ECONOMIES OF CITY SIZE: PER CAPITA COSTS OF PROVIDING COMMUNITY SERVICES

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PREFACE

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CHAPTER I

INTRODUCTION

The economic efficiency of our large cities is increasingly called into question. The private costs of production and distribution appear to be low enough to attract firms, jobs and people. Yet problems of congestion, air pollution, crime and violence plague the metropolis. One hypothesis explaining metropolitan growth despite these problems lies in the disassociation of private and social costs. The entire social costs of metropolitan problems are not fully reflected in the private accounts of firms making location decisions. If the full social costs were included, firms might find the metropolis less attractive and might locate elsewhere. Furthermore, if the costs of adequate hospital and schooling services were charged to the firms, perhaps many firms would find small towns unattractive locations. As a long-run solution to city problems, public policies to redirect population flows may be less expensive than a direct effort and large subsidies to solve crucial problems in the metropolis. Estimates of economies of city size can help to resolve such issues of decentralization, the optimal rural-urban balance, and viable size growth centers for multi-county development districts. Estimates are also of value to those planning community services.

While the public has had no conscious policy aimed at an optimal growth pattern among city sizes, this need not always be so. Location of government employment and of some private employment (by firms who rely on government funds), zoning, subsidies to industry, welfare payments, housing subsidies, transportation, government interests, and numerous other public policies can favor the growth of one size of city over another.

To apply such policies, some guidelines are needed to determine an optimal size of city--the size of city where more of our people might be encouraged to locate. One measure for the optimal city size is the per capita cost of providing community services. City sizes with low per capita costs of public services might be encouraged to grow until they reach a size at which costs of services per person begin to mount. Supplemental data, not included in this study, on private production costs and attitudes would provide an even more comprehensive basis for determining optimal city size.

The overall objective of the study is to construct a unit cost curve, showing the cost of social services per capita by city size and adjusted for externalities and quality of services. Previous estimates of the cost of education, hospital services and utilities will be used to complete the bundle of services publicly provided by society. The principal contribution of this study is to include the full cost of police protection, air pollution and fire protection when externalities and quality of services are taken into account. Specific objectives are:

1. To estimate the per capita cost by city size of police protection, holding crime rate constant.

2. To estimate the per capita cost by city size of a given quality of air--with the pollution level reduced to an acceptably low level.

3. To estimate the per capita cost by city size of a given quality of fire protection--including both public outlays for fire departments and private outlays for fire insurance.

4. To utilize previous per capita cost estimates of providing other services to complete the bundle of services.

5. To combine the estimated per capita costs from (1), (2), (3), and (4), forming a unit cost curve that will show overall economies and diseconomies of size city.

The Current Study in Relation to Other Studies in Economies of City Size

Economists as well as sociologists, geographers, and other social scientists, have shown interest in the idea of an optimal size city since the turn of the century. The criteria used for determining an optimal size for cities have varied greatly. Some authors also have made value judgments about nonquantifiable factors that relate to optimal city size.

Ebenezer Howard (1902), an English authority on city planning, places the maximum population of the ideal city at about 32,000, depending somewhat on the size of the component families.[1] Increase in population should be accommodated he says by building another city nearby. He advocates a "Garden City" covering 6,000 acres--½ cultivated, ½ covered with streets and buildings. Brennan (1949), basing his findings on a desirable social life for the inhabitants, rates the optimal size to be 10,000-20,000.[2] Ogburn (1937) concluded that the American city size from 30,000 to 50,000 was optimal.[3] After studying advantages and disadvantages of cities of differing size classes, Duncan

(1949) concluded that the city of 50,000, give or take a few thousand, appears to be the best size for providing a more stable, better educated, economically secure people.[4] He contends there is no fundamental reason why a city of such size might not come close to the ideal as a place to live, work, and play, especially if it achieves good working relations with similar communities in its area. In a similar study, Sharp (1940) also concludes that the optimal size is 50,000-100,000 people.[5] Both Sharp's and Duncan's studies did not consider the quality and scope of the services as well as their length and continuity of operation.

A large number of studies have been undertaken by a group of economists, interested chiefly in public finance, concentrating on the fiscal aspects of municipal governments. These empirical expenditure determinant studies concern themselves with both general spending levels and specific service spending levels. One of the earliest such studies was made in 1936 by Colm.[6] He used scatter diagrams to find a positive relationship between state-local expenditures and income, urbanization, industrialization and population density. Two services--police protection and education--were analyzed using city size and per capita costs as the variables. Again, a positive relation was apparent in the diagrams. Fabricant, using cross sectional data for 1942, found current expenditures of local governments strongly related to population density, urbanization, and income.[7] The Fabricant analysis was repeated several times using newer data and modified models. Fisher (1961) used 1957 data and concluded that the variables used by Fabricant no longer explained as much of the variation in spending.[8] Sacks and Harris (1964) added federal and state aid and found aid payments and income levels explained a large part of the expenditure variation.[9] Finally, Kurnow (1963) altered the Fabricant approach by using a joint regression model as opposed to an additive model and the joint model was deemed more appropriate for studying expenditure determinants.[10] The Fabricant analysis and the three similar studies that followed used per capita state and local expenditures for the individual states. The three independent variables--population density, percent of the population that is urban and per capita income--were for the state as a whole and not for individual cities.

Hawley (1951) examined the relationship between municipal expenditures of the central city and 18 social and economic characteristics for 76 metropolitan areas using correlation analysis.[11] He found central city expenditures positively related to population density within the city and to the population size and other characteristics of the satellite area. Scott and Feder (1957) made a multiple regression analysis of per capita municipal expenditures of 196 California cities with over 25,000 population.[12] They used per capita property valuation, per capita retail sales, percent population increase, and median number of occupants in dwelling units as independent variables. The first two variables accounted for almost all the explained variations in expenditures. Brazer (1959) used sophisticated statistical techniques to determine the relationship between city expenditures and a number of independent variables, including city size, geographical location, variance in and among states and median income for 452 cities using 1951 data.[13] The analysis was made not only for total general operating expenses, but also for police protection, fire protection, highways, recreation, sanitation, general control, and others. Brazer states,

". . . the association between population and per capita expenditures is statistically significant only with respect to police protection when other factors are taken into account."[14] Even though the positive relation between police expenditures and city size was significant, the magnitude of the coefficient was so small that the per capita expenditures would only increase $.07 as cities grew from 10,000 to 1 million.

In terms of economies of scale, Hirsch (1967) suggests that city governments serving from 50,000 to 100,000 might be most efficient.[15] The Advisory Commission on Intergovernmental Relations (1968) reported that higher relative costs are likely to emerge in large urban aggregations.[16] The examination of public expenditures and employment for communities of 25,000 to 250,000 in three representative states indicated that at least up to the 250,000 level, cities do not, in general, demonstrate any tendency toward either major economies or diseconomies of scale. In discussing urban economies of size, Alonso faults the minimum cost approach mainly because only inputs are measured and the outputs are implicitly assumed constant.[17] He presents an aggregate theory of city size that includes per capita output as well as per capita cost. However, the empirical data presented for average output and cost in German and Japanese cities were not adjusted for externalities such as crime or air pollution.

The methodology employed in the previously cited studies falls short of what is required to examine the existence of economies or diseconomies of scale with regard to city size and public services. The use of the actual expenditures approach gives a cloudy picture of the quality and quantity of services provided by urban governments. Another major weakness of past studies of economies of city size is that they do not account for demographic differences among cities and for externalities associated with crime, air pollution and fire protection. These externalities are social costs borne by individuals but do not enter the private accounts of the firms for which the people work. Previous research on costs of police protection, air pollution control and the fire protection will be discussed below with emphasis on the attempts to correct for quality differences among cities providing the service.

Previous studies of the cost of police protection have focused on factors influencing expenditures. Hirsch (1959) estimated per capita total expenditures for police protection in the St. Louis area and concluded that the average unit cost curve is about horizontal.[18] Schmandt and Stephens (1960) studying Milwaukee County, Wisconsin, concluded that per capita expenditures for police protection were correlated with population and service level; however, no significant scale economies were discovered.[19] The problem of measuring the output (especially the quality dimension) of public services has been a major barrier to research. Efforts to deal with the problem have taken several forms. Hirsch employed an 'eyeball' rating scheme to the police force; Schmandt and Stephens counted the number of subfunctions performed by the police department.[20] A more recent study by Bradford, Malt and Oates (1969) examined the per capita expenditures for police protection over time and among cities of varying size.[21] The results indicated larger cities spend more per capita than smaller cities on police protection. The authors were concerned with the rising expenditures through time for police protection and other local public services. Bradford, et al., point out that the per capita cost of providing a given level of safety in urban centers probably has risen more rapidly than the per capita cost of maintaining a given police force. Two vectors were employed to illustrate this dimension; however, the authors acknowledged the possibility of the "degree of safety" vector differing from individual to individual and concluded that a single safety vector cannot be utilized. The trend in insurance premiums was offered as a measure or guide to changes in the safety level; still no attempt was made to estimate a cost associated with a level of safety or to relate the crime rate, which is a likely candidate to measure the degree of safety, with police force numbers and city size.

Air pollution cost studies to date have concentrated on the annual total cost of air pollution, either the cost of cleaning the air or the property and health costs of not cleaning the air. One frequently quoted cost of air pollution damage, $11 billion, originates from an estimate of cleaning costs from the smoke damage data for Pittsburg in 1913.[22] The cost was estimated to be $20 per person per year. In 1958, this figure was updated by the commodity price index and multiplied by the 1958 population to arrive at the $11 billion mark.[23] Another variation of this study results in the cost of $4 billion, obtained by multiplying the updated 1958 cost by the urban population.[24]

Ridker (1967) identified and estimated total costs for a variety of potential effects of air pollution including maintenance costs of residential, commercial and industrial facilities; damage to trees, agricultural crops and livestock; and costs associated with illness and death of humans.[25] The proportion of the cost due to air pollution was $5.5 billion. More recently Lave and Seskin concentrating on the health costs alone argue that 25 percent of all respirator disease is associated with air pollution.[26] They concluded that in 1963 health damages totaling $2 billion were attributable to air pollution. Mason, Ozolins and Morita (1969) compared air pollution sources and emissions for metropolitan areas in terms of city size, location, area and other parameters.[27] These estimates of total costs and benefits of air pollution control activities are helpful in making the initial decisions whether to instigate programs, but more comprehensive empirical analysis is warranted to determine what type of policy towards air pollution should be followed.

Hirsch (1959) estimated a unit cost curve for fire protection in the St. Louis area and concluded that the minimum per capita cost of fire protection occurred at city size 110,000.[28] The quality variable used by Hirsch was a standardized average inverse of fire insurance premiums. The premiums which indicate the fire risk were obtained from the Missouri Inspection Bureau. The sample of cities for this study included a central city and the surrounding satellite communities. Will (1965) employed a different approach in computing the per capita costs of fire protection.[29] He relied on engineering data related to service level and professional expertise related to service requirements to compute the cost of providing the necessary level of public services. This approach was used to estimate annual per capita standard service requirements for fire protection, in dollars, for 38 cities varying in size from 50,000 to 1,000,000. The statistically significant geometrical relationship was that of a hyperbola eventually becoming asymtotic to the horizontal axis. A recent study by Hitzhusen (1972) uses Texas and New York data to estimate the costs of providing fire protection and finds economies of size for the larger communities.[30] People and property value protected were used as measures of fire protection output. The costs used in the study included both public and related private costs. Trade-offs between fire department expenditures and fire insurance premiums were also analyzed in this comprehensive study.

The present study improves upon the previous estimates of economies of city size by incorporating the disassociation of private and social costs of providing police protection, air pollution control and fire protection services. Thus, this study includes more dimensions than previous studies dealing with the economies of city size.

General Outline of the Study

The organization of this study is built around the ultimate objective of determining the optimal city size for providing a bundle of public services of equal quality in all city sizes, with city characteristics standardized for variables other than size. The costs of providing each service are estimated separately and then combined to form a unit cost curve representing a given quality of services by city size. The assumption is that these costs are additive. Chapter II deals with the costs of providing police protection. Variables in the regression analysis are used to adjust for differing social and economic structures among city size. The cost of a given level of police protection is estimated using the crime rate as the degree of safety. Actual police department expenditures are compared to the costs of a given level of safety. Two methods of reducing the level of crime are discussed--a direct attempt by increasing the police force and a policy of decentralization.

Chapter III analyzes the costs of controlling air pollution via the government proposed regulations and a perfectly discriminatory application of controls. The costs of a given quality of air by city size is estimated by holding the pollution level constant after correcting for climatic variations and economic variations and economic activity. Also the costs of controlling by both methods discussed above are contrasted with the previous cost estimates of allowing pollution to continue in our economy. Again, the comparison is made of a direct attempt to control pollution and a policy of decentralization.

Chapter IV analyzes the costs of fire protection. Public outlays for fire departments and private outlays for fire insurance are used to estimate the cost of a given quality of fire protection. The measure of quality used in Chapter IV is the state rating bureau's evaluation of city fire defenses.

The cost of providing hospital and education services are analyzed in Chapter V, and the costs of providing utilities (water, electricity, sewer, and garbage and refuse disposal) are calculated in Chapter VI. These two chapters rely heavily on previous work, although all have been altered to apply to this study. The disassociation of private and social costs of the services in Chapter V and of utilities in Chapter IV are expected to be much less than those for police protection and air pollution control.

The final chapter combines the costs (on a per capita basis) estimated in Chapters II, III, IV, V, and VI to form a unit cost curve of a given quality of public services by city size. The unit cost curve measures economies and diseconomies of city size as well as potential saving in community service costs from a shift toward more nearly optimal size cities.

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CHAPTER II

THE COST OF CONTROLLING CRIME

This chapter deals with only one aspect of city size--the economies of controlling crime. The purpose of this chapter is to:

1. Estimate by size of city the crime rate adjusted for race, sex, and other variables.

2. Measure the social cost of crime by the outlay per capita for police necessary to hold the crime rate at a given level among all city sizes while statistically holding constant city characteristics other than size.

3. Compare the social cost of controlling crime by the policy of decentralization versus the policy of increasing police protection.

The Model

The problem of measuring the output (especially the quality dimension) of public services has been a major barrier to researching economies of size for public services. In this study, the output of the police force is measured by its effectiveness in controlling crime. Per capita crime rates C, per capita police numbers P, and other characteristics of cities including population size S, racial composition N, median income levels Y, population density D, age structure A, and sex structure X, comprise the variables in an econometric model of the form:

$$\hat{C}_t = f(\hat{P}_t, S, N, Y, D, A, X) \qquad (1)$$

$$\hat{P}_t = f(P_{t-1}, C_{t-1}, S, N, Y, D, A, X) \qquad (2)$$

The model is a simultaneous system, with C_t and P_t jointly determined in the current year t. The equations are recursive. The police number per capita in year t is a function of lagged endogenous variables C_{t-1} and P_{t-1}, and exogenous variables S, N, Y, D, A, and X. The predicted value $\hat{P}_t$ from (2) is used to estimate the coefficients in equation (1), thereby reducing least squares bias. The lagged value P_{t-1} in (2) indicates a distributed lag form--this allows the adjustment of P_t to the explanatory variables to occur over a period of years rather than in just one year.

The coefficient of $\hat{P}_t$ is expected to be negative in (1)--a larger number of police per capita is expected to reduce the crime rate in year t. The coefficient of C_{t-1} is expected to have a positive sign in (2). A higher crime rate is expected to lead to more policemen per capita but with a lag.

The coefficients of (1) provide an estimate by city size S of the crime rate C adjusted for other variables N, Y, D, A, and X. The size variable is divided into a set of dummy variables S_i so that the crime rate need not be a simple linear function of population over all city sizes.

Ideally, the social cost of crime would measure the net disutility in the populace that stems from crime for each city size. This ideal concept poses difficult problems of measuring the trauma of individual and collective fear and other nonquantifiable costs of crime in cities characterized by high crime rates. An empirical counterpart to the ideal measure of the social cost of crime is used in this study and circumvents problems of measuring the individual components of the social cost of crime. This approach is to compute the cost in dollars of holding the crime rate down to some given level over all sizes of cities. The empirical procedure is to vary police numbers by city size based on the coefficient of $\hat{P}_t$ in (1) so that the crime rate is statistically held constant at some given level over all city sizes. This approach avoids problems of externalities (differences between private and social cost) by statistically holding the crime rate constant. The approach assumes that (a) crime can be controlled, (b) the cost of controlling crime at the levels used in this study is less than the social cost of allowing it to occur, and (c) the social cost per capita is the same among cities in which the measured crime rate is the same. We shall see that assumption (a) may not be met in large cities. The preponderance of references to "law and order" in the political dialogue gives credence to assumption (b).

The Data

The model was applied to data from 754 cities with populations ranging from under 25,000 to over 1 million inhabitants.[1] Data on police and crime rates were obtained from the Federal Bureau of Investigation for the years 1967 and 1968.[2] The police rate P is the total number of police department employees, both police officers and civilians, expressed in per capita terms.[3] The measure of crime used in this study is compiled by the FBI. The crime rate per 100,000 inhabitants consists of the total violent crimes (offenses of murder, forcible rape, robbery and aggrevated assault) and the total property crimes (offenses of burglary, larceny entailing $50 or more, and auto theft). Clearly, this is not an ideal measure of crime and the FBI is quick to point this out. First of all, the measure does not report the number of criminal acts that actually occur, but those that are reported to or by the police. Second, the index gives equal weight to each crime although some crimes should be weighted more heavily than others. A disaggregated analysis reported later at least partially deals with this second limitation.

