SOME MEASUREMENT CRITERIA FOR COMMUNITY SERVICE OUTPUT AND COSTS: THE CASE OF FIRE PROTECTION IN TEXAS*

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INTRODUCTION

Considerable use has been made of per capita (or per unit of income) expenditures of various community or local government services to indicate size economies and inter-community service quality and fiscal effort differentials. Indiscriminate use of these per capita measures (particularly those including only operating expenditures) may lead to very questionable policy recommendations on local government consolidation, state and federal grant-in-aid formulas, etc. Many related public and private costs are not included in most per capita expenditure data. In addition, expenditure figures are seldom adjusted for price or service "quality" differentials between governmental units.

In measurement difficulty, it would appear that fire protection falls somewhere between water supply and waste disposal at one extreme and education and health services at the other. In addition, there appear to be substantial indirect public and private costs related to fire protection, which may exceed direct public costs of fire protection. These factors and the relative scarcity of research on this service prompted its selection as a logical starting point in the effort towards improved measurement, economic analysis and evaluation of local government services.

Although fire protection is usually associated only with the fire department, a complete view of fire protection must include public water supply, building code enforcement and fire prevention activities. In addition, private fire prevention equipment and activities and private fire insurance represent very important aspects of total fire protection output and costs. Finally, examination of the rather unique trade-off relationship between various public fire protection expenditures and practices, and private fire insurance costs requires a more comprehensive view of fire protection costs. Fire protection in the state of Texas was selected for study because of its unique legal-administrative mechanism for establishing fire insurance rates and the availability of data on fire losses and private fire insurance premiums on a community basis.

Research on fire protection output and costs and related factors is both limited and conflicting. For example, Hirsch studied data for 1952 and 1956 pertaining to 32 St. Louis area fire departments in an attempt to determine factors related to per capita total current expenditures plus debt service for fire protection. He found only limited evidence for economies of scale up to a population of 100,000 and substantial diseconomies of scale beyond that point [6].

Will [25] identified relevant standard units of effort related to professionally determined service levels and service requirements for individual municipal fire departments. When these standard service requirements per capita were converted to dollars, he found evidence of major economies of scale up to a population of 300,000 and limited economies beyond that point. Neither of the foregoing studies controlled for output quality variations and neither included any related private fire protection costs, water supply costs or value for volunteer effort. In addition, both studies encountered rather substantial problems due to the limitations of available secondary data.

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A GENERAL FIRE PROTECTION COST-OUTPUT MODEL

On the basis of several theoretical and methodological considerations and criticisms of previous research, some general directions in specifying a cost-output model for fire protection emerge. First, it is possible to delineate closer approximations of quantity and quality dimensions of fire protection output than has been done heretofore. Output quantity can be thought of as either total number of people or total value of property protected. To define uni-dimensional fire protection output quantity would require a common denominator (preferably monetary) for human lives and real property. This is a difficult task from both a measurement and human values standpoint.

One approach to resolving this problem is to look at number of people protected as fire protection output quantity holding constant the value of real property per person protected. Alternatively, one might consider a given unit of property value protected as output quantity and hold constant the number of people per unit of property value protected. Unlike some other local government services, fire protection does provide more benefits to those who own more property. In addition, one might also argue that protection of burnable property from fire loss is crucial to protection of human life. Thus, the importance of property in defining output quantity must be emphasized.[1]

Given these two alternative definitions of output quantity, output quality is how well people and property are protected. Some exogenous factors such as adverse climate, structural age and type, etc., add to the difficulty of defining output quality of public fire protection. However, most of these factors can be identified and held constant in any analysis. Thus, it would seem possible to use the American Insurance Association (AIA) schedule for grading municipal fire defense and setting fire insurance rates as a guide for defining the quality of public fire protection or fire department output.

