Are there Economies of Scale in Fighting Wildfires?

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Abstract

Escalating wildfire suppression costs, and a spate of catastrophic wildfires, has focused attention on government wildfire-fighting policies. Using data compiled from situation reports filed by Incident Commanders during the course of wildfires, we estimate the relationship between firefighting costs, burn area, and the number of agencies participating in the fire suppression effort, among several other explanatory variables. We examine two questions: (1) are there economies of scale in fighting wildfires? and, (2) might consolidation of wildfire-fighting responsibilities among public land-managing agencies result in cost savings?
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The increase in the number, intensity and expense of wildfires in recent years (Mutch, 2002) has reignited debate on government wildfire policy. Policymaker concerns underscore the importance of research on cost-minimizing strategies for wildfire suppression, including benefits of coordination among government agencies with suppression responsibilities (Ingalsbee, 2000, 2001). In this article we ask whether there are economies of scale in suppressing wildfires, or potential cost-savings from consolidation of wildfire-fighting responsibilities among public land-managing agencies.

With respect to acreage, current "initial attack" firefighting protocol emphasizes containing wildfires within established perimeters. Perimeter increases less than proportionally with area; consequently, the policy of immediately seeking to suppress small fires may be increasing wildfire-fighting expenditures *vis* a *vis* a less aggressive initial-response protocol.

Regarding agency involvement, wildfire fighting is currently undertaken by multiple agencies (USDA Forest Service, Bureau of Land Management, Bureau of Indian Affairs, National Park Service, etc.). Each agency has responsibility for initial response to wildfires on land under its management. This may result in, among other things, duplication of infrastructure expenditures, and coordination difficulties in the event of large wildfire events. All of the agencies in question make use of a shared Incident Command Structure (ICS). Our analysis provides some insight as to the efficacy of this standardization.

Our analysis revolves around empirical estimation of a cost function relating the cost of wildfire suppression, burn area, and the number of agencies involved in the firefighting effort. Our data are from wildfire incident management situation reports submitted daily by wildfire Incident Commanders, for fires occurring in the 1999-2001 period. Both least-squares and feasible generalized least squares (FGLS) estimation procedures are used.

Background and Existing literature

Economic theory has long been used to help shed light on issues surrounding the cost of fighting wildfires. Early research focused on developing an economic framework for analyzing the tradeoffs between fire prevention and fire suppression and fire-related economic losses (Headley, 1916; Sparhawk, 1925). Recognition that wildfires also convey ecological and economic benefits, along with congressional requirements that requests for federal funds for fire-related expenditures include cost-benefit studies, led to models that include its beneficial effects (Gorte and Gorte, 1979; Donovan and Rideout, 2003).

Understanding the cost-side of fighting wildfires has spawned research on the productivity of firefighting resources on fire suppression (Simard and Young, 1978; Phillips and Barney, 1984; Hirsch and Martell, 1996; Wittala, 1999). Early research led to the development of fire-fighting strategies that emphasize aggressive initial-attack tactics to suppress small fires and reduce the possibility of larger fires. These strategies, by increasing fuel load and inducing ecological changes towards fire-prone vegetation, may be partly responsible for increases in wildfire-fighting expenditures. Researchers have explored these impacts on the increased probability and severity of wildfires (Arno and Brown, 1991; Mutch, 1994) and the effects of prevention strategies, such as fuel management programs, on reducing the severity and cost of fighting wildfires (Omi and Martinson, 2002).

Increases in wildfire-related expenditures in recent years have intensified calls for restructuring the administration and financing of fire management in the nation (Schuster, Cleaves et al., 1997; Hesseln, 2001). Firefighting efforts are distributed among a complex web of federal, state and local, and private units with different institutional missions and overlapping jurisdictions (Pyne, Andrews et al., 1996). Coordination of efforts by various government agencies on wildfire suppression has been a recurring issue over the last 40 years, and greatly increased during the 1960s and 1970s with the creation of the National Interagency Fire Center (NIFC). The NIFC brings together all the federal agencies whose charges include fighting wildfires. In 1976, it joined with the National Association of State Foresters to form the National Wildfire Coordinating Group (NWCG). The NIFC and the NWCG spearheaded the creation of the National Interagency Incident Management System (NIIMS) and its operational organization, the Incident Command System, which provides a command system for responding to wildfires and other emergency incidents across the nation. Pressure for administrative centralization of firefighting efforts has recently gained new impetus with the creation of the U.S. Department of Homeland Security and the increased need to coordinate emergency responses in the era following the terrorist attacks of September 11, 2001. In spite of the call for increased coordination of firefighting responses, research on the effects of increased coordination on the costs of fighting wildfires is lacking.