Many crimes are not reported, leading to errors in the dependent variable C. The crime rate is biased downward for all city sizes. If a greater proportion of crimes are unreported for large cities than small cities, then the results of the study will be biased toward economies for large cities. We have found no convincing evidence that reporting bias is greater for large than for small cities, and this data problem is not expected to indicate unwarranted economies to any particular size of city in the analysis. Sources of error in the crime index that are of a random nature give rise to inefficiency but not biasedness in the least squares estimates to be presented later.

The outlays for police protection are found by dividing the total police department wage and salary expenditures obtained from the International City Manager's Association by the number of police employees.[4] The population and socioeconomic data are from the U. S. Bureau of the Census.[5] The set of dummy variables used for city size was selected to give intervals of equal total population rather than equal city numbers.

Regression Analysis and Results

The coefficients of equations (1) and (2) were estimated by recursive least squares. Table I contains the estimates for equation (1) which shows the relationship of police numbers, city size and other variables to the crime rate. The coefficients of racial composition, measured as the percent of the city population nonwhite, was the most highly significant (t = 4.98) in the equation. Based on the coefficient, a 1 percent increase of nonwhites in a city is associated with 23.26 additional crimes per 100,000 or an .83 percent increase in the rate using the average crime rate of cities in this study (2,818). Density of population, expressed as population per square mile, is also positively correlated with crime and the coefficient is significant at the 0.005 probability level. As the sex structure of the city population changes to a higher proportion of males, the crime rate increases by 40.14 offenses for each 1 percent rise in the proportion of males. The coefficients of family median income and median age are negative, the latter significant at the .05 level. Another measure of income, the percent of families having incomes less than $3,000 was also examined but did not improve the results.

A set of dummy variables R_i was used to account for regional differences in people's attitudes and other characteristics associated with crime but unaccounted for by other variables.[6] The four regions--the West, South, Northeast, and Northcentral--correspond with the U.S. Bureau of the Census regions (see Figure 1). After adjusting for other socioeconomic characteristics in equation (1), the highest crime rates

TABLE I

ESTIMATED COEFFICIENTS AND STANDARD ERRORS OF CRIME EQUATION (1) WITH THE CRIME RATE C_t, THE DEPENDENT VARIABLE, A FUNCTION OF THE INDICATED INDEPENDENT VARIABLES

Independent Variable		Regression Coefficient	Standard Error
Constant		-3,370.12	
Police/100,000(t)	$\hat{P}_t$	22.95*	1.00
Percent nonwhite	N	23.26*	4.71
Median age	A	-26.74**	11.58
Median income	Y	-.01	.03
Density	D	.03*	.01
Percent males	X	40.14	27.91
Region (Northcentral in constant)			
Northeast	R_1	-452.34*	112.92
South	R_2	-244.52	133.72
West	R_3	1,253.74*	116.73
City size (under 25,000 in constant)			
1 million and over	S_1	12,779.76*	3,779.12
500,000 - 1 million	S_2	3,598.32*	852.49
250,000 - 500,000	S_3	3,529.54*	693.10
125,000 - 250,000	S_4	1,920.56**	919.74
80,000 - 125,000	S_5	1,930.72*	515.37
60,000 - 80,000	S_6	2,714.13*	441.49
40,000 - 60,000	S_7	3,102.06*	405.07
25,000 - 40,000	S_8	1,427.12*	314.02
Size-police interactions			
	$\hat{P}_t S_1$	-41.33*	10.28
	$\hat{P}_t S_2$	-13.68*	3.23
	$\hat{P}_t S_3$	-11.85*	2.92
	$\hat{P}_t S_4$	-6.17	4.47
	$\hat{P}_t S_5$	-7.59*	2.46
	$\hat{P}_t S_6$	-12.54*	2.08
	$\hat{P}_t S_7$	-15.83*	2.00
	$\hat{P}_t S_8$	-7.34*	1.51
R^2		.67	

Source: See text. N, A, Y, D and X are 1960 data; other variables 1968 data.

*Significant at .01 level.

**Significant at .05 level.

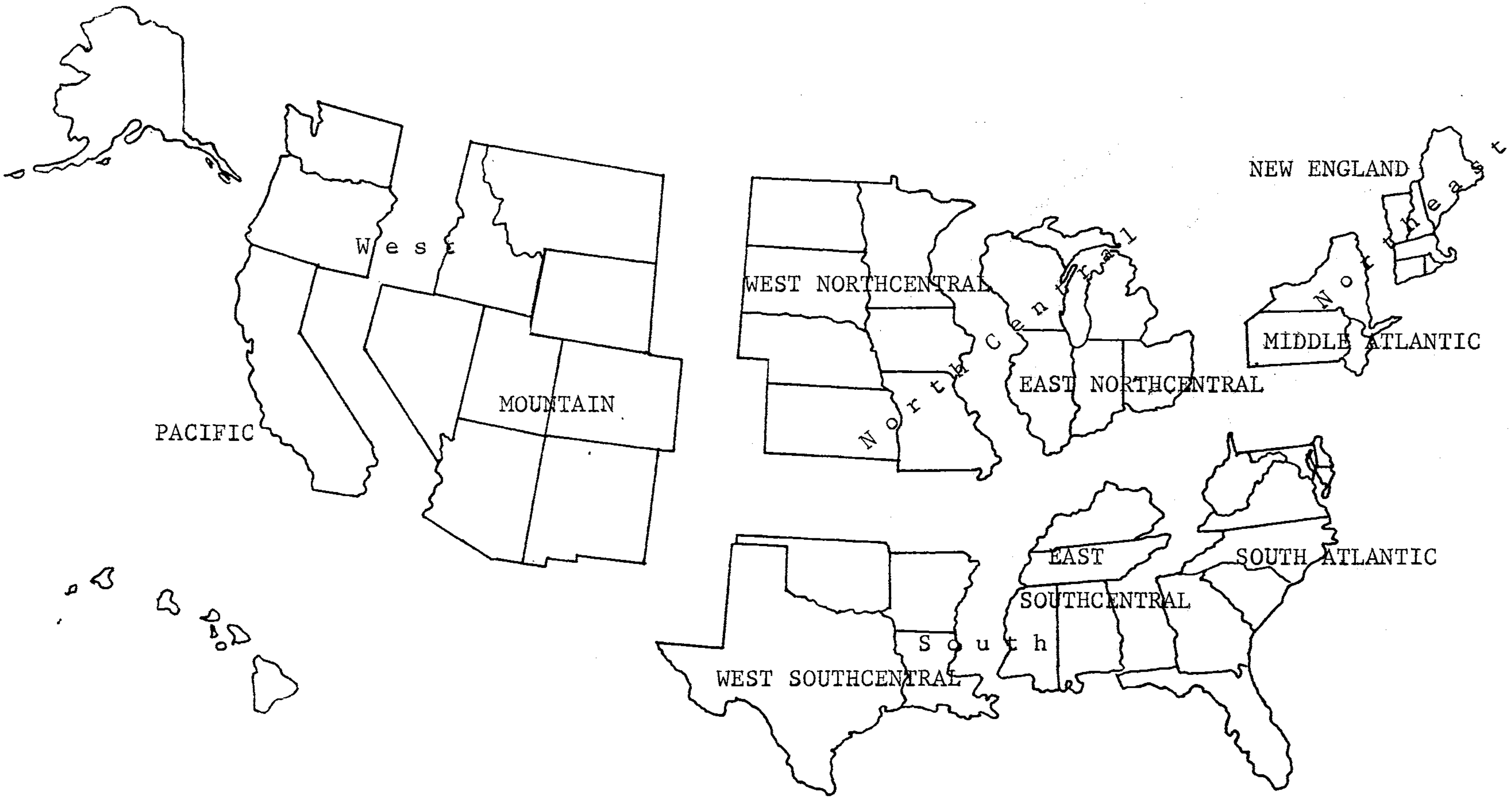


Figure 1. Census Regions and Divisions of the United States

are indicated for the West, followed by Northcentral (in equation constant), South and Northeast.

Table II contains the estimated coefficients for equation (2). An increase in the crime rate for year t results in an increase of policemen in year t+1 as was expected. The equation is used principally to derive an estimate $\hat{P}_t$ which in turn is used as a variable to estimate equation (1). Since nominal structural use was made of the coefficients in equation (2), the results are not discussed at length.

Disaggregated Estimates

The crime rate as previously defined is disaggregated into two major components, violent crimes and property crimes, each per 100,000 of population. Each of the disaggregated crime indices was regressed on the independent variables in equation (1) and the results are shown in Table III.

The various forms of equation (1) presented in Tables I and III display considerable similarities. Except for police per 100,000, all the significant coefficients possess the same, expected sign. The level of significance tends to be highest in the aggregate equation (Table I). The similar pattern of results from the three forms of equation (1) will be apprent in subsequent graphs of the social costs calculated from equations presented in Tables I and III.

Adjusted and Unadjusted Crime Rates by City Size

The Δ's in Figure 2 show unadjusted, actual crime rates by city size. The points of the solid curve indicate the resulting aggregate crime rate $\hat{C}_t$ after adjustment for socioeconomic characteristics and

TABLE II

ESTIMATED COEFFICIENTS AND STANDARD ERRORS OF POLICE EQUATION (2) WITH THE POLICE RATE P_t, THE DEPENDENT VARIABLE, A FUNCTION OF THE INDICATED INDEPENDENT VARIABLES

Independent Variable		Regression Coefficient	Standard Error
Constant		-24.3609	
Police/100,000 (t-1)	P_{t-1}	1.0173*	.0119
Crime/100,000 (t-1)	C_{t-1}	.0266*	.0005
Percent nonwhite	N	-.0165	.0647
Median age	A	.1356	.1582
Median income	Y	.0005	.0004
Density	D	-.0003**	.0001
Percent males	X	.3750	.3834
Region (Northcentral in constant)			
Northeast	R_1	-.3395	1.5814
South	R_2	-1.4186	1.6850
West	R_3	2.8494	1.8321
City size (under 25,000 in constant)			
1 million and over	S_1	8.3914	6.2881
500,000 - 1 million	S_2	1.3286	3.5721
250,000 - 500,000	S_3	-5.2187	3.1991
125,000 - 250,000	S_4	-2.0425	2.6583
80,000 - 125,000	S_5	-1.2232	2.1983
60,000 - 80,000	S_6	-1.2520	2.2717
40,000 - 60,000	S_7	-2.7613	1.8454
25,000 - 40,000	S_8	-1.6846	1.6686
R^2		.96	

Source: See text. N, A, Y, D and X are 1960 data; other variables 1967 and 1968 data.

*Significant at .01 level.

**Significant at .05 level.

TABLE III

ESTIMATED COEFFICIENTS AND STANDARD ERRORS OF CRIME EQUATION (1) WITH VIOLENT CRIMES C_{vt} AND PROPERTY CRIMES C_{pt}, THE RESPECTIVE DEPENDENT VARIABLES, A FUNCTION OF THE INDICATED INDEPENDENT VARIABLES

Independent Variable		Violent Crimes Equation Regression Coefficient	Violent Crimes Equation Standard Error	Property Crimes Equation Regression Coefficient	Property Crimes Equation Standard Error
Constant		-769.90		-2,073.49	
Police/100,000 (t)	$\hat{P}_t$	1.78*	.18	20.51*	.98
Percent nonwhite	N	10.46*	.85	12.71*	4.60
Median age	A	.70	2.09	-21.74	11.31
Median income	Y	-.003	.006	-.04	.03
Density	D	.008*	.002	.02**	.01
Percent males	X	10.92*	5.03	24.51	27.26
Region (Northcentral in constant)					
Northeast	R_1	-109.65*	20.35	-408.16*	110.29
South	R_2	-45.65	24.10	-293.21**	130.60
West	R_3	55.26*	21.03	1,153.39*	114.01
City size (under 25,000 in constant)					
1 million and over	S_1	2,115.56*	680.97	10,237.34*	3,691.14
500,000 - 1 million	S_2	-99.72	153.61	3,453.35*	832.64
250,000 - 500,000	S_3	83.34	124.89	3,182.74*	676.96
125,000 - 250,000	S_4	259.00	165.73	1,337.80	898.32
80,000 - 125,000	S_5	191.69**	92.87	1,498.35*	503.37
60,000 - 80,000	S_6	282.93*	79.55	2,188.65*	431.21
40,000 - 60,000	S_7	244.43*	72.99	2,598.50*	395.64
25,000 - 40,000	S_8	144.80**	56.58	1,054.52*	306.71

TABLE III (Continued)

Independent Variable	Violent Crimes Equation Regression Coefficient	Violent Crimes Equation Standard Error	Property Crimes Equation Regression Coefficient	Property Crimes Equation Standard Error
Size-police interactions				
$\hat{P}_tS_1$	-5.18*	1.85	-34.95*	10.04
$\hat{P}_tS_2$	-1.24**	.58	-14.22*	3.15
$\hat{P}_tS_3$	.67	.52	-11.76*	2.86
$\hat{P}_tS_4$	-.73	.80	-4.29	4.36
$\hat{P}_tS_5$	-.37	.44	-6.54*	2.40
$\hat{P}_tS_6$	-.98*	.38	-10.88*	2.03
$\hat{P}_tS_7$	-1.17*	.36	-13.86*	1.95
$\hat{P}_tS_8$	-.65**	.27	-6.04*	1.47
R^2	.57		.62	

Source: See text and Table I.

*Significant at .01 level.

**Significant at .05 level.

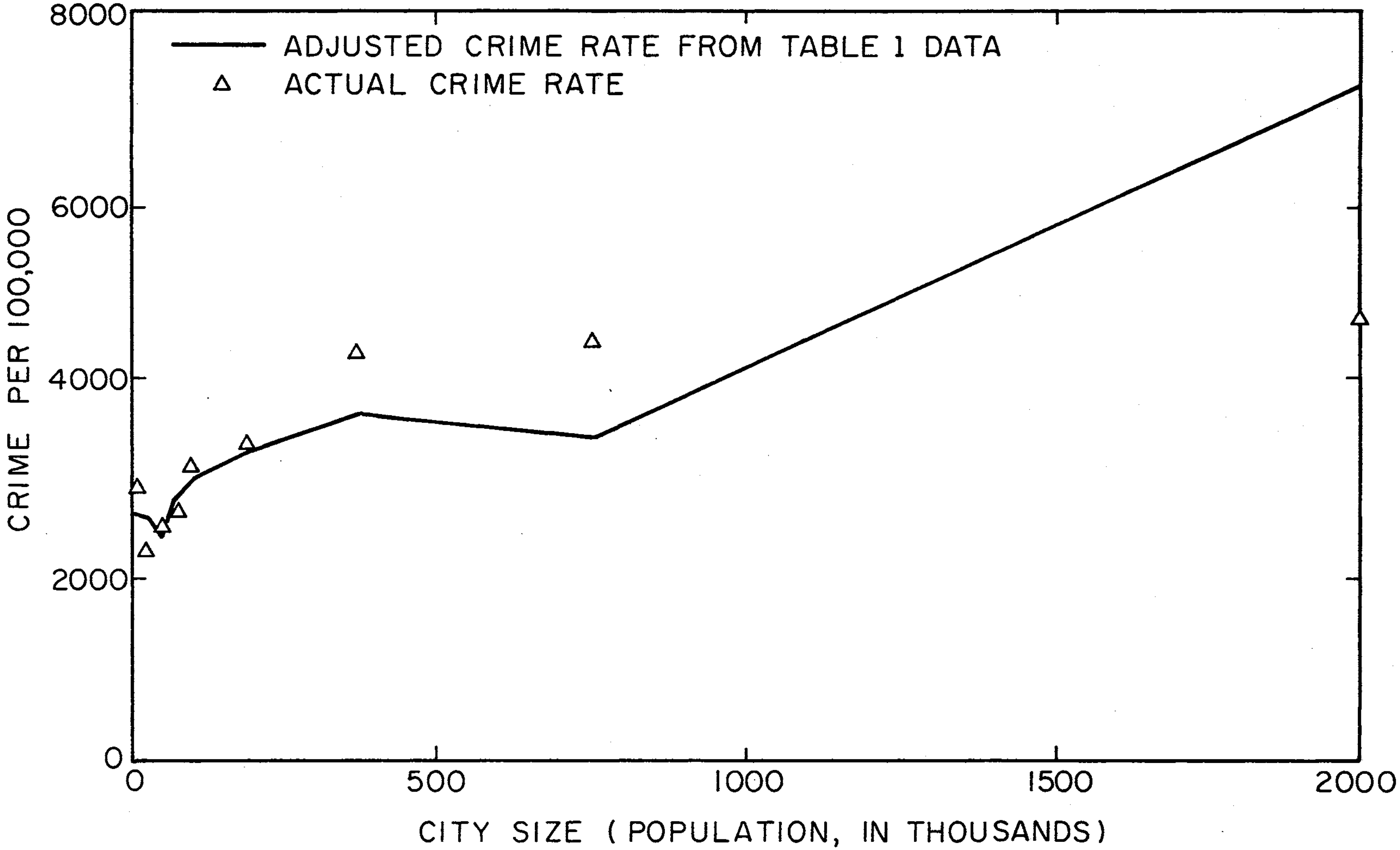


Figure 2. Crime Rates by City Size, 1968

police per capita with the latter variables for each city set at the average level of all cities in the sample. The adjusted estimates are from equation (1) in Table I. The actual and adjusted crime rates are very similar until cities reach 375,000 population. When the socioeconomic characteristics and the number of police per capita are statistically held constant, the crime rate soars to 7,158 per 100,000 for cities with 2 million inhabitants as compared to the 1968 actual rate of 4,559. In short, the graph illustrates a tendency for crime rates to fall slightly, then rise as city size increases with other variables statistically controlled.