The AIA Grading Schedule has been utilized with modifications since 1916 and is composed of six major features (water supply, fire department, fire alarm, fire prevention, building department, and structural conditions) of municipal fire defense quality. Grading engineers assess deficiency points within each of these major features based on potential loss of property and life from fire. Total deficiency points are utilized to arrive at a final AIA classification number for a municipal fire defense system. Thus, it is possible to get a fairly objective evaluation of an individual municipal fire defense system's output quality based on over 50 years of municipal grading and associated fire loss experience.

A more comprehensive concept of costs is needed. None of the previous fire protection cost studies have attempted to impute a value to volunteer effort, and only one or two of the studies have given any consideration to related local government (e.g. water supply) and private (e.g. fire insurance) costs of fire protection. Accordingly, this general cost-output model will incorporate a relatively comprehensive concept of fire protection costs.

The general cost-output or average cost model might be stated as follows,

$$C_i/O_j = f(O_j, Q, X_1, X_2, - X_n, U)$$

where C_i represents five alternative definitions of fire protection public and private costs, U is a disturbance term reflecting the stochastic nature of the relationship, O_j is an independent variable representing the two measures of output quantity or size and Q an independent variable reflecting output quality as determined by the AIA Grading Schedule. Independent variables X_1, — X_n represent other factors affecting fire protection unit costs which one wants to estimate and hold constant in examining the net relationship between output quantity and unit or average costs.

Based on a review of previous theory and research, and numerous discussions with local, state and national fire protection personnel, several factors or independent variables emerge as important in explaining the variations between communities in average fire protection costs. The factors include population and dwelling density, income and wealth, urbanization, proportion of population transients, proportion of multi-unit and older housing, percent property commercial, percent population Negro or of German or Mexican origin (hypothesized effect on fire losses),[2] adverse climatic conditions (high winds,

[1] Public fire protection is also typically heavily supported (with the exception of the fund raising volunteer departments) by the property tax at the local level. Thus, one encounters a relatively unique and direct relationship between costs and benefits in the case of fire protection, even though this service does not typically utilize a user charge.

[2] Discussion with several fire grading engineers in Texas led to the inclusion of these ethnic variables. They had observed higher fire losses in communities with a high proportion of Negroes and lower fire losses in communities with a high proportion of residents of Mexican or German origin. Very strict fire laws in Mexico and Germany were cited as a possible factor. Discrimination in housing and in actual public fire protection provided may be intervening factors, particularly with the Negro population.

hot, dry weather, etc.), base salary differentials, and amount of state and federal aid received by other local government services (a "substitution" effect). Other factors such as whether the fire department is part paid, full paid or volunteer are mainly the result of improper measurement of costs.

SAMPLE SELECTION AND DATA COLLECTION

A stratified random sample including approximately 16 percent (140) of the 883 Texas municipalities was drawn. The sample was stratified to allow for comparisons within municipality size groups and some effort was made to keep the sample representative both from the standpoint of population density and full value of real estate per capita frequency distributions in the total population of Texas municipalities.

With the help of both local and state fire protection officials in Texas, a questionnaire on public fire protection costs and related factors was designed, pre-tested, and mailed out to the appropriate official (fire chief or city manager) in each municipality in the sample. Texas has no state agency charged with the responsibility of collecting data on various municipal expenditures and revenues. Thus, with the exception of the six largest municipalities in the sample it was necessary that all needed information on public fire protection costs and revenues be secured by questionnaire.

There are other reasons for utilizing a survey questionnaire to obtain public fire protection expenditure data by municipality. One problem with most secondary expenditure data on public fire protection is that no adjustments have been made for contractual arrangements and costs incurred in providing fire protection outside the municipality or for fire protection services received from outside the municipality. Another problem relates to ambulance-rescue and other non-fire protection activities. These activities make up a significant proportion of total expenditures in some fire departments and are non-existent in others. Finally, the water supply system is an integral part of the public fire protection system and some proportion of the operating and capital expenditures for water supply should be allocated or charged to public fire protection. A questionnaire was also necessary to secure data on volunteer effort, actual population protected and percent property commercial.