Description of data

The data for this study are drawn from Situation Incident Reports (SIT) filed by Incident Report Commanders as part of their participation in NIIMS. The data are collected and distributed through the NWCG website and cover fires reported through the system in 1999-2001. Day-to-day SIT were aggregated by fire incident and include data on the size and cost of the fire, the resources used to fight the fire, the number of agencies responding to the fire, and the number and types of structures threatened or damaged during the fire. Descriptions of the variables are provided in Appendix 1.

The original data contained information on 1215 fires during the three-year period from 1999-2001, but values for costs, acres, personnel and agencies were not reported for 227 of these incidents. In the subsequent analysis, it became apparent the data included fire incidents where the costs per acre were either unexplainably high or low and these were also discarded.[1] This resulted in a total sample of 502 fires for the three-year period. The means, standard deviations, and the minimum and maximum values of the variables, including dummy variables and interaction terms, used in the analysis are given in Table 1.

Of the 502 fires, the average fire encompassed about 2000 acres and cost approximately $625 per acre to fight in 1990 constant dollars. The average fire incident lasted just over six days and required the participation of approximately four agencies and 858 person-days. The USDA Forest Service was involved in over 93% of the fire incidents in the sample. In an average fire, three commercial structures, sixteen outbuildings, forty-three primary residences, and less than one seasonal residence were threatened or destroyed. The number of large fires, defined as over ten thousand acres, was approximately 3% of the sample.

Econometric models and methodology

In order to test whether economies of scale exist in wildfire-fighting, we specify and estimate three equations. Our three dependent variables are log(*recosts*), log(*perscnt*), and log(*sovhd*), which are the natural log of real costs, total personnel, and total overhead personnel respectively. The independent variables are the same in each econometric model.[2] We choose a log specification for our dependent variables for two reasons: (1) to ease the interpretation of estimated coefficients; and, (2) to admit the possibility of normally distributed error terms.[3]

Among the independent variables, we are primarily concerned with log(*acres*), *dfs*, *non_fs_agcnt*, and interaction terms including the latter two variables. The coefficient on log(*acres*) – total acres burned – suggests the degree to which physically larger fires are "cheaper" to fight. That is, we assess whether there are economies of scale in the traditional sense. The log-log specification with log(*acres*) is primarily for ease of interpretation, as well as capturing nonlinearities between burn area and total costs.[4]

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[1] Outliers were identified using a computer algorithm from Insightful. Robust Mahalanobis distances were calculated between observations for cost, acreage, and personnel. Observations for which distances exceeded a threshold value were omitted. The large number of outliers is attributable to the nature of the raw data. Each observation is compiled from multiple forms that are submitted daily by Incident Commanders during the course of a wildfire. There is, then, considerable scope for human error in data entry through, for example, transcription from written forms and incorrect units. The most common error appears to be erroneous entry of dollars vs. thousands of dollars, and number of crew members vs. number of crews.

[2] The single exception is the independent variable *sovhd* in estimation where log(*sovhd*) is the dependent variable.

[3] *Recosts*, *perscnt*, and *sovhd* are all strictly positive. Consequently, the Classic Linear Model assumption of normally distributed population error terms is violated in equations where the aforementioned dependent variables are not allowed to take on negative values.

[4] Polynomial terms for acres of order three and higher proved to be statistically insignificant, and are therefore not included in our regressions.

Our examination of the impact of agency involvement on wildfire-fighting costs revolves around *fs* – a dummy variable for participation of the USDA Forest Service (hereafter "Forest Service") – and *non_fs_agcnt*, a discrete variable indicating the number of non-Forest Service agencies that participated in the firefighting process. We use Forest Service participation as a proxy for centralized administration of wildfire suppression, as it has the most forested land and most firefighting assets of the public-land managing agencies. Consequently, the Forest Service is the most likely to take lead agency role at any firefighting start.

A representative econometric model is:

$$\begin{aligned}
&\log(recosts_i) = \beta_0 + \beta_1 \log(acres_i) + \beta_2 daycnt_i + \beta_3 scrw1_i + \beta_4 scrw2_i + \beta_5 shel1_i + \beta_6 shel2_i + \\
&\beta_7 shel3_i + \beta_8 sengs_i + \beta_9 sovhd_i + \beta_{10} sccount_i + \beta_{11} socount_i + \beta_{12} spcount_i + \beta_{13} sscount_i + \beta_{14} dfs_i + \\
&\beta_{15} non\_fs\_agcnt_i + \beta_{16} dfs_i * non\_fs\_agcnt_i + \beta_{17} dfs_i * large\_fire_i + \\
&\beta_{18} large\_fire_i * non\_fs\_agcnt_i + \beta_{19} dfs_i * large\_fire_i * non\_fs\_agcnt_i + u_i
\end{aligned}$$

where u_i is a normally distributed error term for observation i, $i=1,\ldots,n$.