Figure 2 applies to cities in the Northcentral region. By adjusting the curve upwards or downwards as dictated by the coefficients of the location variables, the graph can relate to any other region. All subsequent charts in this chapter also apply to the Northcentral region.

The Social Cost of Crime

The points on the solid curve in Figure 3 result from varying the coefficient of $\hat{P}_t$ in the equation presented in Table I so that the crime rate C is statistically held constant at 3,000, the sample average rate. The police rate P in the i^{th} city size necessary to accomplish this is determined from the following formula:

$$P_i = \frac{C^k - A - d_i}{(p + s_i)}$$

where

C^k = 3,000,

A = constant comprised of coefficients used for correcting equation (1) for socioeconomic characteristics,

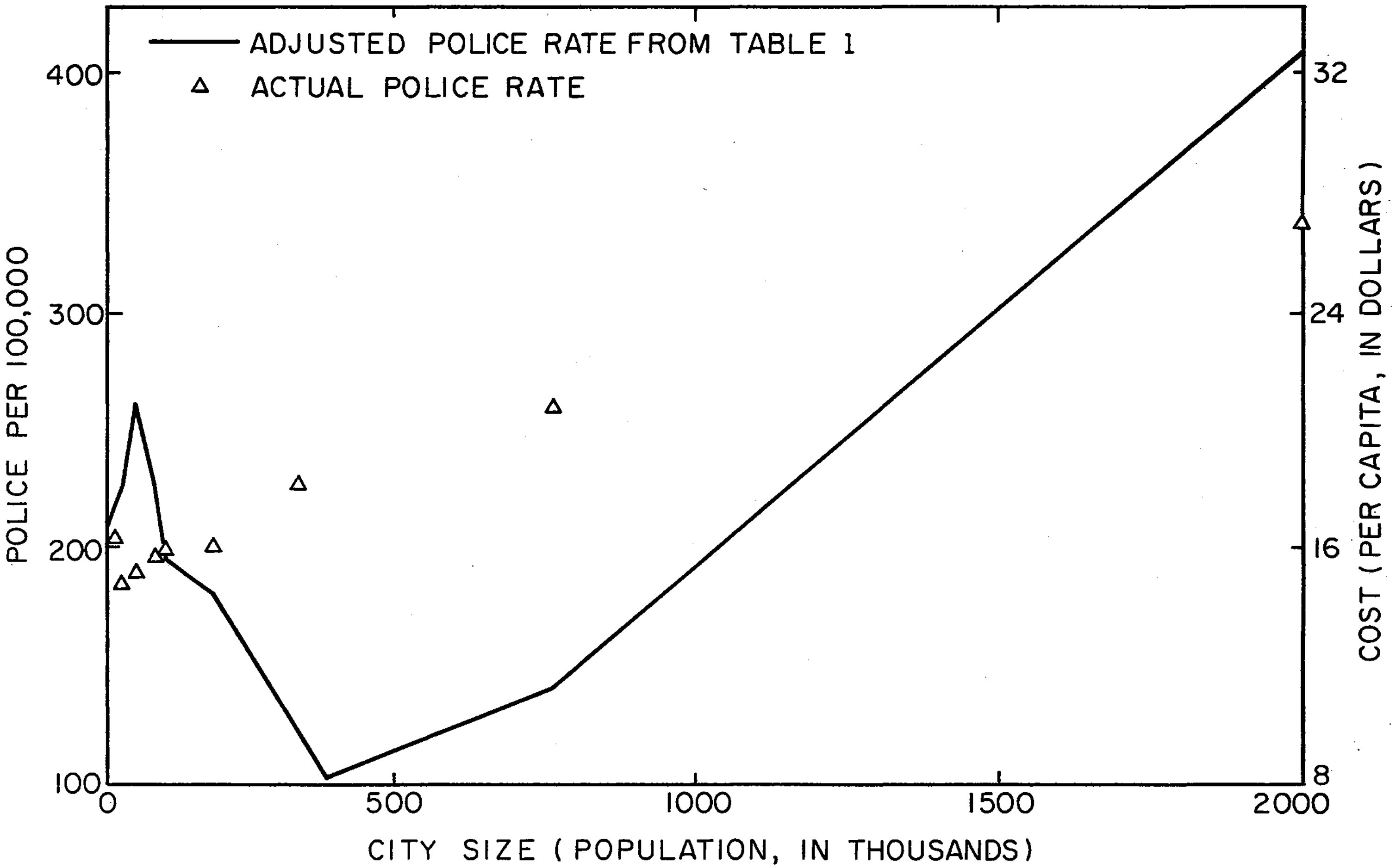


Figure 3. Actual Police Rates, Adjusted Police Rates and Per Capita Social Costs for 1968 by City Size for a Crime Rate = 3,000

d_i = coefficient associated with the city size i dummy variable S_i where the latter is 1 for city size i and zeroes elsewhere,

p = coefficient of $\hat{P}_t$,

s_i = coefficient of the interaction term between police $\hat{P}_t$ and city size S_i.

The use of a 3,000 average crime rate for cities in this study is arbitrary and of course exceeds the actual rate for the smallest cities and falls short of the actual rate for the largest cities. Other rates could be used as the standard. The constant A is determined by using the mean values of the socioeconomic variables. The procedure allows costs associated with police numbers to be analyzed as all cities move toward a homogenous structure of socioeconomic characteristics and crime rates. This adjustment statistically raises the crime rate and the social cost of crime in small cities, an effect which would be expected if the smaller cities had higher percentages of nonwhites and other characteristics associated with high crime rates in larger cities.

Figure 3 comparing actual police rates (x's) with the adjusted police rates (points on solid curves) based on equation (1) shows that as the smaller cities take on the larger city characteristics, the number of policemen necessary to hold the crime rate constant increases. The "real" cost of controlling crime is larger than the actual cost. Likewise the adjustment of larger cities to average conditions results in a decline in policemen per capita to hold crime constant--except for cities over 1 million which still require a higher police rate.

The three coefficients, d_i, p and s_i, must be interpreted simultaneously. The coefficient of $\hat{P}_t$ is positive. But the interaction coefficients s_i included to depict the effectiveness of policemen in cities of different size, are all negative with the largest cities

(1 million and over) being associated with the smallest coefficient.[7] The coefficient for police resulting from the combination of d_i and s_i is always positive; implying that an increase in police P results in an increase in crime. This anomalous result may be explained by the nature of the data. Crime and police rates have increased simultaneously over time and the statistical model is unable to separate from the strong positive historical association between crime and police rates the true negative effect of police on crime. Second, a larger number of policemen may result in an increased discovery of crime which in turn increases the reported crimes.

The remaining step in deriving a measure of the social cost of crime involves the conversion of the police rate to a dollar and cents figure. To accomplish this step, the pay rate for police is multiplied by the number of police required per capita to hold crime constant for each size of city adjusted to the same characteristics except size. At least two pay rates are candidates for the calculation. The approach used in Figure 3 is to use a constant rate of pay, the average of wages and salaries per policeman over all cities, for each size of city. Another approach is to use the actual wages and salaries for each size of city. Since pay rates rise with city size, the result is greater diseconomies of city size using the second equation.[8]

The measured social cost of crime in cities with 2 million population is $38 per capita using actual pay compared to $34 per capita using average pay. For cities with a population of 10,000, the social cost is $15 using actual pay compared to $17 using average pay. For cities of size 187,500, the two estimates give the same social cost, $14.44. The higher costs per policeman for the larger cities do not reflect a social cost attributed to size *per se* but rather are the result of supply and demand conditions. Therefore, use of a constant salary in all city sizes was deemed to be the appropriate approach for this study.

The right-hand axis of the curve in Figure 3 records the estimated per capita social cost at a given level of crime assuming a salary of $8,000 per policeman. The minimum cost occurs at a size of 375,000 with a per capita cost of $10.24. This compared with a cost of $34.17 for the large cities with 2 million population.

Disaggregate Estimates of Police Rates and Social Cost

The disaggregate equations for violent crime rates and property crime rates in Table III provide the estimates of the required police rate and social cost to maintain crime rates at a constant level over all city sizes. Figure 4 shows police requirements per 100,000 to hold violent crime rates at 300 annually per 100,000 persons. Figure 5 shows police requirements per 100,000 to hold the property crime rate at 2,500 annually per 100,000 persons. The two curves closely resemble the curve for the aggregate crime index in Figure 3. The minimum points on the curves differ, however. The minimum police requirements and social cost is for cities of 750,000 for property crime and is for cities of 187,500 for violent crime. As expected, the minimum for the aggregate (Figure 3) falls between--for cities of 375,000 inhabitants.

The social costs are shown on the right axis in Figures 3, 4, and 5, and are simply the police rates multiplied by $8,000 per policeman. The difference in police rates and social costs among cities is much greater for violent crimes than for property crimes. It appears

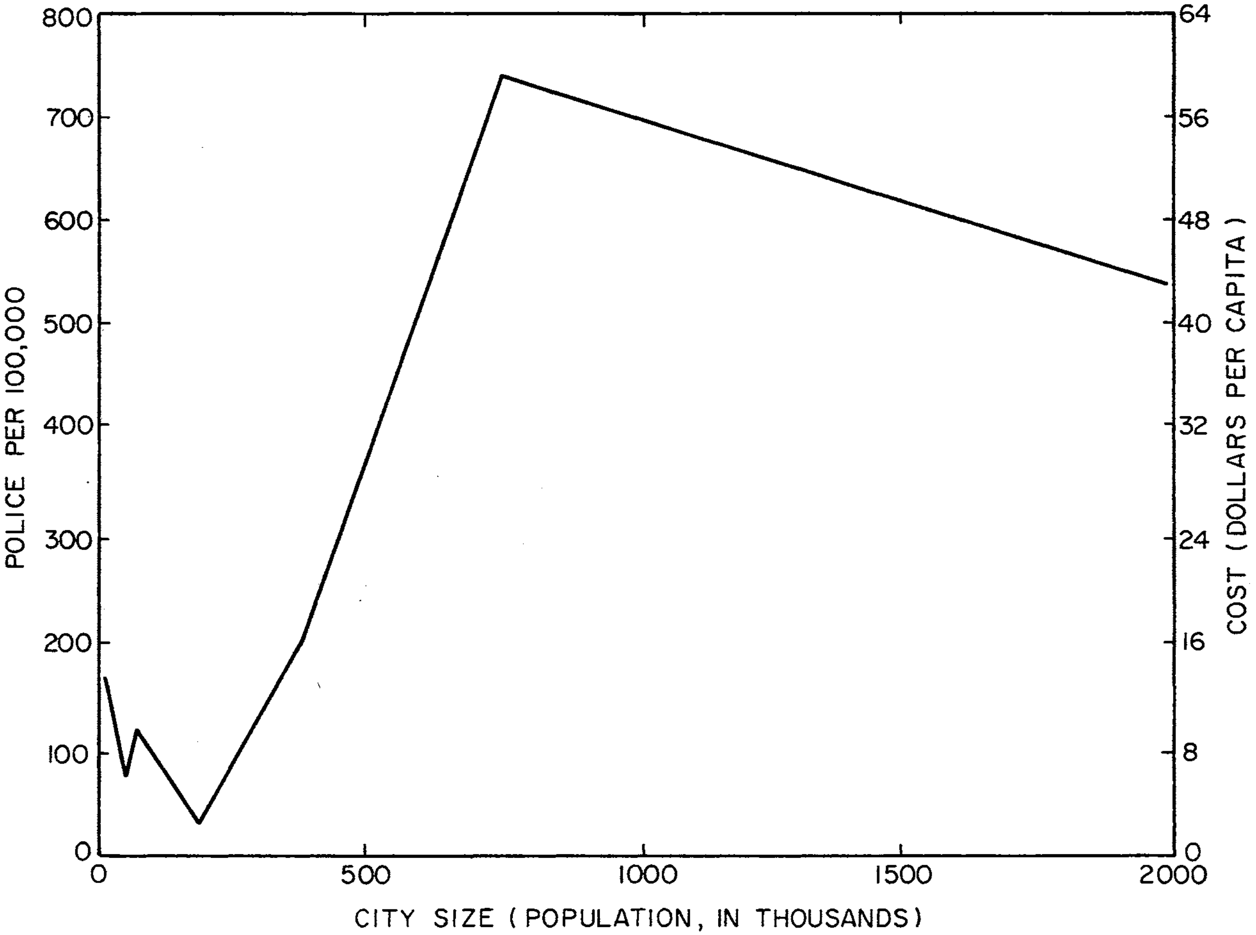


Figure 4. Police Rate and Per Capita Social Cost (Crime Rate = 300) of Violent Crimes, by City Size

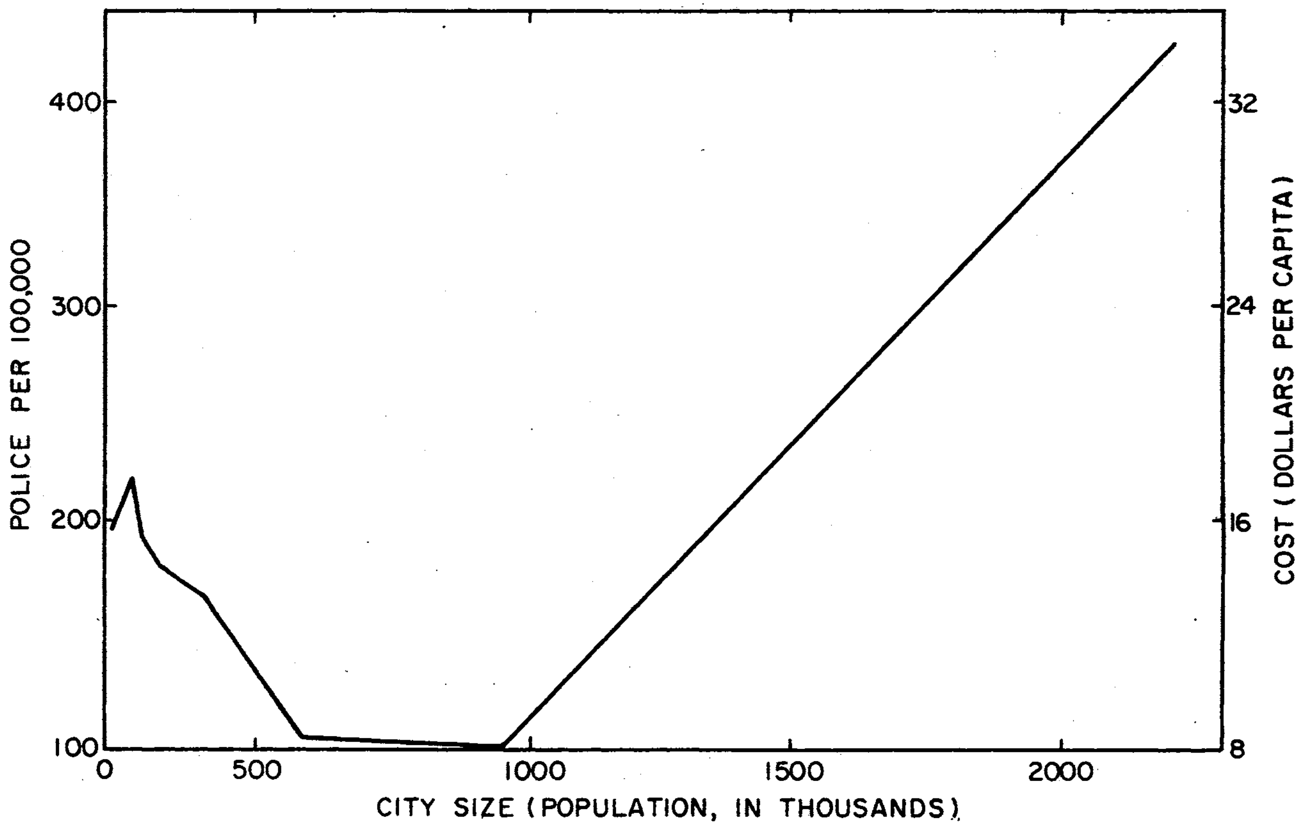


Figure 5. Police Rate and Per Capita Social Cost (Crime Rate = 2,500) of Property Crime, by City Size

unreasonable that police rates and social costs are greater for violent crimes alone than for the aggregate of all crimes. This result is partly explained by the nature of the data. Ideally, the police rates used to estimate the violent crime equation in Table III should entail police time devoted in full to combatting violent crime. In fact, police time used to prevent violent crime is devoted also to preventing property crime, not to mention directing traffic and checking parking meters. So it is not possible to sum the social cost for violent crime and the social cost for property crime to determine the total social cost of crime. It is most efficient for police to jointly control both types of crime. This complementarity causes difficult problems, however, in trying to combine Figures 4 and 5 into a single measure of social cost. Figure 3 is a better measure of total social cost than could be constructed by weighting and combining Figures 4 and 5. In using Figure 3 aggregation error is not necessarily avoided, but it is likely to be smaller and easier to handle.