Follow-up mailings, phone calls and some visits resulted in a final sample of 70 municipalities representing 7.9 percent of all municipalities in Texas and a survey response level of 49.3 percent.[3] On the basis of information from these questionnaires as well as secondary data from the Texas State Board of Insurance, the Fire Prevention and Engineering Bureau of Texas, the Texas Research League, the Texas Municipal League and the *1967 U.S. Census of Government* an attempt was made to fit statistically a general cost-output model.

FINAL COST-OUTPUT CONCEPTUAL MODEL

A primary objective of this analysis is to determine the degree to which fire protection unit costs vary with the size of population and amount of property value protected. An attempt is made to account for variations between municipalities in unit costs of fire protection using five measures of unit costs. Two measures of output quantity and controlling for variations in output quality.

On the basis of the foregoing theoretical and analytical considerations, the following variables were specified for the sample of 70 Texas municipalities:

C_1	=	Adjusted 1969 fire department operating costs.
C_2	=	C_1 + annual charge for capital.
C_3	=	C_2 + annual charge for volunteer effort.
C_4	=	C_3 + annual charge for water supply.
C_5	=	C_4 + private fire insurance costs estimated from projected premiums.
C_5'	=	C_4 + private fire insurance costs estimated from key rate and property value data.
O_1	=	Population protected in 1969 (output quantity).
O_2	=	Full value of property protected in 1968 (output quantity).
Q	=	Inverse of output quality or total AIA deficiency points assessed against public fire protection (water supply, fire department, fire alarm and fire prevention).
X_{1a}	=	Full value of property per capita, O_2/O_1 (for equations C_i/O_1).
X_{1b}	=	Population per $10,000 full value unit of property, O_1/O_2 (for equation C_i/O_2).

[3]The final response of municipalities by population size included: 11 under 2500; 12 from 2500 to 10,000; 12 from 10,000 to 25,000; 13 from 25,000 to 50,000; 12 from 50,000 to 100,000 and 10 over 100,000.

X_2 = Total property taxes collected in 1966-67 per unit of property value protected.

X_3 = Full paid vs. other fire department manpower arrangements (for equations C_1/O_1, C_1/O_2, C_2/O_1, and C_2/O_2).

X_4 = Average monthly salary for firemen or hosemen in 1969.

X_{5a} = Intergovernmental revenue received in 1966-67 per capita (for equations C_i/O_1).

X_{5b} = Intergovernmental revenue received in 1966-67 per unit of property value protected (for equations C_i/O_2).

X_{6a} = Population protected (O_1) per square mile (for equations C_i/O_1).

X_{6b} = Full value of property protected (O_2) per square mile (for equations C_i/O_2).

X_7 = Total AIA deficiency points assessed for adverse climatic conditions.

X_8 = Total AIA deficiency points assessed for unusual occurrences.

X_9 = Percent of property protected commercial.

X_{10} = Percent of structures built in 1939 or earlier.

X_{11} = Percent of population Negro in 1960.

X_{12} = Percent population of Mexican foreign stock in 1960.

X_{13} = Percent population of German foreign stock in 1960.

Alternative functional forms considered for the net cost-output relationships (the output quantity variables O_1 and O_2) included linear, quadratic, semi-log (logarithm to the base e of just the output quantity variable) and reciprocal functions. On the basis of previous empirical and theoretical work on fire protection, scatter diagrams and some inherent advantages of the reciprocal vs. the semi-log function, it was decided to fit a linear, quadratic and reciprocal function to each of the net cost-output relationships. The "best fitting" functional relationship (between unit costs and output quantity) as measured by the magnitude of the adjusted multiple coefficient of determination (R^2) was the reciprocal function in all 12 equations. This is the functional form reported in Table 1 for each of the net cost-output relationships. A linear-function was utilized for the density variables (as well as for all other independent variables except output quantity) in the cost-output analysis.