There is strong evidence of heteroskedasticity in all three equations that we estimate.[5] Consequently, we use a least squares estimation approach and report White heteroskedasticity-consistent standard errors. Estimation using feasible generalized least squares (FGLS) yields very comparable coefficient and standard error estimates.[6] Our least squares results are tabulated in Table 1 and the FGLS estimates are provided in Table 2. Each table provides coefficient estimates, estimated standard errors for the coefficients in parentheses, and *p*-values for the two-tailed test of significance for each variable.

Results

There are very strong economies of scale with respect to acres, *ceteris paribus*. The estimated elasticity of acres with respect to real costs is 0.105; thus, a one percent increase in burned acreage corresponds to a 0.105 percent increase in cost. The FGLS estimates suggest stronger economies of scale, with an elasticity of 0.079. The relationships between burn area and both total personnel and overhead personnel are statistically insignificant, and are also difficult to interpret, in practice.

The effects of additional agencies are qualitatively very similar in all three specifications. Focusing on the impact of real cost:

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[5] For example, the LM statistic for the White test for heteroskedasticity in the log(*recosts*) equation is 57.651, versus a 9.21 critical value.

[6] The exception to this is the standard errors in the log(*sovhd*) regression, which differ significantly from the least squares standard errors.

- The presence of the Forest Service increases costs by 128%, *ceteris paribus* – more than twice the increase in cost attributable to the addition of another, non-Forest Service agency (51%).
- These additional costs are more extreme in large-fire events, where a "large fire" is one greater than ten thousand acres in size. In these events, the Forest Service adds nearly four times the cost of other agencies (271%, vs. 74%).
- The Forest Service greatly mitigates the costs associated with other agencies' presence. In the cost case, when the Forest Service is present, each additional agency increases cost by 22.5%, vs. 51% in the absence of the Forest Service. This relationship is not statistically significant, however (p-value of 0.189), except in the case of large fires.

Roughly the same relationships hold when personnel and overhead personnel are the dependent variables. For example, the Forest Service contributes three times as many personnel (total, and overhead only) as other agencies do independently.

Conclusions

In recent years, there has been increased appreciation of the ecological value of wildfire. It has also become clear that wildfire incidence and severity can be reduced by fuel treatment, including prescribed burning. These considerations have led to a shift away from the presumption that all fires must be immediately suppressed.

This work offers an additional consideration in determining a strategy for dealing with wildfire starts: there are economies of scale in fighting wildfires. The current wildfire-fighting protocol of aggressively attempting to establish perimeter containment may result in cost-inefficiencies. The alternative is, of course, difficult to assess in the absence of a treatment group. That is, a less aggressive initial response may lead small fires to become significantly larger fires, with concomitant larger expenditures.

Economies of scale can be captured through two channels. First, rather than establishing perimeter containment around several small, proximal fires, the fires can be allowed to merge. Second, Incident Commanders can make use of 'good' natural or manmade firebreaks, which may necessitate larger burn areas. That is, a strategic, rather than tactical, firefighting approach can be taken, enabling the use of efficient firefighting tools.

There are two actionable policy implications from the two channels stated above. First, economies of scale provide an argument for contiguous land ownership. Small fires may only be allowed to merge if they, and the likely combined burn area, are all on public land. Pockets of private land may also preclude efficient firefighting strategies; for example, a fire may not intentionally be allowed to burn to a river, when the land bordering the river is privately owned. Second, there are similar arguments for the nature of the wildland-urban interface. Development should be clustered to permit larger, contiguous, burn areas. Perimeter defense of a cluster of structures is much less costly than perimeter defense of multiple structures, due to the nonlinear relationship between perimeter and area.

Our results lend support to efforts to improve coordination among agencies with wildfire-fighting responsibilities. The shared use of a single Incident Command Structure (ICS) may correspond to cost-efficiency gains, particularly in the case of large wildfires. We use the presence of the Forest Service as a proxy for centralized administration of wildfire control, and get suggestive results from looking at multi-agency fires where the Forest Service is involved. While not statistically significant, our results suggest that the presence of the Forest Service makes other agency involvement more efficient, in terms of number of personnel and total cost. The beneficial impact of the Forest Service is both practically and statistically significant in large fires. It remains an open question whether consolidation of wildfire-fighting responsibilities (i.e., dissociating wildfire-related responsibilities from public land-managing entities, such as the Forest Service and BLM) results in cost savings.