Cost of Reducing Crime

The positive police coefficient in equation (1) does not preclude realistic comparisons of differences in social costs of crime among cities as in Figures 3-5, but the positive coefficient does rule out realistically predicting the effect of generally lowering the crime rate by increasing policemen and expenditures. The resolve this dilemma, each city size was analyzed separately using time series data for the past decade on the crime rate and the police rate. The coefficients of the police rates varied from -30.38 to 58.39 with the smaller city sizes possessing negative coefficients. Cities of size 187,500 were assumed to have a typical relation between crime and police corrected for trend since the coefficient was midway between the extremes and had a value of -2.79 which means each additional policeman per 100,000 reduced the crime rate 2.79 crimes per 100,000. Furthermore, these cities appear to have little divergence between adjusted and unadjusted crime rates (see Figure 3). If each city hires a given quality of policemen for $8,000 and each of these policemen per 100,000 reduced the crime rate by 2.79 offenses, then the per capita cost of reducing the crime rate from 3,000 to 2,000 is $28.67. This cost figure is somewhat high for cities with less than 187,500 inhabitants and may be unrealistically low for larger cities since they provide no evidence from the data examined herein that the crime rate can be reduced by increasing the police force. Furthermore, no provision was made for private outlays to reduce crime, such as hiring of private guards and increasing the security of homes and businesses with burglar alarms, secure locks and trained watch dogs in cities associated with high crime rates; thus, the cost of controlling crime in the largest cities is underestimated.

The social cost of controlling crime in the optimal size city is $10.24 per capita. The per capita social cost of police protection with an adjusted crime rate of 3,000 over all cities, given the current distribution of population among cities, is $19.37 as an average over all cities. The per capita social cost is $34.17 for cities of over 1 million. In other words, a policy of restructuring the urban population into optimal city sizes would appear to reduce the per capita social cost of crime on the average by $9.13 (47 percent) and by up to $23.93 for large cities.

The conventional wisdom may be that the way to reduce the amount and the cost of crime is to increase the number of policemen. Since data used in this study provide no evidence that crime can be controlled by the police in large cities, the results at least raise the possibility that a more cost-effective long-term method is to redirect the population towards more nearly optimal city sizes. The conclusion must be regarded as tentative because the cost of controlling crime is only one of many costs that determine optimal city size.

Summary

Sizable economies and diseconomies of size exist with regard to a given quality of police protection. The results show that the per capita social cost of crime declines slowly with larger cities until a low point is reached in cities with a population of 375,000. Social costs rise sharply for cities of over 1 million inhabitants. By and large, the smaller cities are able to reduce their crime rates with an increase in police numbers while the larger cities fail to do so based on evidence from time series analysis. Thus the results underestimate the social cost of crime in large cities even though they show the cost to be lower in small cities than in large cities.

FOOTNOTES

[1] An advantage of this method is that data on police, crime, and other socioeconomic characteristics can be more specific to a particular population, whereas use of the SMSA as a unit of observation would "wash out" through averaging many of the differentiating characteristics. A disadvantage is that some of the unique characteristics of a city that arise because it is a component of a metropolitan area may be lost in the statistical analysis.

[2] U. S. Department of Justice, Uniform Crime Reports for the United States, 1967 and Uniform Crime Reports for the United States, 1968, U. S. Government Printing Office, Washington, D. C.

[3] Alternative measures of P were considered. The police rate used should reflect both economies and diseconomies of size. As a police department expands, clerical and lab personnel may be added to the department to allow officers more time "in the street;" however, as the size continues to increase the resulting bureaucracy may become so great as to impair the operations. The inclusion of both officer and civilian personnel was deemed necessary to reflect the effectiveness of the police department in combatting crimes.

[4] International City Manager's Association, Municipal Year Book, 1968 (Washington, D. C., 1968).

[5] U. S. Bureau of the Census, Census of Population, 1960 and County and City Data Book, 1967 (A Statistical Abstract Supplement), U. S. Government Printing Office, Washington, D. C.

[6] The coefficient of R_i indicates the magnitude of a difference (increase or decrease, depending on the sign) in the estimated crime rate in cities in the i^{th} region as compared to cities in the Northcentral region with other explanatory variables held constant.

[7] Equation (1) was originally estimated using only $\hat{P}_t$ to account for the effect of police on the crime rate. The results were inferior to the reported results using the interactions (police and city size).

[8] Actual wage and salary expenditures per policeman (comprising seven-eighths of police department expenditures) were expressed as a function of city size, yielding an upward sloping cost function. Wages

and salaries/policeman $= 6{,}168 - 49R_1 - 841R_2 + \underline{1{,}201}R_3 + \underline{1{,}792}S_1 + \underline{1{,}382}S_2 + \underline{947}S_3 + \underline{831}S_4 + \underline{1{,}029}S_5 + \underline{711}S_6 + \underline{427}S_7 + 383S_8$. The variables are defined as those of Table I. Underlined coefficients are significant at the .01 level.

CHAPTER III

THE COST OF CONTROLLING AIR POLLUTION

This chapter deals with one aspect of city size--the economies of controlling air pollution. Society has embarked on a program of air pollution abatement directed as industrial and motor vehicle sources. Areas with low and high levels of air pollution are subject to many of the same controls. Of particular interest is comparison of expected outlays by firms and individuals to control air pollution with the cost of allowing pollution to continue.

The purpose of this chapter is to:

1. Estimate by size of city the level of air pollution adjusted for climatic factors and economic activity.

2. Estimate by size of city the per capita cost of controlling industrially emitted pollutants.

3. Estimate the per operator cost of the proposed emission control package for motor vehicles.

4. Estimate the per capita social cost of air pollution--measured by the outlay per capita necessary to hold air pollution at a given level among all city sizes while statistically holding constant city characteristics other than size.

5. Compare costs estimated from this study of controlling air pollution with the costs estimated from previous studies of allowing pollution to continue.

Ideally, the social cost of air pollution would be measured as the net disutility of the population resulting from the polluted air. The inability to quantify disutility operationally precludes use of this measure. In this chapter, social cost of air pollution is defined as the per capita cost in dollars of obtaining a given quality of air for each city size. This cost is computed from the air pollution level by size of city adjusted for industry composition, climatic elements and other factors except size. Some assumptions underlying the approach are (1) the same level of air pollution causes the same amount of disutility per capita in all city sizes, (2) the cost of controlling air pollution is less than the cost of allowing it to occur, (3) air pollution can be controlled by known techniques, and (4) the cost of these techniques is measurable. The estimates will show that perfectly discriminating application of measures to abate air pollution--tailoring controls to each city to achieve only the minimum required abatement--will entail less social and private costs than allowing pollution to continue in accordance with assumption (2). But indiscriminate controls applied to all vehicles, even those in sparsely settled areas, leads to the disturbing finding that private costs of controlling emissions will exceed costs (estimated in previous studies reported in Chapter I) of allowing it to continue.

The Model

For the purposes of this chapter, the pollutants under consideration will be analyzed by source of emission, e.g. industrial or transportation.

Sulfur Oxides and Particulates

The pollutants predominately emitted by industrial plants, sulfur oxides SO_x and particulates P, are hypothesized to be functions of city size, type of economic activity and climatic factors in the following econometric model:

$$\hat{SO}_x = s(S, M, R, W, T) \quad (1)$$

$$\hat{P} = p(S, M, R, W, T) \quad (2)$$

where

SO_x = sulfur oxides per square mile;
P = particulates per square mile;
S = city size;
M = manufacturing index;
R = annual median precipitation (inches);
W = annual median wind velocity (mph); and
T = annual number of degree days.

M, the percent of the workforce engaged in manufacturing, is included to measure pollution contributed by industrial processes and fuel combustion in stationary sources.[1] M is used for lack of a more precise measure of pollution emissions by industrial sources. It fails to account adequately for (1) the emission controls already adopted by manufacturers, (2) differences among manufacturing plants in volume of pollutants, and (3) the number of manufacturing plants.

R, W, and T reflect conditions that affect the amount of pollution that remains over an area. Precipitation is a cleansing agent in the atmosphere. Gases and moisture combine to form acid mists that collect on buildings, cars and the ground. Particulates are removed from the air via three mechanisms: (1) rainout--particulates acting as condensation of sublimation nuclei; (2) particulates entering clouds or adhering to clouds because of random molecule (Brownian) motion and turbulent motions; and (3) washout--particulates caught in downdrifts of falling rain. The major air pollution episodes have been associated with quiet, quasi-stationary conditions over the troubled area. Low surface wind velocity, approximately 7 mph or less, tends to result in the accumulation of air pollutants. As the wind velocity increases, the amount of air pollution over the area of interest decreases as it is blown away. T is defined as the annual sum of the difference between the mean daily temperature T_m and 65°F when $T_m < 65°F$. The significance of this climatic factor is the influence that ambient temperatures impart on space heating requirements and the attendant fuel consumption during wintertime.[2]

Statistically holding M, R, W, and T constant allows the relation between city size and SO_x or P to be analyzed net of the effect of the former variables. The estimated cost C of controlling SO_x and P emissions, on a square mile basis are expressed as a function of city size, S, and pollutant levels in (3).

$$\hat{C} = f(S, SO_x, P) \tag{3}$$

The social cost of controlling SO_x and P is computed by inserting into equation (3) levels of SO_x and P derived from (1) and (2), after correcting for industrial and climatic factors so that the social cost is a function of city size only--all other variables were statistically held constant. Conversion to a per capita figure is achieved by using a constant population density per square mile. The use of a constant density per square mile is necessary to insure that the estimated social cost is a function only of city size.

Carbon Monoxide

The major motor vehicle emitted pollutant, carbon monoxide, measured in tons per square mile, is expressed as a function of the previously defined climatic factors, R, W, and T, city size S, city density D, and gasoline sales G per square mile in the following econometric model:

$$\hat{CO} = f(S, \hat{G}, R, W, T) \qquad (4)$$

$$\hat{G} = f(S, D) \qquad (5)$$

The combustion of fossil fuels in motor vehicles accounts for 63 percent of technologically formed CO emissions or 58 percent of CO from all sources in the United States. However, in urban areas the motor vehicle contributes from 60 percent to 99 percent of the CO emissions. Gasoline service station sales in dollars per square mile, G, is the variable chosen to measure fuel used in motor vehicles in various city sizes. The actual measure of G used in the quantitative analysis is less than ideal. Other products that do not go into the fuel tank, e.g. grease, oil, and anti-freeze, are included in the measure. The fuel purchased in a given area is not necessarily combusted in that area. Variations in price among different geographical locations will appear to be differences in quantities of fuel sold. Nevertheless, this variable should give a reasonably adequate measure of fuel consumption and the resulting emission of CO into the city air. The population per square mile and the actual size of the city will influence the amount of gasoline sales per square mile. Positive coefficients of D and S in (5) are expected.

The relation between city size and CO is analyzed net of the effects of the other variables in equation (4) by statistically holding G, R, W, and T constant. Utilizing the methodology described for the SO_x and P models, the social cost of CO pollution is estimated by computing the cost of reducing CO to a given level in all city sizes.

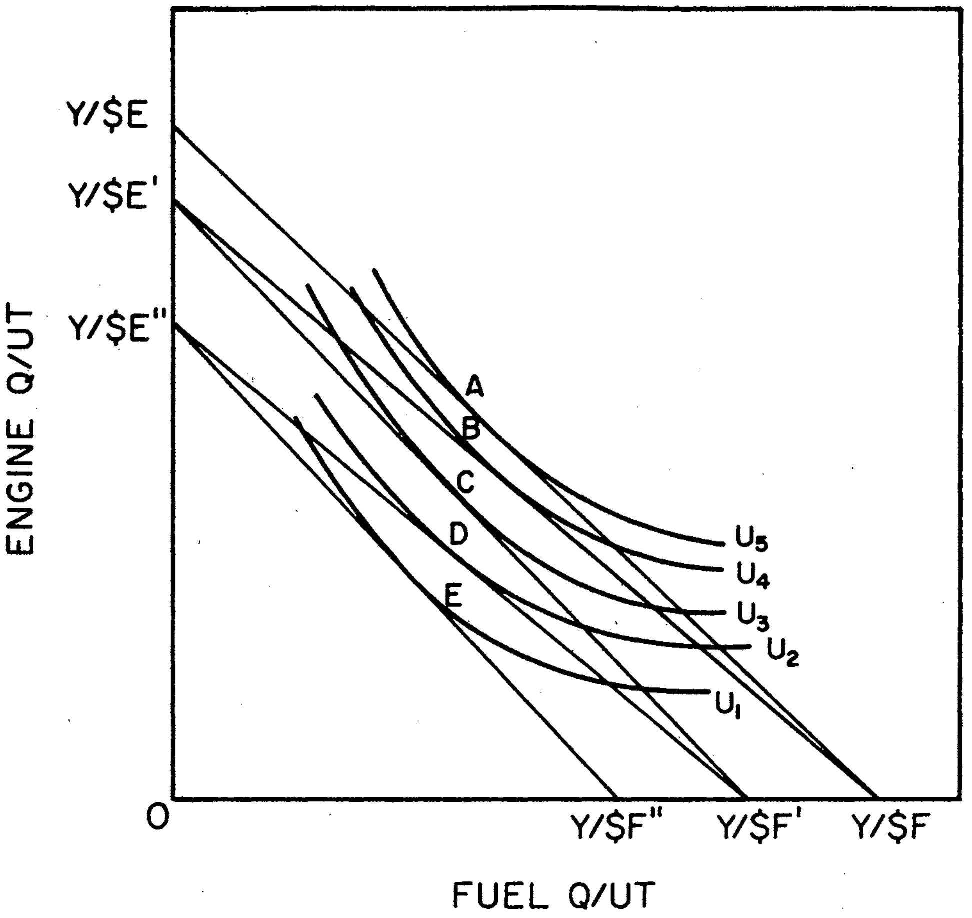
The "total vehicle" concept, advanced by the automotive industry, calls for the development of systems that concurrently reduce emissions of carbon monoxide, hydrocarbon and oxides of nitrogen to acceptable levels. By governmental standards, current permissible emissions from the 1971 models are 2.2 gpm of hydrocarbon, 23 gpm of carbon monoxide and in California, 4 gpm of oxides of nigrogen. By 1975 these emissions must be reduced to 0.46 gpm of hydrocarbon, 4.7 gpm of carbon monoxide and (1976) 0.84 gpm of oxides of nitrogen. If these reductions are to be achieved, automobile technicians state that many engine changes in addition to lead-free fuel and a catalytic converter will be necessary.

This chapter focuses on costs, both direct and indirect, the consumer must bear to operate a motor vehicle that emits the allowable amount of CO. The estimate concurrently includes the cost of reducing emissions of hydrocarbon and oxides of nitrogen. These latter pollutants are largely emitted from fuel combustion in motor vehicles, and the rate of required reduction is practically the same for all three pollutants. Hence the cost associated with reducing CO to a given level in all city sizes can be considered the cost of reducing automobile emitted pollutants.

The cost to the consumer resulting from emission controls can be illustrated conceptually utilizing indifference curves in Figure 6. The consumer allots a given amount of income, Y, each year for the purchase of engine (power, price and economy considered) and fuel (price and quantity considered). U_1 through U_5 show the various combinations of engine and fuel purchases that yield the same level of utility with U_5 being the highest level attainable with income Y and the given prices for fuel and engine.

To achieve the emission standards, new models will be equipped with a pollution reduction package of which the principal component is the catalytic converter. The annualized cost of this package will reduce the size of engine that can be purchased with Y and reduce utility to U_4 as shown in the movement from A to B in Figure 6. The converter functions properly with lead-free fuel. This fuel is more expensive per gallon than conventional fuels, reducing the amount of fuel that can be purchased with income Y. The higher fuel cost places the consumer at point C which indicates utility U_3. The lower octane rating of the lead-free fuel requires a lower compression ratio and requires a larger engine to recover power losses, hence the movement to D. The larger engine requires more fuel per mile, thus the consumer finally realizes utility level U_1. The cost of reducing motor vehicle emitted pollutants is calculated as the cost of returning the consumer to indifference curve U_5.

The implicit assumption underlying consumer adoption of the emission control package which reduces his utility derived from his automobile is that the utility from cleaner air will at least offset the reduction in utility shown in Figure 6; hence, some level of



$F = COST OF FUEL--INCLUDES BOTH PRICE AND QUANTITY CONSIDERATIONS

$E = COST OF ENGINE

Y = INCOME ALLOTTED TO AUTO EXPENDITURES PER UNIT OF TIME

Figure 6. Indifference Curves and Budget Constraints for Engine and Fuel Components of Automobile Consumption

utility greater than U_5 will prevail. Since the individual consumer has no perceptible influence on air pollution, lone adoption of the control package would reduce his utility to U_1 with no offsetting rise in utility due to cleaner air. Acting alone and rationally, he would not adopt the control package. Forcing all consumers by law to adopt the control package raises utility through cleaner air. Perhaps utility is raised well above U_5 for metropolitan consumers and little if any above U_1 for rural consumers.

The Data

Yearly emissions expressed in tons per square mile per year for 27 metropolitan areas with population ranging from 370,000 to 15,420,000 comprise the set of pollution data used in this chapter. The data are from surveys for the years 1966-1968 conducted by the National Air Pollution Control Administration, NAPCA, in addition to state and local agencies.[3] The SMSA constituted the unit of observation for these surveys. SMSA's that are adjacent to each other are treated as one observation as for all practical purposes they are the same urban complex. This combination of SMSA's reduces the original 60 surveyed areas to 32; however, only data for 28 such metropolitan areas are made available through publications by NAPCA, the source of data for this chapter.[4]

These 27 areas include the largest metropolitan areas in the country with all but four having populations exceeding one million. Sixty percent of the urban population is accounted for in these areas. All parts of the country are represented in this group, but the Northeast and Midwest contain the most observations.