STATISTICAL MODEL AND RESULTS

An ordinary least squares multiple regression technique was utilized to estimate the final statistical fire protection cost-output model for Texas which can be stated as,

$$C_i/O_j = b_0 + b_1\, 1/O_j + b_2\, Q + b_3\, X_1 + \text{—} + b_{15}\, X_{13} + U$$

where the fire protection output quantity independent variable (O_j) is expressed as a reciprocal. In other words, when b_1 is positive, fire protection average costs (C_i/O_j) decrease with an increase in output quantity (O_1 or O_2). The opposite is true when b_1 is negative. All other independent variables involve a linear fit, i.e., coefficients other than the one (b_1) attached to O_1 and O_2 are linear in arithmetic values.

The two cases of highest intercorrelation may be worth noting. Fire protection output quantity defined as the inverse of the full value of property protected ($1/O_2$) is positively correlated (a partial correlation coefficient of .889) with the ratio of people to property value protected (O_1/O_2). In addition, property taxes collected per unit of property value (X_2) shows a .661 correlation with the full-paid vs. other fire department manpower arrangements dummy variable (X_3). In both cases, the structural relationships are expected to hold over time and the independent variables are considered sufficiently important to include in the model in spite of the difficulty of interpreting their respective regression coefficients.

The format of Table 1 is arranged to allow evaluation of the net Texas fire protection cost-output relationship and the relative importance of several other hypothesized explanatory factors with progressively more comprehensive measures of fire protection costs (C_1, — C_5). In addition, output quantity is expressed both in population protected (O_1) and $10,000 full value units of property protected (O_2). Volunteer effort is evaluated on a modified alternative cost estimate of six dollars per alarm. This is based on an AIA grading rule-of-thumb that it takes approximately four volunteer firemen to equal one full-paid fireman in effectiveness. Finally, private fire insurance costs are estimated utilizing two alternative techniques. One estimate is based on the projection of fire insurance premiums paid in 1956-57 (C_5), and the other estimate is derived from the key rate and full value of commercial and residential property data for each municipality (C_5').

Except for the output quantity independent variables, the regression coefficient and t-test values are reported in Table 1 only for those cases where the t-test values (ratio of each independent variables regression coefficient to its standard error) are significant at the 25 percent level or higher. However, very little explanatory importance should be attached to those independent variables significant at only (P) = 0.25. The type of fire department organizational arrangement dummy variable (X_3) is omitted from those equations ($C_3 - C_5$) where an imputed value has been assigned to volunteer firemen effort.

The percent of total variation in alternative measures of fire protection unit costs explained by all of the independent variables ranges from a low $\bar{R}^2$ value of .0877 for equation C_5/O_1 to a high $\bar{R}^2$ value of .9381 for equation C_4/O_2. Without exception, the individual cost equations have a higher R^2 value when they are expressed in terms of property value protected rather than population protected. In addition, where property value protected is the unit of output, the cost equations have progressively higher explanatory power as the definition of fire protection unit costs becomes more comprehensive. The opposite is true (except equation C_5'/O_1) where population protected is the unit of output. The implication seems to be that value of burnable property in Texas is generally more closely correlated with fire protection inter-community cost differentials than is population.

There would appear to be merit in emphasizing the cost-output equations (C_5'/O_1 and C_5'/O_2) with the most comprehensive measure of public and private fire protection costs (fire department adjusted operating and capital expenditures, volunteer effort, water supply and private fire insurance costs). Utilizing the relative size of the Beta coefficients as a criterion, one can draw some conclusions about the relative importance of the various independent variables in these equations. With public and private costs on a per capita basis (equation C_5'/O_1), property value per capita is the most significant explanatory variable (positive) followed by population size (negative), property taxes per unit of property value (positive) and adverse climatic conditions (positive). With Texas public and private fire protection costs expressed on a per unit of property value basis (equation C_5'/O_2), total property value is the most significant explanatory variable (negative) followed by the number of people per unit of property value protected (positive), hosemen average monthly salary (positive) and property taxes per unit of property (positive).[4]

