[2] (years)	12	20	15	4	2	
PRE[3] (years)	45	60	50	15	4	
Value lost CAA[4] (pct)	65,6	72,3	68,1	50,6	43,9	60,3
Value lost CAA (euros/ha)	5.019	4.325	4.485	2.182	1.942	3.348
Value lost CVA[5] (pct)	79,5	83,5	81,0	70,6	66,6	76,7
Value lost CVA (euros/ha)	4.670	6.640	5.788	2.989	3.563	4.201

Source: Modified, from the Junta de Andalucía and the Generalitat Valenciana (regional governments)
[1] Percentage considered by dominant specie, naturally regenerated surface area and the zone studied
[2] Regeneration period
[3] Recovery period
[4] Autonomous Community of Andalusia
[5] Community of Valencia

The lost value percentages in each of the areas are calculated differently for large-scale fires and others. In extensive fires all the value of surface area is lost as it does not regenerate, in the remainder income is depleted for a number of years until the forest land recovers; this reduction in value is calculated with the difference between Current Net Values of the permanent sustainable income and the flow of income shown in *figure 1*.

In small fires the value lost is calculated in the same way as with regenerated areas which have suffered large-scale fires since these recover naturally in their entirety. The total values lost per hectare for each of the Autonomous Communities studied, shown in the last column of *table 3*, have been calculated bearing in mind the lost values of each of the forested areas, considered with their respective territorial divisions.

The total value lost is greater in the ACV, because the proportion of extensive fires is much greater than in the ACA —86,52 % and 54,78 % respectively of the total surface area burned in the study period—.

Cost–efficiency function

The function which relates the efficiency of the preventive actions against forest fires measured by the surface area burned as a dependent variable, with the cost of that preventive action - the prevention plus suppression budget —, incorporates another independent variable — the Birot index—, which includes the meteorological conditions for the year with the following logarithmic formula:

$LnSQ = A_1 + A_2 \text{ x } LnP + A_3 \text{ x } LnIB$

SQ being the surface area burned, P the protection budget, and IB the Birot index; all of which refer to a specific year; and A_1, A_2, and A_3 the corresponding regression parameters, which are shown together with some statistics in *table 4*.

Table 4— Parameters of the cost-efficiency function

Concepts	Autonomous Community of Andalusia		Autonomous Community of Valencia	
	Value	T Student	Value	T Student
Independent Term. A_1	378.660	12,00	420.748	8,79
Budget Coefficient. A_2	0,9999624	-2,32	0,9999369	-4,17
Birot Index Coefficient.A_3	0,8935705	-4,63	0,9106788	-1,30
Correlation. Coefficient ^{2}	0,74		0,69	
Error of dependent variable. ey	0,6313135		0,8887510	
Snedecor's F. F	11,37		8,87	
Degrees of Freedom	8,00		8,00	

Source: The authors' own

The two regressions are significant with 95 % reliability except T of Student A_3 in the ACV, which only has an 85 % reliability. As expected, due to the numerous factors which affect the total burned surface area and the simplicity of the regression model, errors in the estimation are high, which causes extremely varied estimates. Nevertheless, the results may be considered sufficiently accurate to enable the determination of a range of budgets required for a given level of surface area burned.

The function determining the upper limit of distribution of errors for the surface area burned estimated with 95% reliability is:

$LS = e^{(LnSQ+1,96 \text{ ey})}$

LS being the upper limit of distribution of errors of the estimate of the surface area burned SQ, and ey the error of estimation.

Marginal costs

The cost-efficiency function gradients and the upper limit of 95 % reliability of distribution of error means that he hectares saved from fire by each 1000 euro increase in the budget. The equations for the gradients of these functions are those corresponding to their derivatives with respect to the variable Budget and, respectively are expressed:

$$SQ' = A_1 \times A_2^{P} \times A_3^{IB} \times LnA_2$$

$$LS' = e^{(LnSQ+1,96\ ey)} \times LnA_2$$

In reality the marginal cost being sought is the opposite of these gradients multiplied by 1,000, which is the sum of euros by which the budget should be increased to safeguard an additional hectare. The form of the functions determines that the marginal costs decrease when the budget is increased.

In this way an objective system is available —for a given meteorological situation— which permits a budget increase until the value of the surface area safeguarded is equal to the increase required to achieve it.

Discussion

The presence of meteorology in the cost-efficiency function implies that the optimum budget depends on the meteorological conditions, and, in addition, the distribution of error in the estimation of the surface area burned gives rise to a range of budgets to reach a specific surface area burned. These circumstances have been used to define the conditions surrounding the optimum budget, and those of the two e two Autonomous Communities studied are shown in *table 5*, by simply fixing three meteorological conditions :average Birot index for the period, index minus a typical deviation corresponding to an especially arid year and index plus a typical deviation to include the opposite situation; and the estimated cost efficiency function – minimum budget-and the upper limit of 95% reliability of distribution of errors – maximum budget- .

Table 5— *Conditions surrounding the optimum budget (financial figures in thousands of euros)*

Annual Drought	Autonomous Community of Andalusia			Autonomous Community of Valencia		
	Birot Index	Minimum budget	Maximum budget	Birot Index	Minimum budget	Maximum budget
High	6,04	84.711	117.636	7,91	63.012	90.636
Medium	14,27	60.083	93.008	12,24	56.592	84.216
Low	22,49	35.455	68.379	16,57	50.172	77.796

Source: Authors' own

Budgets for recent years have obtained an intermediate surface area burned between that which would be expected for the estimated cost-efficiency function and the upper limit of its distribution of errors with 95 % of reliability. As aridity is not completely foreseeable, a conservative hypothesis should be assumed. In this situation it is understood that the optimum budget would be the average of those corresponding to a high aridity in the cost –efficiency function- maximum budget – That is around 90 million Euros in the ACA and 75 million Euros in the ACV.

The average budgets of the last five years are approximately: 66 million Euros in the ACA and 68 million Euros in the ACV. Consequently, neither of the two

Autonomous Communities would be at the optimum budget level, ACA being 73 % and the ACV 91%..

The optimum budget is higher in the ACA because it covers a larger area and because the aridity is more heterogeneous and extreme.

The productive values represent 23 % in the ACA and 10 % in the ACV, thus under no circumstances can the level of budget adjudicated to forest fire prevention be justified which probably explains why the present budgets are perceived in some quarters as very high.

by increasing protection to the optimum level (Riera and Mogas 2003), which confirms that the optimum social budget is greater at current levels in the Mediterranean area.

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