This relatively small sample of aggregated data gives rise to some problems: (1) Using observations for the largest, highly industrialized metropolitan areas handicaps the application of the results to smaller cities. (2) The use of an SMSA results in the averaging of pollution levels over the industrial area of the central city and residential suburbs surrounding it in the case of SO_x and P. CO levels are typically higher along the congested streets of a downtown area than the lesser traveled outlying areas. Thus, the effects of certain explanatory variables may be washed out in the statistical model. This problem is compounded with SMSA's are combined. (3) At best, emission data are approximations and tend to be very sensitive to the methods used in making the estimates. If the reporting errors are random and the same magnitude for the three agencies that contributed data, the least squares estimates reported later may be inefficient but not biased. Due to the lack of any evidence to the contrary, it is assumed that errors in the dependent variable are random from all three agencies.

Technical information pertinent to the computation of the cost of reducing CO emissions was obtained by correspondence from Ford, General Motors and Ethyl Corporations.[5]

Senate Document 91-40, "The Cost of Clean Air," contains estimated annual costs of sulfur oxides and particulate control (maximum) by metropolitan areas for both stationary combustion and selected industrial process sources.[6] A range of estimates is given that includes "low" and "high" costs for fiscal years 1971 through 1974 in addition to sulfur-in-fuel restrictions (1 percent and 1.5 percent) for 32 metropolitan areas in 1971 and 85 such areas in 1974. The cost estimates were based on the assumption that control will be achieved using techniques already available. The range of costs reflects the fact that the costs of air pollution control equipment and installation, operating and maintenance costs vary among plants and regions.

The climatological data, R, W, and T, were obtained from the U. S. Weather Burear for the year 1968.[7] The population and socioeconomic data are from the U. S. Bureau of the Census.[8]

Regression Analysis and Results

The estimated parameters for equations (1), (2), (3), (4), and (5) using ordinary least squares regression on the sample of 27 metropolitan areas are presented below:[9]

$$\hat{SO}_x = -295.6638 + \underset{(0.2079)}{0.4080^{*}S} - \underset{(1.3638)}{1.8507S^2} + \underset{(3.6433)}{3.4378R} - \underset{(15.9449)}{3.8242W} \qquad (6)$$

$$+ \underset{(1.6755)}{2.0379T} + \underset{(2.6794)}{5.6520^{*}M} \qquad R^2 = .5774$$

$$\hat{P} = 32.1210 + \underset{(0.0862)}{0.0427S} - \underset{(0.5656)}{0.2454S^2} + \underset{(1.0962)}{1.5794R} - \underset{(6.6129)}{10.7903W} \qquad (7)$$

$$- \underset{(0.6949)}{0.1256T} + \underset{(1.1120)}{2.3578^{*}M} \qquad R^2 = .4372$$

$$\hat{C}_L = -0.5936 + \underset{(0.0281)}{0.0749^{**}S} + \underset{(0.0083)}{0.0263^{**}SO_x} + \underset{(0.0219)}{0.217P} \qquad R^2 = .6541 \qquad (8)$$

$$\hat{C}_H = -0.7432 + \underset{(0.0323)}{0.0851^{**}S} + \underset{(0.0095)}{0.0370^{**}SO_x} + \underset{(0.0252)}{0.0314P} \qquad (9)$$

$$\hat{CO} = -55.4416 + \underset{(0.1667)}{0.3603^{*}S} - \underset{(0.9662)}{0.4332S^2} + \underset{(1.6502)}{1.7805R} - \underset{(10.0746)}{4.5093W} \qquad (10)$$

$$+ \underset{(0.8366)}{1.0622T} + \underset{(0.3698)}{2.9983^{**}\hat{G}} \qquad R^2 = .9424$$

$$\hat{G} = -0.4366 + \underset{(0.0349)}{0.0596S} - \underset{(0.2049)}{0.5145^{**}S^2} + \underset{(0.0072)}{0.0918^{**}D} \qquad R^2 = .9339 \qquad (11)$$

Considering only equations (6) and (7), the coefficient of M is significant at the .05 level in both equations; whereas the coefficient of S is significant at the .05 level only in equation (6).[10] The resulting nonsignificant coefficient of city size in equation (7) is in accordance with the findings of NAPCA: "Clearly, the larger cities have no monopoly on the upper range of particulate concentrations."[11]

As expected, the coefficient of gas sales is the most significant (t = 8.10) in the carbon monoxide equation. A $1,000 increase in gasoline sales per square mile results in 2.99 tons per square mile increase in CO on a yearly basis. According to the estimate, one gallon of gasoline, upon combustion, emits 2.4 pounds of CO into the atmosphere, assuming a price of 40 cents per gallon. Middleton and Clarkson estimated that the auto emitted 3.2 pounds of CO into the atmosphere for each gallon of gasoline burned.[12] The 2.4 figure estimated in this chapter is probably biased downward due to the nature of the variable G previously discussed. The coefficient of city size is also significant and positive.

In equation (11), the coefficient of city size squared is significant at the .01 level, whereas the coefficient of S is positive but not significant. The coefficient of density is positive and significant at the .01 level.

The climatic variables in equations (6), (7), and (10) do not have significant coefficients. The coefficient of W is negative as expected. The positive sign of the coefficient of R is at odds with a priori reasoning. The anomalous coefficient probably mirrors the fact that firms and cities with high pollution levels "just happened" to locate where levels of precipitation are high. The statistical model was not able to separate the true relationship of air pollution to precipitation

The coefficient of T possess the expected positive sign in equations (6) and (10).

Equation (3) was estimated using both "high" and "low" projected 1974 cost data from Senate Document 91-40 and with one percent sulfur-in-fuel restrictions. Coefficients of S and SO_x are significant at the .01 level and are positive. The nonsignificant coefficient of P perhaps can be explained by the already widespread use on smokestacks of a control system for particulates. These controlled smokestacks are believed to be distributed somewhat randomly throughout city sizes and industry groups.

Adjusted and Unadjusted Pollution Levels by City Size

Figures 7 through 9 show the adjusted levels of SO_x, P and CO respectively by city size. The adjusted levels, depicted by the solid curves, were obtained from the estimated equations (6), (7), and (10) by statistically holding all explanatory variables other than city size constant at the average level of all cities in the sample. The Δ's in Figures 7 through 9 represent the differences between the actual and predicted levels of SO_x, P and CO added or subtracted from the adjusted level curves. This procedure is helpful in determining whether the functional form of the estimated equation was in fact the appropriate form. Figure 8 shows that the fit for P is not outstanding, however, the parabolic function used did give a better fit than other functional forms that were tested. The parabolic function fitted to the data depicts an increasing and then a decreasing level of pollution in very large cities. These is no reason to believe that this is actually the case in the real world. The parabola was chosen as the appropriate

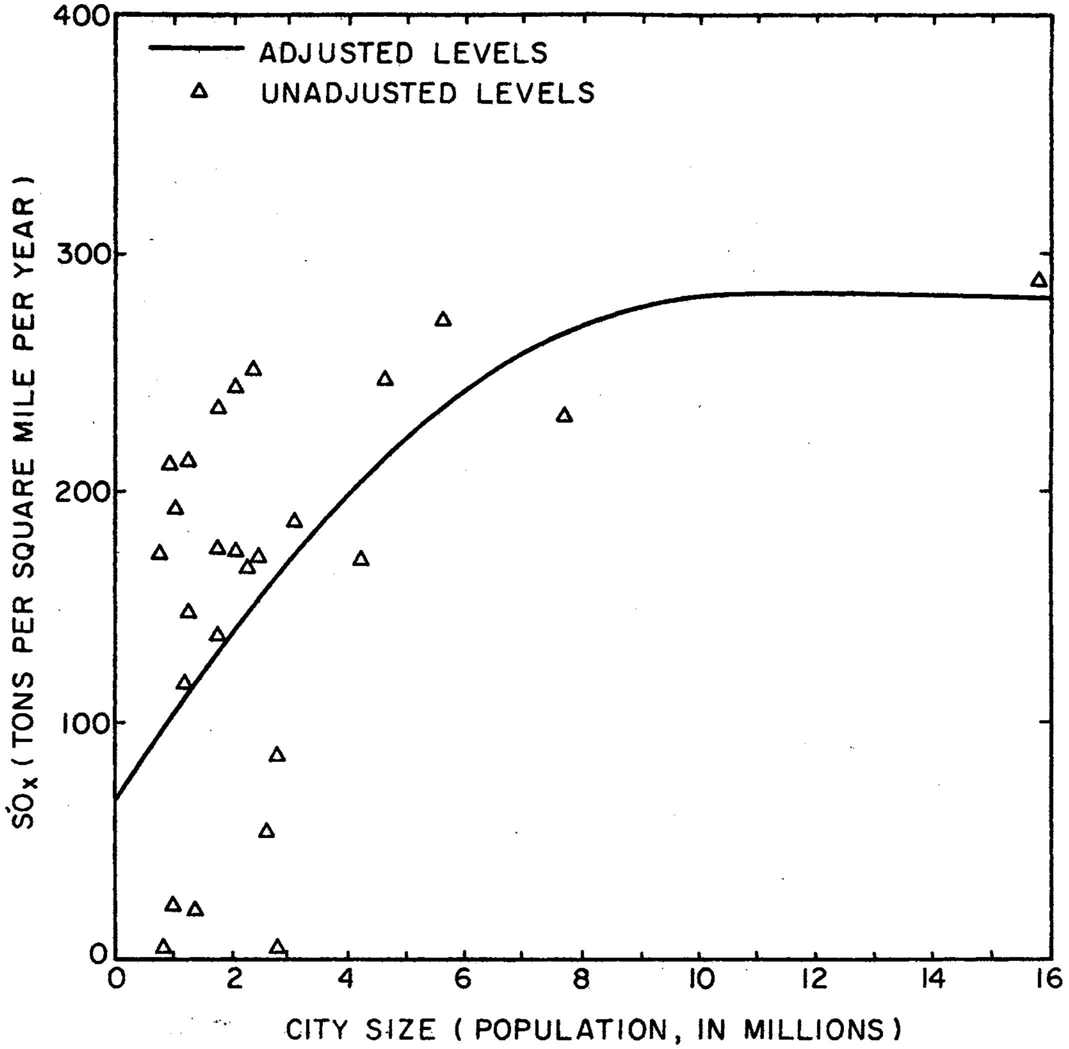


Figure 7. Sulfur Oxides Pollution Levels by City Size

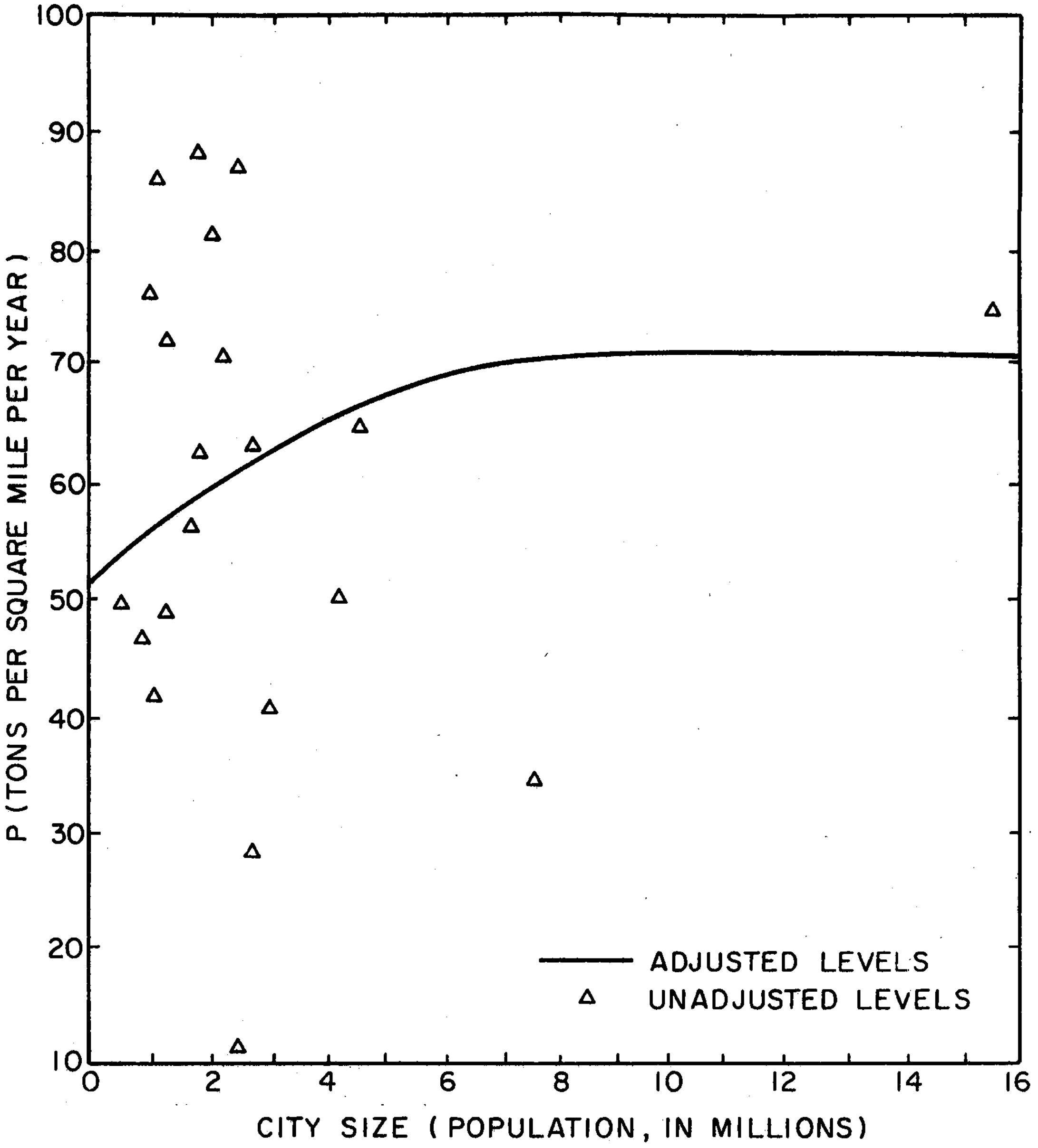


Figure 8. Particulate Pollution Levels by City Size

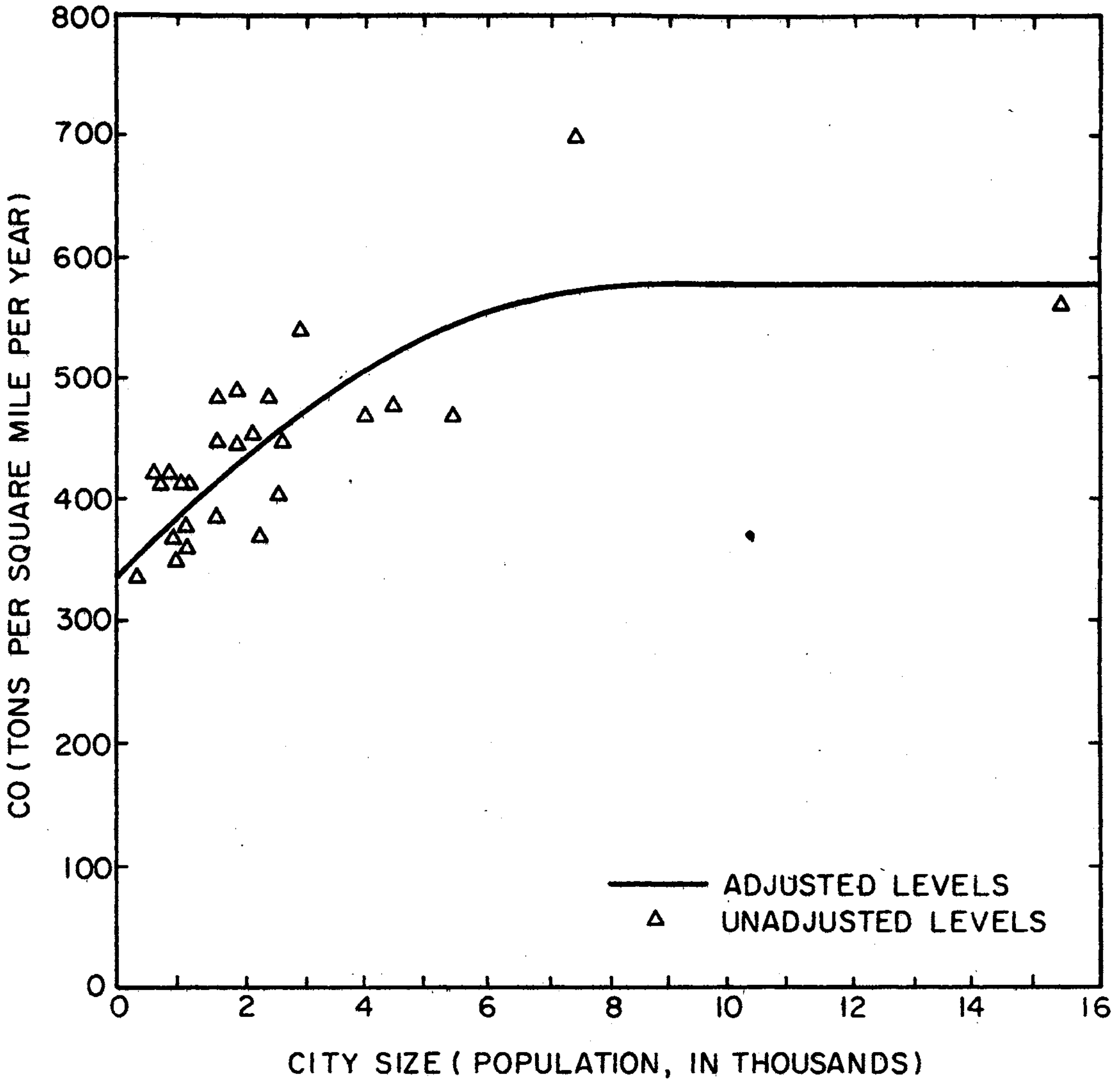


Figure 9. Carbon Monoxide Pollution Levels by City Size

function since the fit is quite good over the range of the majority of observations. After reaching the high point of the parabola, the curve is arbitrarily extended horizontally to the right. The curve may be approaching a saturation point, reflecting the maximum amount of pollutants per square mile the air can hold.