There are generally (except for equation C_1/O_1) "size" economies (i.e. more populous and higher burnable property value communities tend to have lower unit costs) in the provision of fire protection in the Texas communities sampled. However, contrary to the empirical findings by Hirsch and Will, most "size" economies are exhausted at a population protected of around 10,000 people (See Figure 1). Up to a population of approximately 10,000 the magnitude of the "size" economies tends to increase when the unit costs of fire protection include (in addition to fire department operating costs net of ambulance activities) an annual cost for fire department capital, an imputed value for volunteer effort, a charge for water supply, and an estimate of private fire insurance costs. In other words, when the more comprehensive measures of fire protection costs are utilized, the unit costs are not only higher in the smaller communities, but the differential between small and large communities is much greater. Further, adverse climatic conditions, value of property per person protected and percent of structures built in 1939 or earlier tend to be positively and significantly correlated with most of the measures of fire protection unit costs.

SOME POLICY IMPLICATIONS

Small communities located in close proximity to another community may be able to realize reductions in both public and private fire protection unit costs via consolidation or contractual arrangements for fire departments as well as water supply, inspection and other components of the total fire protection system. In other cases it may be possible for adjoining communities to share or for smaller communities to lease or secure certain types of specialized and relatively expensive communications, fire fighting and emergency equipment, inspection personnel and training programs from larger adjoining communities.[5] Some small, isolated communities

[4] Quite different procedures were utilized in estimating property value protected in equation C_5'/O_1 vs. C_5/O_1 (see footnotes to Table 1). This apparently resulted in the lack of significance of the output quality variable (Q) in equation C_5'/O_1. The quality variable was also insignificant in the equations with the dependent variable defined as costs per unit of property value protected.

[5] The original study included a detailed benefit cost analysis of actual fire protection system improvements with benefits being defined as private fire insurance "savings." These findings will be published in a forthcoming research bulletin from Cornell University titled "Public–Private Fire Protection Cost Trade-Offs in Texas and New York: A Benefit Cost Analysis."

Table 1. STATISTICAL RESULTS[a], TEXAS FIRE PROTECTION COST-OUTPUT MODEL

Dependent Variables[b]		Output[c]	Quality[d]	"Demand" Factors				
	Mean Value per Unit of Protection		AIA Fire Protect. Def.Pts.	People & Property /Unit of Protect.	Property Taxes/ Unit of Property	Full Paid Dept.=1 Other=0	Hosemen Av. Mo. Salary	Intergovt. Revenue
Defined	($)	$1/O_j$	Q	X_{1a} & X_{1b}	X_2	X_3	X_4	X_{5a} & X_{5b}
C_1/O_1	6.26	-.1213 (-.4948)	-.0197 (-2.570)	.0494 (3.804)	g	1.516 (1.491)	.0027 (1.388)	g
C_2/O_1	7.57	.6292 (2.434)	-.0218 (-2.697)	.0417 (3.045)	g	1.454 (1.357)	.0028 (1.372)	-.2567 (-1.308)
C_3/O_1	8.07	1.217 (3.970)	-.0280 (-3.005)	g	g	f	g	-.2670 (-1.211)
C_4/O_1	11.44	1.282 (3.608)	-.0300 (-2.775)	g	.0523 (1.834)	f	.0033 (1.209)	-.4609 (-1.803)
C_5/O_1	22.35	.9043 (1.250)	-.0504 (-2.290)	g	g	f	g	-.6997 (-1.344)
C_5'/O_1	19.35	1.035 (2.389)	g	.2140 (9.681)	.0454 (1.306)	f	g	g
C_1/O_2	12.89	.1654 (1.219)	g	.0118 (1.678)	g	g	.0109 (3.169)	g
C_2/O_2	16.89	.6497 (4.310)	g	.0113 (1.448)	g	g	.0072 (1.885)	g
C_3/O_2	21.11	2.208 (7.919)	g	.0486 (3.394)	g	f	.0229 (3.010)	g
C_4/O_2	29.73	2.248 (7.896)	g	.0764 (5.196)	.1557 (1.839	f	.0261 (3.333)	g
C_5/O_2	54.81	1.061 (2.058)	g	.1207 (4.562)	g	f	g	g
C_5'/O_2	45.78	2.192 (6.555)	g	.0850 (4.950)	.1263 (1.279)	f	.0269 (2.943)	g