The authors recognize that economics is not foremost in the minds of Incident Commanders as they approach a wildfire start. Our results suggest, however, that the national debate on wildfire strategy should include a discussion on economies of scale.

Table 1: Descriptive Statistics

	Mean	Maximum	Minimum
ACRES			
DAYCNT			
DFS	0.934263	1.000000	0.000000
LARGE_FIRE	0.025896	1.000000	0.000000
NON_FS_AGCNT	3.181275	9.000000	0.000000
PERSCNT	858.0120	7352.000	14.00000
RECOSTS	5136.957	46250.00	14.40444
SCCOUNT	3.191235	326.0000	0.000000
SCRW1	8.557769	116.0000	0.000000
SCRW2	17.26096	204.0000	0.000000
SENGS	31.88048	316.0000	0.000000
SHEL1	1.272908	41.00000	0.000000
SHEL2	3.567729	40.00000	0.000000
SHEL3	3.665339	41.00000	0.000000
SOCOUNT	15.58566	2833.000	0.000000
SOVHD	178.7629	1617.000	0.000000
SPCOUNT	42.87052	2719.000	0.000000
SSCOUNT	0.547809	65.00000	0.000000

Table 2: OLS Results with Heteroskedasticity-Consistent Standard Errors

	(1) log(recosts)		**(2) log(perscnt)**		**(3) log(sovhd)**	
(Intercept)	4.0022 (0.5323)	0.0000	3.6032 (0.3134)	0.0000	1.1371 (0.4984)	0.0230
log(acres)	0.1051 (0.0392)	0.0075	0.0268 (0.0242)	0.2685	-0.0254 (0.0409)	0.5361
daycnt	0.0215 (0.0091)	0.0189	0.0264 (0.0072)	0.0003	0.0588 (0.0138)	0.0000
scrw1	0.0226 (0.0031)	0.0000	0.0234 (0.0025)	0.0000	0.0203 (0.0028)	0.0000
scrw2	0.0195 (0.0025)	0.0000	0.0200 (0.0019)	0.0000	0.0190 (0.0026)	0.0000
shel1	0.0023 (0.0140)	0.8695	-0.0112 (0.0089)	0.2096	-0.0048 (0.0127)	0.7069
shel2	0.0219 (0.0078)	0.0050	0.0124 (0.0057)	0.0317	0.0244 (0.0078)	0.0017
shel3	0.0094 (0.0090)	0.2962	0.0090 (0.0065)	0.1662	0.0363 (0.0109)	0.0009
sengs	0.0034 (0.0010)	0.0010	0.0040 (0.0008)	0.0000	0.0044 (0.0010)	0.0000
sovhd	0.0003 (0.0003)	0.2779	0.0002 (0.0002)	0.4768	NA	NA
sccount	-0.0066 (0.0030)	0.0304	-0.0057 (0.0023)	0.0126	-0.0084 (0.0036)	0.0190
socount	0.0003 (0.0003)	0.2309	0.0003 (0.0002)	0.1934	-9.85E-05 (0.0003)	0.7304
spcount	-0.0002 (0.0003)	0.4658	-0.0001 (0.0002)	0.4487	0.0001 (0.0003)	0.6097
sscount	0.0043 (0.0093)	0.6478	-0.0052 (0.0050)	0.2978	-0.0105 (0.0076)	0.1693
dfs	1.2762 (0.5198)	0.0144	0.8827 (0.3015)	0.0036	1.2675 (0.4564)	0.0057
non_fs_agcnt	0.5104 (0.2169)	0.0190	0.3004 (0.1280)	0.0193	0.3863 (0.1940)	0.0470
dfs:non_fs_agcnt	-0.2853 (0.2169)	0.1892	-0.1340 (0.1291)	0.2999	-0.1484 (0.1953)	0.4477
dfs:large_fire	2.7100 (0.7402)	0.0003	1.8611 (0.7272)	0.0108	1.2848 (0.8036)	0.1105
large_fire:non_fs_agcnt	0.7418 (0.1431)	0.0000	0.7831 (0.0846)	0.0000	0.3033 (0.1228)	0.0139
dfs:large_fire:non_fs_agcnt	-1.3526 (0.1971)	0.0000	-1.2356 (0.1486)	0.0000	-0.6890 (0.1930)	0.0004