Briefly, these graphs show that air pollution is heterogenous among cities, yet there exists an underlying relation with city size that is, except for particulates, strongly positive in nature to a point.

The Social Cost of Air Pollution

SO_x and P

Constructed from the adjusted levels of SO_x and P from Figures 7 and 8 and the coefficients from equations (8) and (9), Figure 10 shows the social cost per square mile by city size from SO_x and P pollution. Assuming a constant density per square mile of 1,000 for all city sizes, the per capita social cost can be read off the left-hand axis of the curve in Figure 10.

The per capita social cost of SO_x and P pollution is relatively low for the majority of cities, e.g. populations less than, say, 2.5 million.

The social cost of obtaining different qualities of air can be obtained from the curve by merely shifting the curve down until it intersects the horizontal axis at the city size that corresponds to the level of pollution to be tolerated. The curves in Figure 10 reflect the social cost of maximum control (99 percent) in accordance with HEW

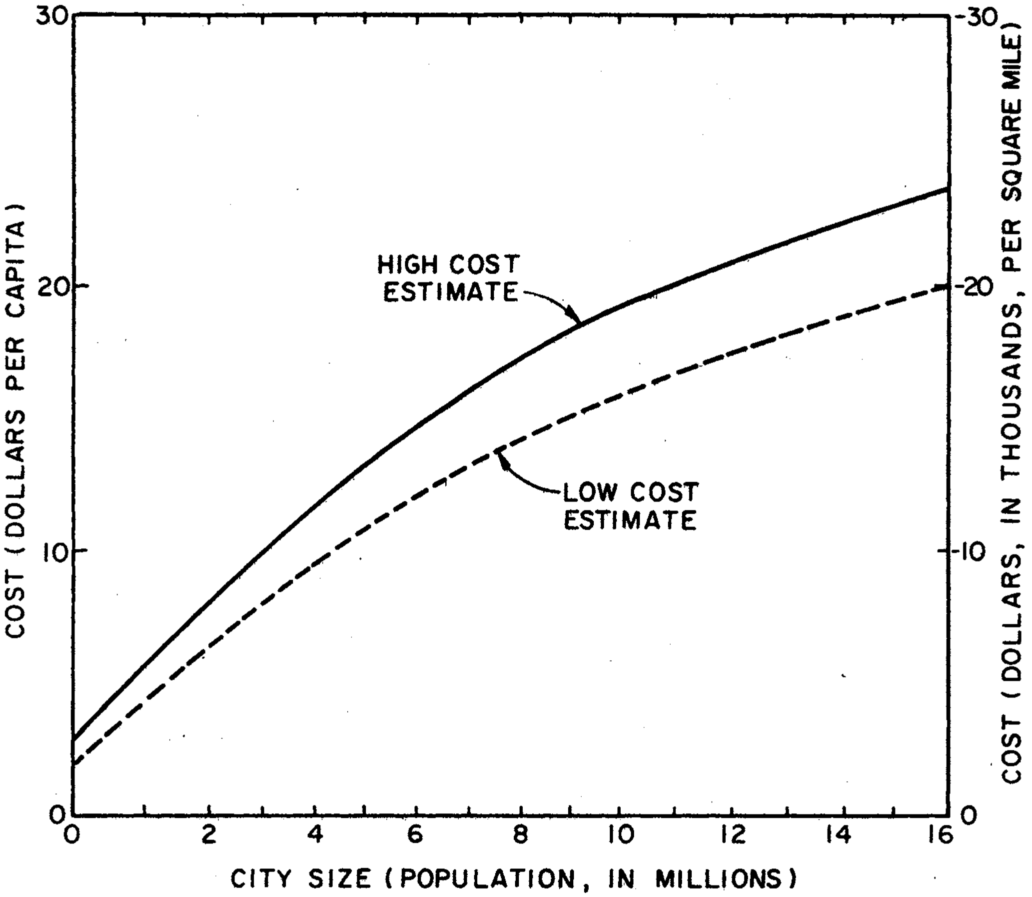


Figure 10. Per Capita Social Cost and Social Cost per Square Mile for Industrially Emitted Pollutants Sulfur and Particulates

criterion for the pollutants SO_x and P rather than a control level of 80 or 90 percent.

CO

The social cost of CO pollution is computed by first estimating the per capita cost to the consumer for the stringent emission controlled vehicle that will soon be mandatory, then calculating the percentage of the urban population that must operate the controlled vehicles to result in a constant level of CO for all city sizes. Finally, this percentage figure for each city times the per capita cost of the emission controlled vehicles yields the per capita social cost of reducing CO in all city sizes.

Industry estimates for the consumer's initial outlay for the emission package is $48 in 1974 or $4.80 annually for a vehicle with a life of ten years. Inclusion of a simple interest charge of 8 percent per annum on the initial outlay raises the annualized cost to $8.64. Lead-free fuel is a necessity for this control package. This type of fuel typically costs 2 to 3 cents a gallon more than regular grade gasoline.[13] The 2 cent figure is used. This increase in gas cost is applied to 666 gallons a year (10,000 miles at 15 miles per gallon) for an average vehicle.[14]

Before the per capita cost of the control package can be estimated, power and fuel economy losses must be examined. When the combustion ratio of an engine is lowered, there are simultaneous losses in both power and fuel economy, and these percentage losses are of about equal magnitude. If the performance level is to be held constant, the fuel economy loss will be 50 percent higher than the loss in performance.

Industry estimates fail to adjust for performance loss and indicate a 5 to 30 percent reduction in fuel economy. The estimates of Heron and Felt are used in this study, which give fuel economy loss of 7.8 percent for regular gasoline cars and of 13.3 percent for premium gasoline cars.[15] Weighting these two figures by 32 percent premium gasoline cars and 68 percent regular gasoline cars (the approximate car population mix) the fuel economy loss becomes 9.6 percent which implies a power loss of 6.4 percent. The consumer must purchase a 6.4 percent larger engine and buy 9.6 percent more fuel to return to his baseline utility level. Assuming the price of lead-free gas is 30 cents a gallon (net of taxes) and the previously stated fuel consumption of 666 gallons a year, the cost attributable to the fuel penatly is $19.18.

The performance can be increased by either changing the engine size or the gear ratios in the car so that the engine runs faster at a given speed. A 6.4 percent larger engine (for purposes of the chapter) does not necessarily cost 6.4 percent more for the consumer or for the resources required to manufacture it. For instance, one could assume that the larger engine will require 6.4 percent additional steel and labor; however, it could conceivably be produced by enlarging the cylinders of the smaller block. To complicate matters even more, the recovery in performance can also be achieved by altering the gear ratio, which results in an increase in fuel consumption as the engine is now running faster at a given speed. It is estimated that the cost of recovering the power by either method described above or a combination of them to be $27 on an annualized basis including interest charges.

The annual cost of the emission control vehicle accepting the performance loss will differ from the constant performance vehicle by the engine size change and the fuel penalty. The fuel penalty will be 6.4 percent with the performance loss and the engine size change will be nil. This approach does not return the consumer back to point A in Figure 6. The move between D and C is not accounted for. However, since most of the driving done (in cities) is at or below half throttle, the loss of performance might not be detectable. Results are presented for both choices in Table IV. The most important component of these cost estimates is the price and quantity of fuel.

TABLE IV

ANNUAL COSTS OF THE EMISSION CONTROL VEHICLES

	With Performance Loss	Constant Performance
Control Package	$ 8.64	$ 8.64
Δ Gas Price	13.32	13.32
Engine	--	27.00
Fuel Penalty	12.79	19.18
Total	$34.75	$68.14

These costs are considerably higher than the $5.80 figure presented in the "Cost of Clean Air."[16] The inclusion of the entire control package results in a more realistic figure than use of just the initial cost. Still the figures in Table IV are probably understated as no allowance was made for maintenance costs. The control of nitrogen oxides may further decrease the efficiency of the engine as the method concurrently proposed by the industry entails recirculating the exhaust gas. This factor was omitted because the degree of control has not been established.

The proposed emission controls for CO in 1975 call for a 90 percent reduction. If all vehicle owners in a city used the controlled vehicles, the CO level attributable to motor vehicles would decline by 90 percent.[17] Selected data indicate that motor vehicles account for roughly 90 percent of the CO emissions in large urban areas. Hence, if all operators adopt the emission control package the net reduction in CO levels present in urban areas is 81 percent. The social cost of CO control can now be estimated for each city size using the control reduction figure and the estimated annual cost in the following formula:

$$SC_i = (A/C) \times B \tag{12}$$

where

SC_i = social cost per capita in city size i;

A = percentage difference in CO level between the base city and the i^{th} city;

B = per capita annual cost of the controlled vehicle; and

C = .81, the proportion of controll attained with all vehicles using the control package.

The per capita social cost of CO both with and without constant performance is presented in Figure 11. The base city is 500,000 population. Alternative city sizes reflecting alternative accepted levels of pollution may be used as the base by merely recalculating A in (12). Diseconomies of size exist from the base size upward. Controlling CO to a level equal to that present in city sizes of 500,000 the per capita cost in a city of 3 million is $19.28 with constant performance and is $9.83 without constant performance. Since taxes must be construed as a social benefit, B in (12) is computed net of any taxes. Later in discussing the private outlays to reduce pollution, annual cost estimates that include taxes will be used.

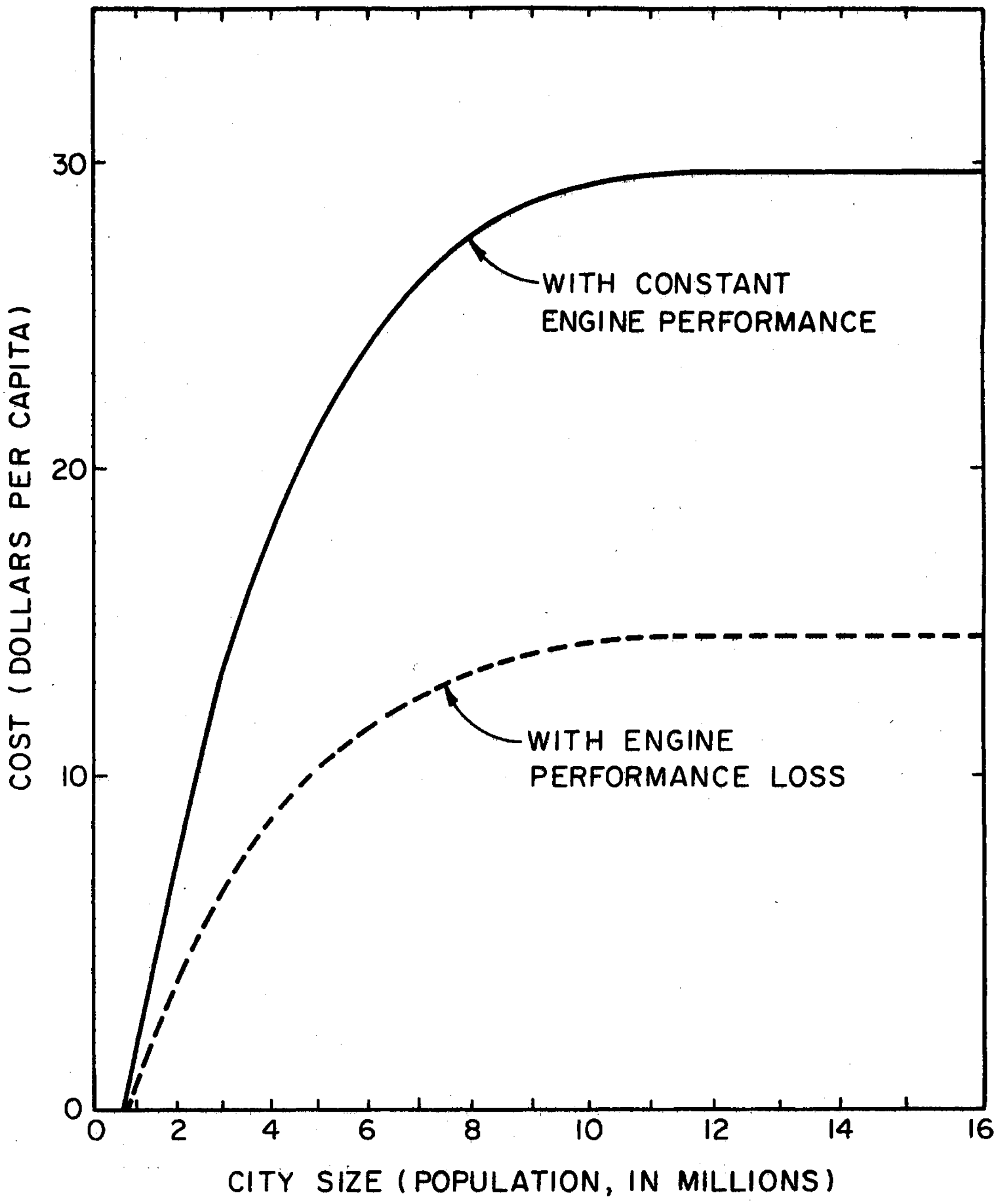


Figure 11. Per Capita Social Cost of Carbon Monoxide (base city size = 500,000 population)

Combined Social Cost of Controlling SO_x, P, and CO

Two social costs for each of the industrially and automobile emitted pollutants were estimated. In combining these cost estimates, four possibilities exist and are presented in Figure 12. Again the base city size is 500,000.[18] The most complete measures of social cost are shown by curves 1 and 2 which were constructed using the low and high cost estimates for the industrially emitted pollutants and the cost of recovering constant automobile performance. Curves 3 and 4 are included as an alternative if the consumer chooses to accept the performance loss of the engine. The per capita social cost of air pollution ranges from zero to \$51.23 and zero to \$48.44 for constant engine performance and high and low industry costs respectively. The corresponding per capita social costs for an urban area of three million, the average size of the sample, are \$24.37 and \$23.57. The curves representing all four combinations of alternative cost estimates show increasing costs throughout the range; however, for urban areas of 8 million and larger the social cost tends to level off due to the modification of the curves for estimated air pollution levels.

The total social cost of reducing air pollution to levels present in urban areas of 500,000 and 1,000,000 is computed using the previous results.[19] The 58 urban areas exceeding populations of 500,000 and containing 53 percent of the total U. S. population contributed a social cost of \$2.53 billion to \$2.64 billion, while the 27 urban areas of population size one million or more contributed a social cost of \$2.03 billion to \$2.12 billion. If the higher pollution level present in urban areas of two million is acceptable, then the social cost of reducing air pollution is \$1.33 billion to \$1.40 billion.