[a]Except for the output quantity independent variable (O_j), the regression coefficient and t-test values (in parentheses) are given only for independent variables that are significant at the 25 percent level or higher. With 70 observations, a total of 15 independent variables and two-tailed t-test, the approximate t-value for each of five significance levels (probability of a Type I error) is as follows:

(P) 0.25 = 1.16
(P) 0.10 = 1.67
(P) 0.05 = 2.00
(P) 0.01 = 2.66
(P) 0.005 = 2.92

[b]C_1/O_j = Adjusted 1969 fire department operating costs per unit of protection per capita (O_1) or per $10,000 full value property (O_2).
C_2/O_j = (C_1 + annual charge for capital investment) per unit of protection.
C_3/O_j = (C_2 + annual charge for volunteer effort at $6 per volunteer alarm unit) per unit of protection.
C_4/O_j = (C_3 + annual charge for water supply) per unit of protection.
C_5' = C_4 + private fire insurance premiums estimated from key rate and full value of property data.

Other Factors Related to Unit Costs								
Population and Property Density	Adverse Climatic Conditions	Unusual Occurrences	Per cent Property Commercial	Per cent Structure Built 1939 or Before	Per cent Population Negro	Per cent Population Mexican	Per cent Population German	
X_{6a} & X_{6b}	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	$\bar{R}^{2e}$
g	.0537 (2.821)	g	g	g	g	g	g	.6402
g	.0585 (2.917)	.0610 (1.187)	g	g	g	g	g	.5182
g	.0601 (2.682)	.0868 (1.493)	g	g	g	g	.9758 (1.692)	.4245
g	.0783 (3.015)	g	g	.0430 (1.250)	g	-.0722 (-1.311)	g	.3804
-.1680 (-1.718)	.1075 (2.031)	g	g	.0902 (1.286)	g	-.1483 (-1.322)	g	.0877
g	.0576 (1.817)	g	g	g	g	g	g	.7266
g	.0972 (2.679)	g	g	g	.1944 (1.345)	.1305 (1.666)	g	.6495
g	.1157 (2.869)	g	g	g	.2711 (1.645)	.1373 (1.577)	g	.7628
.2281 (1.285)	g	g	g	g	g	g	g	.9186
g	.1098 (1.471)	g	.1385 (1.575)	.1489 (1.508)	g	g	g	.9381
-.4557 (-1.389)	.1902 (1.415)	g	g	.2909 (1.638)	g	g	g	.8123
.2611 (1.226)	g	g	.1820 (1.773)	g	g	g	g	.9262

[c]Output quantity variable where O_1 = population and O_2 = full value of property protected. The reciprocal function provided the best fit in every equation and is the functional form reported.

