Forest fire expansion under global warming conditions: multivariate estimation, function properties and predictions for 29 countries

Lohmander, Peter[a]

a. Optimal Solutions in cooperation with Linnaeus University, Hoppets Grand 6, 903 34 Umea, Sweden

Abstract

The topic of this study is forest fires. This study investigates the average relative burned area, as a function of different conditions, in 29 countries. Detailed international statistics of forest fires, published by FAO and European Commission, are used as empirical data. A multivariate fire area function with empirically very convincing statistical properties is defined, tested and estimated. A set of hypotheses was created based on three fundamental factors. The hypotheses could not be rejected on statistical grounds and the estimated parameters obtained the expected signs with very low P-values. Residual analysis supports the selected functional form. Future fire areas are predicted for 29 countries, conditional on three alternative levels of global warming conditions. The areas of forest fires in different countries can be explained by the estimated fire area function, via three fundamental factors: 1. The average area of forest fires divided by the total forest area, is an increasing function of the average temperature. Hence, global warming is expected to make the future forest fire problems even more severe. 2. The average area of forest fires divided by the total forest area is an increasing function of the total forest area. 3. The average area of forest fires divided by the total forest area is a decreasing function of the size of the population.

Methods

A theoretically understandable and reliable mathematical model is defined, estimated and empirically tested. The model predicts the average relative forest fire area in a country as a function of three explaining factors. These factors are constructed from publicly available empirical data.

Hypothesis	Mathematical Explanation	Explanation in words
H_1	$\frac{dB}{dT} > 0$	The average relative burned area is an increasing function of average temperature.
H_2	$\frac{dB}{dP} < 0$	The average relative burned area is a decreasing function of the population's size, which may be viewed as a proxy for the national firefighting capacity.
H_3	$\frac{dB}{dA} > 0$	The average relative burned area is an increasing function of the total forest area's square root, which is approximately proportional to the time it takes for centrally stationed firefighting resources to move to forest areas to fight the fires.

Figure 1.

The relative burned area (B,%) in a country (i) is determined from the following equation. T represents the average temperature. P is the size of the population and A is the total forest area in the country.

$$B_i = e^{(k_0 + k_T T_i + k_P P_i + k_A \sqrt{A_i} + \varepsilon_i)}$$

$$k_0 < 0 \wedge k_T > 0 \wedge k_P < 0 \wedge k_A > 0$$

ε_i is the national residual.

Figure 2.

Parameter statistics from the regression analysis based on the logarithmic version of the function in equation (4).

Parameter	Estimated value	Standard Error	t-value	P-value
k_0	-7,556784807	0,649653609	-11,63202159	1,39626E-11
k_T	0,436094188	0,057418758	7,594977775	5,97838E-08
k_P	-0,031821302	0,012207803	-2,606636244	0,015193428
k_A	0,460127404	0,097563843	4,716167264	7,77542E-05

Figure 3.

Table 6. Predictions of average fire areas as functions of the level of change of the average temperature.

	dT= 0	dT= +1	dT= +2	dT= +3
Country	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**
Algeria	32.105	49,651	76,786	118.750
Austria	0.072	0.111	0.171	0.265
Bulgaria	5.227	8.084	12.502	19.334
Croatia	12.248	18.942	29.293	45.303
Cyprus	1.673	2.587	4.001	6.187
Czech Republic	0.328	0.507	0.784	1.213
Estonia	0.055	0.086	0.132	0.205
Finland	0.519	0.802	1.241	1.919
France	10.906	16.867	26.084	40.340
Germany	0.541	0.837	1.294	2.002
Greece	25.894	40.046	61.931	95.778
Hungary	4.540	7.022	10.859	16.794
Italy	62.286	96.326	148.970	230.383
Latvia	0.591	0.913	1.413	2.185

Figure 4.

Table 6. Predictions of average fire areas as functions of the level of change of the average temperature.

	dT= 0	dT= +1	dT= +2	dT= +3
Country	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**	**Average Fire Area (kha)**
Lithuania	0.087	0.134	0.208	0.321
Morocco	2.916	4.510	6.974	10.786
North Macedonia	4.433	6.856	10.603	16.398
Norway	0.844	1.306	2.019	3.123
Poland	2.966	4.588	7.095	10.972
Portugal	144.555	223.555	345.730	534.674
Romania	1.757	2.717	4.201	6.497
Russian Fed.	2218.100	3430.311	5305.007	8204.239
Slovakia	0.424	0.655	1.013	1.567
Slovenia	0.283	0.438	0.678	1.048
Spain	95.686	147.979	228.851	353.921
Sweden	5.085	7.864	12.162	18.809
Switzerland	0.116	0.180	0.278	0.429
Turkey	6.885	10.648	16.468	25.468
Ukraine	3.625	5.606	8.670	13.408

Conclusion

• The areas of forest fires in different countries can be explained via a function based on three fundamental factors. The function has been empirically tested and estimated based on detailed data from 29 countries and the level of reliability is very high.

• The area of forest fires divided by the total forest area, increases with the average temperature and the size of the total forest area. It decreases with the size of the population, which is a proxy for the national firefighting capacity.

• The estimated model predicts that global warming will increase the areas of forest fires. The future developments of expected forest fire areas in the different 29 countries have been predicted for alternative levels of global warming.

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Author contact

Peter@Lohmander.com

http://www.lohmander.com/Information/Ref.htm

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