Table 3: Feasible Generalized Least Squares (FGLS) Results

	(1) log(recosts)		(2) log(perscnt)		(3) log(sovhd)	
(Intercept)	4.3952 (0.5242)	0.0000	3.6868 (0.3404)	0.0000	1.5036 (0.6214)	0.0159
log(acres)	0.0795 (0.0352)	0.0242	0.0182 (0.0249)	0.4651	-0.0378 (0.0381)	0.3213
daycnt	0.0137 (0.0066)	0.0385	0.0215 (0.0058)	0.0002	0.0540 (0.0088)	0.0000
scrw1	0.0168 (0.0021)	0.0000	0.0211 (0.0019)	0.0000	0.0194 (0.0028)	0.0000
scrw2	0.0138 (0.0018)	0.0000	0.0182 (0.0016)	0.0000	0.0180 (0.0023)	0.0000
shel1	-0.0020 (0.0079)	0.8011	-0.0094 (0.0078)	0.2267	-8.70E-05 (0.0123)	0.9943
shel2	0.0142 (0.0061)	0.0198	0.0116 (0.0055)	0.0344	0.0259 (0.0080)	0.0014
shel3	0.0035 (0.0074)	0.6367	0.0061 (0.0063)	0.3324	0.0353 (0.0094)	0.0002
sengs	0.0021 (0.0008)	0.0072	0.0033 (0.0007)	0.0000	0.0038 (0.0011)	0.0006
sovhd	0.0003 (0.0002)	0.2407	0.0002 (0.0002)	0.2996	NA	NA
sccount	-0.0040 (0.0013)	0.0016	-0.0058 (0.0013)	0.0000	-0.0097 (0.0024)	0.0001
socount	0.0004 (0.0003)	0.1913	0.0003 (0.0002)	0.1903	-8.181E-05 (0.0004)	0.8031
spcount	-0.0002 (0.0002)	0.3686	-0.0001 (0.0002)	0.4375	0.0002 (0.0003)	0.4731
sscount	-0.0036 (0.0070)	0.6026	-0.0064 (0.0059)	0.2760	-0.0133 (0.0091)	0.1418
dfs	1.3732 (0.4950)	0.0057	1.0323 (0.3171)	0.0012	1.1551 (0.5913)	0.0514
non_fs_agcnt	0.4769 (0.1934)	0.0140	0.3427 (0.1300)	0.0086	0.3463 (0.2254)	0.1252
dfs:non_fs_agcnt	-0.2295 (0.1943)	0.2382	-0.1820 (0.1307)	0.1646	-0.1122 (0.2264)	0.6203
dfs:large_fire	1.4928 (0.7389)	0.0439	1.5974 (0.6723)	0.0179	0.8398 (1.0850)	0.4393
large_fire:non_fs_agcnt	0.7524 (0.4467)	0.0928	0.7648 (0.2911)	0.0089	0.2374 (0.6083)	0.6965
dfs:large_fire:non_fs_agcnt	-1.0964 (0.4650)	0.0188	-1.1394 (0.3138)	0.0003	-0.5178 (0.6369)	0.4166

Appendix 1: Description of Variables

acres: Total area burned by the fire, in acres

daycnt: Sum of days for each incident

dfs: A dummy variable indicating whether the Forest Service is present during the incident

large_fire: A dummy variable indicating whether total burn area exceeded ten thousand acres

non_fs_agcnt: Number of non-Forest Service agencies involved at any point during incident

perscnt: Sum of personnel for each incident

recosts: Real economic costs (deflated by GDP deflator) for each incident

sccount: Number of commercial structures threatened or damaged during incident

scrw1: Sum of Type-I (i.e., skilled, self-sufficient) crews for each incident

scrw2: Sum of Type-II (i.e., basic skills, not self-sufficient) crews for each incident

sengs: Sum of engines, of all types, for each incident

shel1: Sum of Type-I (i.e., largest) helicopters for each incident

shel2: Sum of Type-II (i.e., large) helicopters for each incident

shel3: Sum of Type-III (i.e., smallest) helicopters for each incident.

socount: Number of outbuildings threatened or damaged during incident

sovhd: Sum of overhead personnel for each incident

spcount: Number of primary residences threatened or damaged during incident

sscount: Number of seasonal residences threatened or damaged during incident

Note: Specifications for various crew types, helicopter types, etc. can be found in the NWCG Fireline Handbook (National Wildfire Coordinating Group (NWCG), 2004)

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