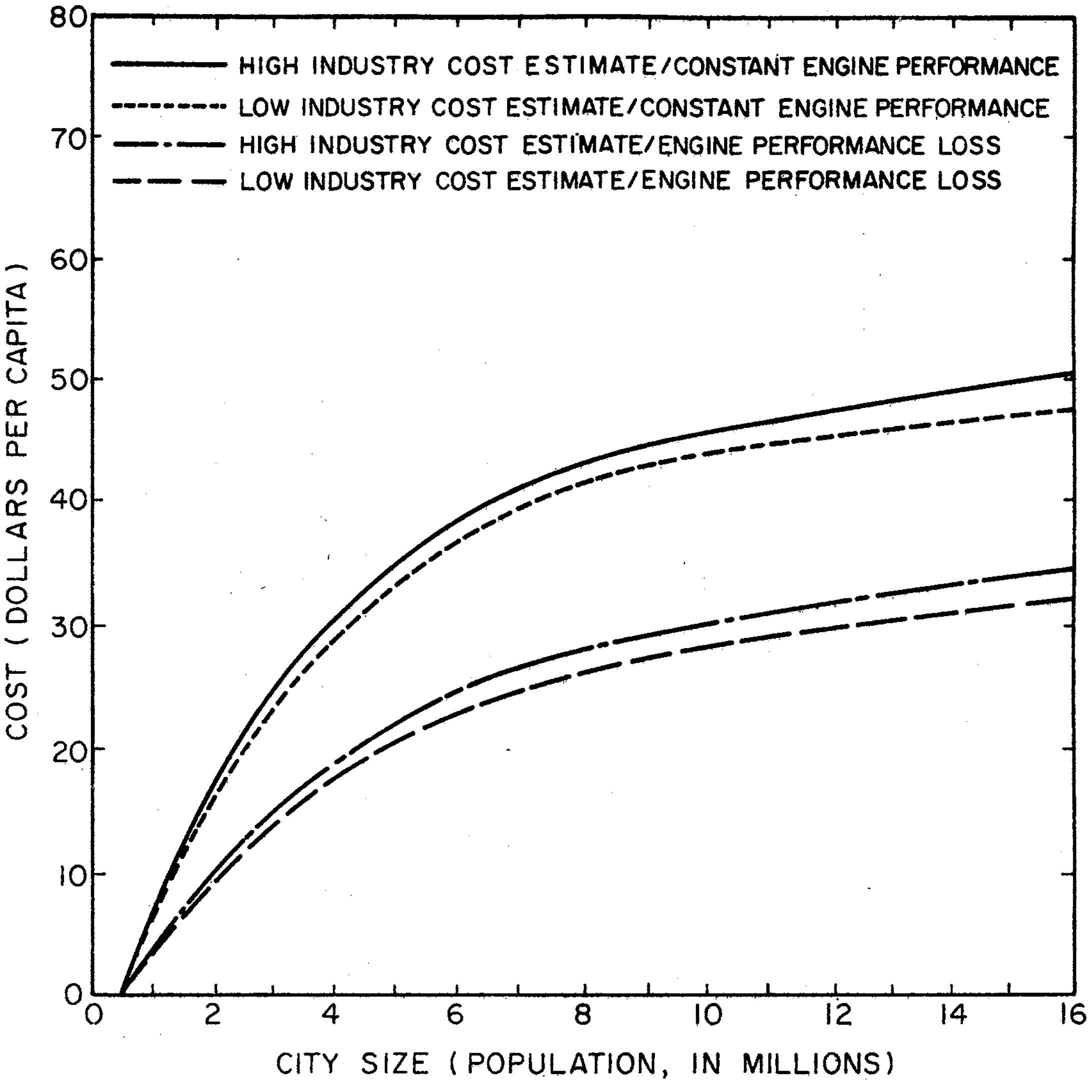


Figure 12. Per Capita Social Cost of Air Pollution

Summary

The results indicate sizable diseconomies of city size with regard to air pollution control. The per capita social cost of air pollution increases rapidly until city sizes of 8 million and greater are reached. The estimated costs of controlling the pollutants emitted by industrial sources coincide with previous government estimates. On the other hand, estimates in this chapter of the direct and indirect cost to the consumer for the emission control package on motor vehicles are substantially higher than the government estimates. Estimates of the social cost of both industrial and vehicular emitted pollutants were based on the use of techniques already available to industry and the gasoline powered engine presently used in vehicles. Adoption of another source of energy for the motor vehicles or new technologies for abating industrial emissions would of course change the estimates presented in this paper.

The basic underlying assumption of this study is that the cost of controlling air pollution is less than the cost of allowing it to occur. The estimates indicate that this assumption may not, in fact, be met. The total projected cost of controlling air pollution via nondiscriminatory application of controls, $10.1 billion to $10.3 billion, is composed of the following components: (1) government expenditures--$454.5 million, (2) industrial expenditures (high and low estimates)--$942.2 million and $765.8 million, and (3) consumer motor vehicle expenditures --$8.9 billion.[20] The motor vehicle component of the total cost is based on Table IV and 120 million automobile equivalents. After updating the damage estimates to 1971 dollars by the consumer price index, the Pittsburg study inflated estimates are $15.7 billion (entire nation) and $5.7 billion (urban population), while the Ridker estimate is $6.8 billion.[21] Only one of the previously cited damage estimates, the highly suspect extrapolation of 1913 Pittsburg data to the entire nation, exceeds the estimated cost of controlling air pollution. Alternatively, a perfectly discriminating application of measures to control air pollution to levels no higher than found on the average in cities of 100,000 population (a city size considered to have tolerable levels of air pollution) results in lower social and private costs ($3.2 billion) of controlling emissions than the previously estimated costs of allowing it to continue. The assumption that the cost of controlling air pollution is less than the cost of allowing it to occur can be satisfied only if the abatement program discriminates by city size, tailoring controls to needs of each city.

A related issue concerns the equity of control expenditures. Since it is difficult to tailor automobile exhaust emission control to the minimum required for each city size, a uniform control program has been proposed. As a result, 38 million rural residents and 26 million residents in the cities with less than 100,000 population and assessed the same costs as the residents of large urban complexes. The rural and small city population is subsidizing the population in larger cities where pollution is a serious problem. The private annual cost of the emission control package is $74.53 regardless of rural or urban residency and is higher than the per capita social cost in even the largest urban area (see Figure 12).

FOOTNOTES

[1] Another manufacturing index, the percent of the workforce engaged in durable manufacturing, was included in equations (1) and (2) but the results were inferior to the reported results using the percent of the workforce engaged in manufacturing.

[2] The effect of temperature per se on the accumulation of air pollution over an area is not accounted for by the variable T. The vertical variation in temperature over a region is one of the most important factors concerning air pollution concentrations as the atmospheric stability determines whether or not inversions will occur. The required data on atmospheric stability over urban areas does not exist in sufficient quantity for this study.

[3] National Air Pollution Control Administration, Air Quality Criteria for Carbon Monoxide, AP-62 (March 1970), Air Quality Criteria for Particulate Matter AP-49 (January 1969), Air Quality Data from the National Air Surveillance Networks, APTD 69-22 (1967); U. S. Public Health Service, Air Quality Criteria for Sulfur Oxides, No. 1619 (March 1967), U. S. Government Printing Office, Washington, D. C.

[4] The Los Angeles SMSA observation was rejected due to the peculiar characteristic of location and topography innate to this SMSA. Further, the immense area (41,000 square miles) over which the pollutants would be disseminated when expressed in per square mile terms results in a less than adequate measure of the level of air pollution inherent in this urban complex.

[5] D. A. Hirschler, Ethyl Corporation, correspondence dated May 27, 1971; U. H. Holmes, Ford Corporation, correspondence dated June 25, 1971; and G. W. Dickinson, General Motors Corporation, correspondence dated June 18, 1971.

[6] "The Cost of Clean Air," First Report of the Secretary of Health, Education and Welfare to the U. S. Congress (June 1969), U. S. Government Printing Office, Washington, D. C.

[7] U. S. Weather Bureau, Climatological Data National Summary, Vol. 19 (1968) U. S. Government Printing Office, Washington, D. C.

[8] U. S. Bureau of the Census, *Census of Business: 1967*; *Census of Population: 1960*; and *County and City Data Book, 1967*, (A Statistical Abstract Supplement), U. S. Government Printing Office, Washington, D. C.

[9] The figures in parentheses are the standard errors of the coefficients. ** indicates significance at the .01 level while * indicates significance at the .05 level with a 1 tail test.

[10] Equations (1) and (2) were also estimated using another source of data. In some respects the estimated equations presented below are superior to the estimated equations in the main text. For instance, the coefficients for city size are positive in sign and highly significant. Both equations possess positive signed coefficients for the manufacturing index though significant in only equation (2"). The climatic variables have coefficients of the expected sign and are significant in equation (2"). However, cost estimates of reducing SO_x and P are not available for the corresponding central cities in the sample; therefore, equations are presented only for comparative purposes.

Average 1967 daily emissions of SO_x and P expressed in milligrams per cubic meter ($\mu g/m^3$) for cities with population ranging from less than 10,000 to over 3 million were obtained from the National Air Surveillance Networks. The sample for SO_x contains 43 observations while the sample for P contains 250 observations. These two data sets are for the city rather than an urban complex such as an SMSA. Small cities are represented in the sample. The estimated parameters for equations (1) and (2) using ordinary least squares regression on the larger samples of SO_x and P are presented below:

$$(1'') \quad \hat{SO}_x = 60.6368 + \underset{(0.0149)}{0.0383^{**}S} + \underset{(0.0206)}{0.0060S^2} + \underset{(0.7197)}{1.0345R} - \underset{(4.1879)}{2.8428W}$$

$$- \underset{(1.5108)}{0.6939T} + \underset{(0.6282)}{0.7226M} \qquad R^2 = .7137$$

$$(2'') \quad \hat{P} = 62.7153 + \underset{(0.0082)}{0.0230^{**}S} - \underset{(0.125)}{0.0136S^2} - \underset{(0.1894)}{0.4839^{**}R} - \underset{(1.2273)}{4.2177^{**}W}$$

$$+ \underset{(0.3988)}{0.8823^{*}T} + \underset{(0.1701)}{0.8477^{**}M} \qquad R^2 = .1690$$

The variable T is defined as the July median temperature (degrees) in the above equations and all other variables correspond to those defined in the text.

Even though the positive relation between the pollutant and city size is more significant in equations (1") and (2") than the equations in the text, the cost estimates would not be materially altered if the above equations were used for the estimated levels of SO_x and P.

[11] National Air Pollution Control Administration, Air Quality Data from the National Air Surveillance Networks, APTD 69-22 (1967) U. S. Government Printing Office, Washington, D. C., p. 3.

[12] J. T. Middleton and D. Clarkson, "Motor Vehicle Pollution Control," Traffic Quarterly (April 1961), pp. 306-317.

[13] The higher cost of lead-free fuel with respect to leaded fuel is attributable to distribution costs rather than refining costs. As more and more motor vehicles require the lead-free fuel, the price will decline.

[14] The cost of the control package is estimated for the average automobile. Trucks and buses are also under the emission control requirements and they are converted to automobile equivalents based on fuel usage when total costs of pollution control are discussed later in the paper. Diesel fuel is presently lead-free and diesel engines are only subjected to opacity of the exhaust control; therefore, the total number of automobile equivalents used in this study is minus diesel trucks and buses.

[15] S. D. Heron and A. H. Felt, "Cylinder Performance--Compression Ratio and Mechanical Octane Effects," Society of Automotive Engineers Quarterly Transactions, Vol. 58, No. 4 (October 1950).

[16] "The Cost of Clean Air," First Report of the Secretary of Health, Education and Welfare to the U. S. Congress (June 1969) U. S. Government Printing Office, Washington, D. C.

[17] It was assumed that the pollution in each city attributable to motor vehicles is emitted from vehicles owned by residents of the city in question. What this assumption fails to take into account is the emissions from vehicles operated in the city by owners who reside outside the city limits or in another city. However, it is felt that this omission is minor as the unit of observation is an SMSA.

[18] The city size chosen as the base for the social cost estimates of CO and the combined social cost estimate of CO, SO_x, and P is more or less arbitrary. A city size of 500,000 was chosen. This city size approaches the lower population limit of the cities in the sample to reflect the social cost of a larger reduction in pollution than if a city size greater than 500,000 was used as the base. Based on Figures 7-9, the reduction in SO_x, P and CO pollution from the largest city size in the sample to the 500,000 base city size is 69 percent, 27 percent, and 37 percent, respectively. These reductions differ from the advocated emission control benchmarks established by the government.

[19] These calculations were made assuming that the air pollution level present in one city is independent of the air pollution level in another city regardless of the proximity of the cities.

[20] The government and industrial expenditure estimates are from "The Cost of Clean Air," pp. 1-2. The consumer motor vehicle expenditures are taken from the text.

[21] R. G. Ridker, Economic Costs of Air Pollution (1967) Praeger, New York; Schmidt, A. W., "The Pittsburg Program in Retrospect: The Economic Evaluation," ASME Paper No. 59 (1959) Pittsburg Bicentennial Conference, Pittsburg, Pennsylvania.

CHAPTER IV

THE COST OF CONTROLLING FIRE

Society gains protection from fire damage and loss in a twofold manner: (1) by private outlays for insurance to recover losses should a fire occur, and (2) by public outlays to sustain a fire department. The two components of fire protection costs are interdependent: insurance rates depend upon the quality of the fire department. The cost of providing fire protection as computed in this chapter will include both public and private outlays for this service.

The aims of this chapter are to:

1. Estimate the class--a numerical measure used by state rating bureaus in evaluating fire defenses and physical conditions of cities--of fire protection by city size, holding per capita public expenditures for fire department services constant.

2. Compute private insurance costs by city size for a given level of per capita wealth in all city sizes.

3. Construct a unit cost curve for a given quality of fire protection services by city size including public and private outlays.

Class of Fire Protection

The problem of measuring the quality dimension of a city's fire defenses has plagued researchers interested in the full cost of fire protection. Table V shows that actual per capita expenditures for fire protection are lowest in small cities. Even disregarding quality of services at this point, these figures do not include all costs because fire departments in small cities are frequently manned by volunteers. When a charge is made for the opportunity cost of volunteer labor and the loss from fires while the volunteer force is assembling, then the per capita costs may no longer be lowest. When the quality factor is introduced to the analysis, the full cost of protection may be high for small cities because insurance rates are high. These high rates result in part because, as is shown later in the chapter, the small cities have lower quality fire protection.

TABLE V

ACTUAL PER CAPITA EXPENDITURES FOR FIRE DEPARTMENT SERVICES BY CITY SIZE

City Size	Per Capita Expenditures
less than 75,000	$ 7.73
75,000-150,000	15.09
150,000-250,000	16.79
250,000-400,000	17.02
400,000-750,000	18.33
750,000-1,000,000	18.68
greater than 1,000,000	20.67

Source: U. S. Bureau of the Census, <u>City Government Finances in 1969-70</u>, U. S. Government Printing Office, Washington, D. C.

The measure used in this chapter to depict differing quality levels of fire protection among city sizes is the classification determined by the Standard Grading Schedule of a city's fire defense and physical condition.[1] Applying the Standard Schedule, state rating bureaus class a city into one of ten classes ranging from Class 1, the ultimate in fire protection, to Class 10, little or no fire protection. The Grading

Schedule considers mainly the fire fighting facilities of the community. The relative value of the individual components considered in the classification procedure are as follows: water supply (34 percent), fire department--including manpower, apparatus, hose, and other fire-fighting equipment (30 percent), structural condition of buildings (14 percent), fire alarm system (11 percent), fire prevention codes (7 percent), and building codes (4 percent).

Once a city has been classified by the rating bureau, a foundation for the basis rate exists. The basis rate, determined largely by the loss experience over a number of years, varies according to building construction and the class of fire protection. The lower the fire protection class, the lower the basis rate.

The Standard Schedule was first adopted in 1916 and was revised in 1917, 1930, 1942, and 1956. The present Standard Schedule is the 1956 edition with 1963 and 1964 amendments. The Standard Schedule has been criticized for lack of definite correlation between the classification of a city and the loss per capita or the number of fires. This criticism has been dismissed by fire chiefs who contend that per capita losses from fires is not a meaningful measure for classifying cities. An excellent fire loss record in a city can be ruined by one large random or sporatic fire under conditions such that the fire department is completely helpless. Despite criticisms, the Standard Schedule is widely accepted as an adequate and satisfactory measure of the relative standing of cities with regard to their fire protection facilities and physical conditions.[2]

The Model

C, the class of fire protection as determined by the rating bureau, is hypothesized to be a function of city size S and per capita expenditures for fire department services in the following econometric model:

$$C = f(S, F) \tag{1}$$

The coefficient of S is expected to be negative in (1)--a larger sized city is expected to have a higher quality fire protection program than a smaller sized city, hence a lower value of C. The coefficient of F is also expected to have a negative sign in (1)--an increase in per capita expenditures for fire department services should improve the quality of service provided. The most heavily weighted component of C --water supply--does not appear in (1). It is included implicitly in S as the quality of the water supply, including capacity at fire hydrants, is positively correlated with city size S.

The coefficients of (1) provide an estimate by city size S of the class of fire protection C adjusted for per capita expenditures on fire department services. Basic fire insurance rates can be applied to property values in each city size according to the class of fire protection determined in (1). The private insurance costs plus the per capita outlays for fire departments will constitute the cost of fire protection used in this study.

Ideally, the social cost of fire protection would measure the net disutility in the populace that stems from public and private outlays for fire protection and from accepted fire losses for each city size. This ideal concept poses difficult problems in measuring utility and accounting for the heterogenous structure of cities with respect to the type of construction and value of property present among the current distribution of cities. Fire rates vary not only for different types of construction or number of stores in a building, but also for characteristics of adjoining buildings. The total number of possible combinations of characteristics such as construction, occupancy or exposure --all influencing fire rates--is astronomical. An empirical counterpart to the ideal measure of the social cost of fire is used in this study and circumvents problems of measuring the individual components of the cost of fire protection, especially the private insurance outlays. This approach is to compute the cost of fire insurance for a given level of per capita wealth among all city sizes. Public per capita expenditures on fire departments to protect the given level of per capita wealth among all city sizes is assumed to be constant. The empirical procedure is to use the class of fire protection from (1) and the corresponding basic rates for insurance to determine the private outlay by city size for fire protection. Then the constant public per capita expenditures for fire departments are combined with the private per capita outlays for fire insurance, to form the per capita costs of fire protection by city size used in this chapter. Still, not all costs have been included. Private outlays for fire protection and fire warning devices have been omitted from the analysis. The outlays for alarms and sprinkler systems, for instances, is probably higher in the large cities than the small cities. Hence, the estimates presented later are biased downward for the large cities.