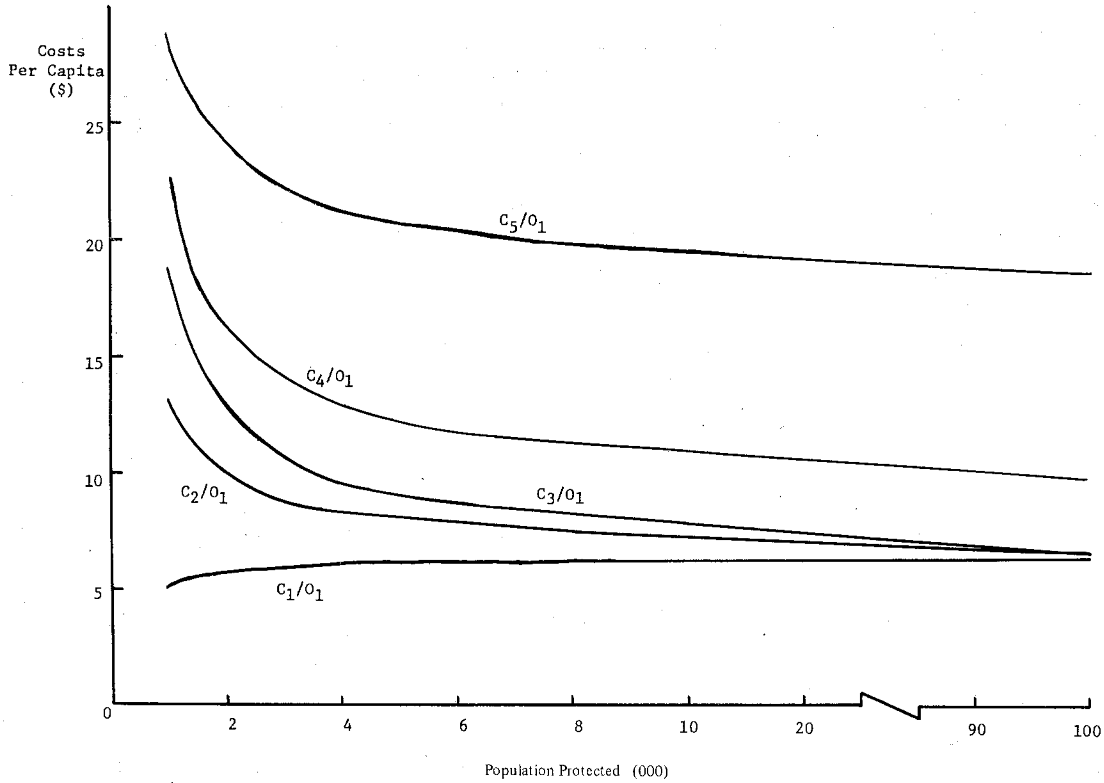
[d]Sum of AIA deficiency point assessed against municipal water supply, fire department, fire alarm and fire prevention activities.

[e]Multiple coefficient of determination adjusted for degrees of freedom.

[f]Variable omitted from equation.

[g]Variable included in equation estimation but not significant by the above t-test criterion.

Figure 1. RELATIONSHIP BETWEEN POPULATION PROTECTED AND FIVE MEASURES OF FIRE PROTECTION PER CAPITA COSTS IN 70 TEXAS MUNICIPALITIES, 1969



may not be able to work out cooperative or contractual arrangements. Further, the potential "size" economies in fire department operating and capital costs appear to be quite limited without improving the water supply and fire prevention components of the fire protection system, and imputing a value to volunteer effort.

The most comprehensive fire protection unit cost measures (C_5/O_1 and C_5/O_2) had mean values over three times higher than those for the least comprehensive measures (C_1/O_1 and C_1/O_2). Other local government services may have significant related (particularly inversely related) public and private costs. Thus, the impact of increasingly more comprehensive measures of costs on the unit cost differentials between different sizes and types of communities may have some general application. Prime examples of some of these related costs are the services of volunteer hospital workers, private health insurance costs, private transportation and other costs incurred in securing public services, and expenditures for private and parochial schools. Even simple comparisons of unit costs of various local government services between communities of like size and type would gain considerable validity and usefulness if more comprehensive and precise cost and output measures were utilized.

Similar geographic and technological constraints to those discussed in the case of fire protection complicate implementation of consolidation and contractual arrangements to realize "size" economies in existence with other local government services. Some qualifications are also necessary in generalizing to other services the fire protection findings on unit cost differentials between various measures of public and private costs. However, more comprehensive and precise definitions of costs and output may lead to quite different conclusions on unit cost differentials between various sizes and types (e.g., rural vs. urban or county vs. city) of communities with services other than fire protection. To the extent that various measures of local government service unit costs reflect or are utilized to establish criteria for the allocation of state and federal money and in-kind grants, these findings may be quite significant.

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