The Data

The model was applied to data from Oklahoma cities with populations ranging from 7,787 to 366,481 inhabitants. Data on the classification of a city were obtained from the Insurance Services Office of Oklahoma for the year 1970.[3] City size data for 1970 are from the Bureau of the Census as are per capita fire protection expenditures.[4]

Estimates of total nonfarm wealth in the United States are taken from a Congressional Report.[5] The basic fire insurance rates for both mercantile and residential buildings were provided by the Insurance Services Office of Oklahoma.[6]

Regression Analysis and Results

The estimated parameters for equation (13) using ordinary least squares regression on the sample of 26 Oklahoma cities are presented below:[7]

$$\hat{\log} C = \underset{(0.0232)}{0.8330^{**}} - \underset{(0.0032)}{0.0081^{*}F} - \underset{(0.00009)}{0.00077^{**}S} \qquad (2)$$

$$R^2 = 0.81$$

The coefficient of F, the per capita expenditure by cities for fire department services, is significant at the .05 level and negative in sign. The result indicates that cities spending more per capita on fire departments have a higher quality of service than those cities spending less. The coefficient of city size is also negative in sign and significant at the .01 level. This conforms to the prior reasoning that larger cities receive a lower classification (denoting higher quality service) than smaller cities.

Figure 13 was constructed from the coefficients of (2) by varying city size while holding per capita fire department expenditures F constant at $15.88, the national mean value. The curve indicates what classification a city will receive if all cities spend an equal amount per capita on fire defense. A 10,000 size city would be very near Class 6 while a city with 600,000 inhabitants would be classified as Class 2. Class 1 is realized by a city of 1 million and, since this is the lowest possible classification, the curve is merely extended horizontally to the right. The curve in Figure 13 will be used to determine the class and subsequently the fire insurance rates to determine the private outlay per capita in all city sizes for fire protection.

Cost of Fire Protection

The private outlays for fire insurance are dependent upon the insurance rates and the property valuations. Per capita property valuation used in this study is total nonfarm wealth (total tangible assets) divided by population. By using a constant per capita wealth figure, including public and private holdings for each city size, no particular city size is chastised for being a high wealth city or a low wealth city. This procedure allows costs associated with fire protection to be analyzed as if all cities moved toward a homogenous structure of per capita wealth and per capita expenditures for fire departments.

Table VI contains estimates for total and per capita nonfarm wealth in 1968. These estimates are divided into two groups--residential and mercantile--and used as the value of property insured against fire. The mercantile wealth component is assumed to be composed of 10 percent A construction--fire proof, 10 percent B construction--fire

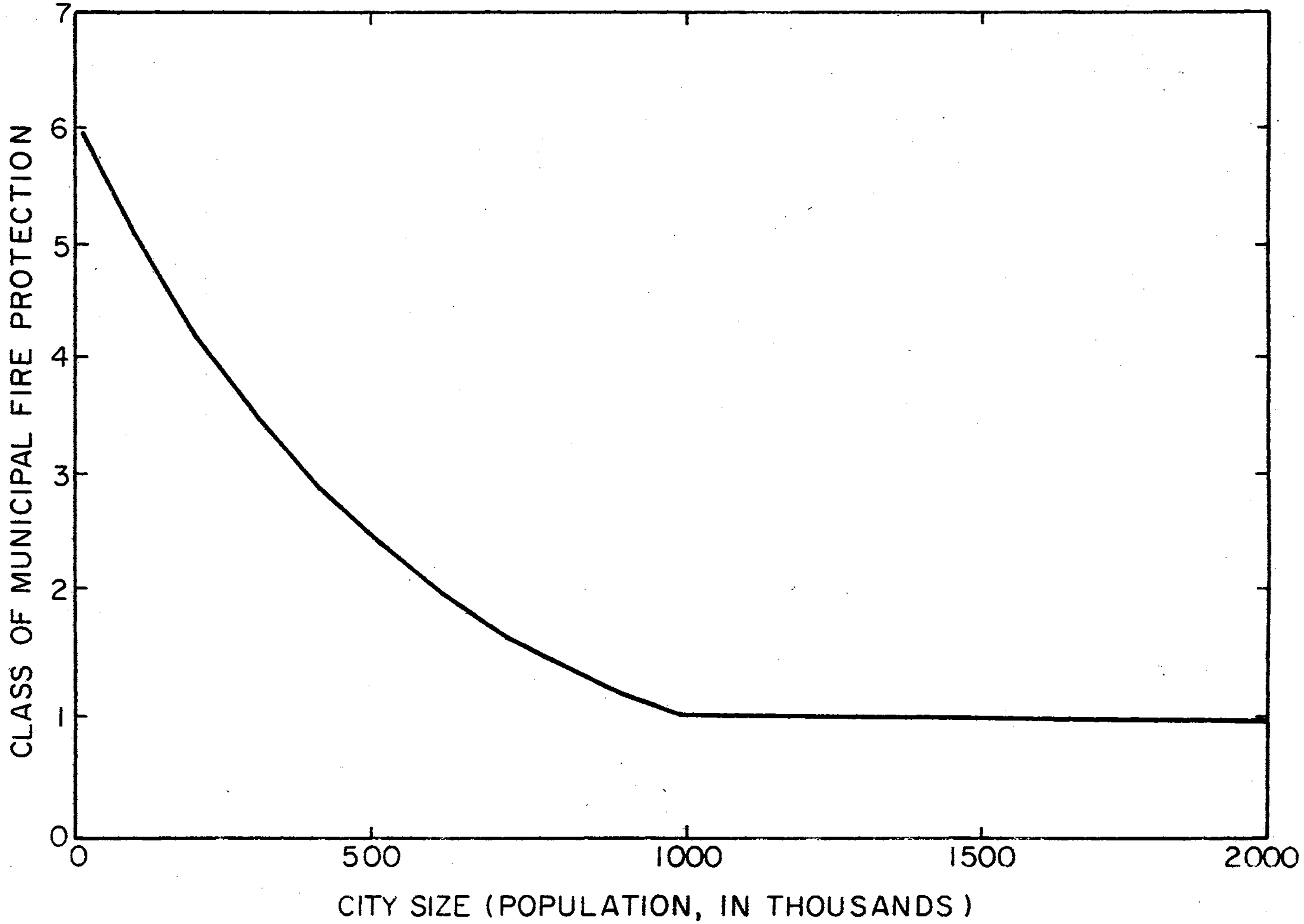


Figure 13. Class of Fire Protection by City Size

resistive, and 80 percent D construction--frame. These estimates are based on discussions with personnel in the Fire Protection Technology Department at Oklahoma State University. Not all cities presently have this distribution of construction, but as cities move toward a greater percent of say A or B construction, the increase in construction costs will probably more than offset the decrease in insurance rates so that if an overall error is made in the proportions of construction types, the cost estimates presented later in the chapter for fire protection would not be materially affected. The residential component of wealth --$4,598.32 per capita--is assumed to be composed of 56.68 percent houses and 43.32 percent apartments based on Census of Housing estimates. The house component is further assumed to be one-half brick construction and one-half frame construction.

TABLE VI

TOTAL AND PER CAPITA NONFARM WEALTH IN THE UNITED STATES, 1968

	Total		Per Capita
Structures			
Residential	$ 682.7	B	$ 3,425.28
Other Private Nonresidential	288.7	B	1,448.48
Institutional	55.7	B	279.46
Public Nonresidential	459.8	B	2,306.93
Equipment			
Consumer Durables	233.8	B	1,173.04
Producer Durables	377.0	B	1,891.50
Inventories			
Private	172.7	B	866.48
Public	14.0	B	70.41
TOTAL	$2,284.4	B	$11,461.41

Source: U. S. Congress, Institutional Investor Study Report of the Securities and Exchange Commission Supplementary, Vol. I, House Document 92-64, Part 6, March 1971.

The insurance outlays in Table VII are computed using the master basis tables and the level of wealth previously discussed. The estimated insurance costs in Table VII are increased by $15.88--the constant per capita cost of fire department services--to complete the computation of the cost of fire protection. Using the class of fire protection and city size relation from (2) and the insurance costs from Table VII along with the constant per capita social expenditures for fire protection, the curve in Figure 14 was constructed which shows the relation between city size and the full cost of fire protection. Economies of city size exist until a city of one million population is attained at which time the curve becomes horizontal to the city size axis. The magnitude of the economies of city size is $12.44 per capita as cities increase from 10,000 to one million population.

The results reported in this chapter compare favorably with previous studies. In an earlier study by Hirsch in 1959 for the St. Louis area, the per capita expenditure function for fire protection in the St. Louis area was approximated by a parabola with the trough at a population of 110,000.[8] Will estimated per capita costs for a standard service requirement (a given quality) of fire protection in 1965 and concluded that, "There are significant economies of scale associated with the provision of municipal fire protection services, at standard levels of service, for central cities ranging from 50,000 to nearly one million in population."[9] Both the Hirsch and Will studies were directed at the public expenditures for fire department services. A more recent study by Hitzhusen (1972) considers both public and private outlays for fire protection services and concludes, ". . . there were generally "size" economies (i.e., more populous and higher burnable

TABLE VII

PRIVATE INSURANCE OUTLAYS FOR A GIVEN LEVEL OF NONFARM WEALTH BY CITY SIZE (IN DOLLARS)

Class	1	2	3	4	5	6
Mercantile						
A Construction	3.42	3.46	3.49	3.53	3.56	3.60
B Construction (4 stories)	4.36	4.64	4.92	5.24	4.47	5.93
D Construction (3 stories)	41.85	43.52	45.20	47.00	48.82	40.76
Residential						
Brick	9.41	9.41	9.41	9.41	9.93	9.93
Frame	12.67	12.67	12.67	12.67	13.33	13.33
Apartments (brick)	15.60	15.60	15.60	15.60	16.20	16.20
TOTAL	87.31	89.30	91.29	93.45	97.41	99.75

Source: Table VI. Western Actuarial Bureau, Analytic System (1969). Oklahoma Inspection Bureau, Oklahoma Dwelling Schedule (1971).

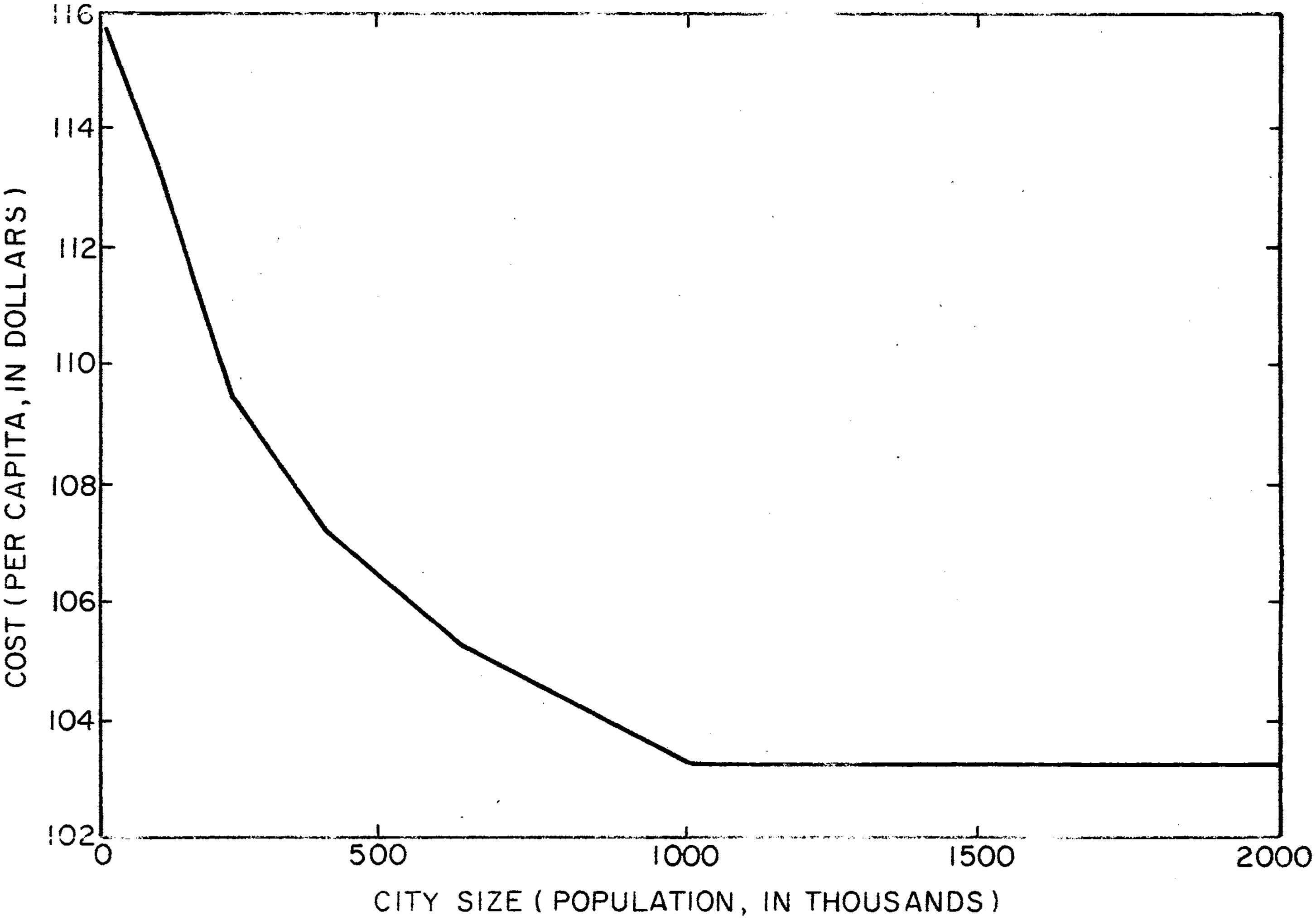


Figure 14. Per Capita Costs of Fire Protection by City Size

property value protected respectively) in the provision of fire protection in the Texas and New York communities sampled. Evidence for "size" economies tended to increase when the unit costs of fire protection included (in addition to fire department operating costs) 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."[10] The Will and Hitzhusen studies lend credence to the results reported herein that economies of city size for fire protection costs exist until cities of one million population are reached.

Summary

The results indicate sizable economies of city size with regard to fire protection when all costs--public and private--have been fully accounted for in the analysis. This result differs from the actual expenditures made by cities where the cost of fire protection increase with city size. The major weakness of the analysis in this chapter was the small sample of cities used to estimate the costs of fire protection. It is reassuring that results of the previous studies cited in the text broadly support estimates reported in this chapter.

FOOTNOTES

[1] Standard Schedule for Grading Cities and Towns of the United States with Reference to their Fire Defenses and Physical Conditions, (New York: American Insurance Association).

[2] Origin, Development and Use of the Standard Schedule for Grading Cities and Towns with Reference to their Fire Defenses and Physical Conditions, (New York: National Board of Fire Underwriters), pp. 7-8.

[3] Town Index (1970), Insurance Services Office of Oklahoma.

[4] U. S. Bureau of the Census, Census of Population: 1970, U. S. Government Printing Office, Washington, D. C.

[5] U. S. Congress, Institutional Investor Study Report of the Securities and Exchange Commission Supplementary Volume 1, Document 92-62, Part 6 (March 1971).

[6] Oklahoma Inspection Bureau, Oklahoma Dwelling Schedule (1971), Western Actuarial Bureau, Analytic System, (1969).

[7] The figures in parentheses are the standard errors of the coefficients. ** indicates significance at the .01 level while * indicates significance at the .05 level.

[8] Werner Z. Hirsch, "Expenditures Implications of Metropolitan Growth and Consolidation," The Review of Economics and Statistics, Vol. 21 (August 1959).

[9] Robert E. Will, "Scalar Economies and Urban Service Requirements," Yale Economic Essays, Vol. 5 (Spring 1965), p. 60.

[10] Fred J. Hitzhusen, "Some Policy Implications for Improved Measurement of Local Government Service Output and Costs: The Case of Fire Protection," (Unpublished Ph.D. dissertation, Cornell University, 1972).

CHAPTER V

THE COST OF HOSPITAL AND EDUCATION SERVICES

The aims of this chapter are to:

1. Discuss previous estimates of the per capita costs of hospital services by city size.

2. Discuss previous estimates of the per capita costs of primary and secondary educational services by city size.

Hospital Costs by City Size

Hospitals provide a mix of services composed of two general types of care: basic care (room, board, and routine nursing attention) and varying levels of specialized services. The heterogenous mixture of services among hospitals create problems in estimating the cost of a given level or quality of services. Typically, the larger hospitals offer more specialized services. The costs in this section are for hospitals that offer essentially the same number of services.

Carr and Feldstein estimated total costs for hospitals using multiple regression analysis on data from 3,147 voluntary short-term general hospitals.[1] These 1963 total cost estimates were subsequently expressed on an average-cost-per-patient-day basis. The sample of hospitals was stratified into five service-capability groups according to the number of services provided, and cost estimates were made for each group. As expected, an increase in the number of services provided by the hospital was associated with an increase in per patient day cost. However, the higher service-capability group provides more services at a lower per patient day cost at the optimal hospital size than the next two lower service-capability groups. The cost estimates shown below are associated with hospitals in the highest service-capability group.

The estimated regression coefficients and standard errors for total cost (in 1963 dollars) in relation to patient days and other characteristics for voluntary short-term general hospitals in the highest service-capability group is presented below:

$$TC = 590398.0 + \underset{(5.25)}{27.25^{**}(PD)} + \underset{(0.0000069)}{0.000037^{**}(PD)^{2}} - \underset{(0.2152)}{0.0479(S*PD)} \qquad (1)$$

$$+ \underset{(0.85)}{6.20^{**}(OPV)} + \underset{(104622.0)}{5404.0(NS)} - \underset{(760.0)}{2621.0^{**}(N)} + \underset{(12705.0)}{70491.0^{**}(IRP)}$$

$$+ \underset{(1315.0)}{4157.0^{**}(IR)} + \underset{(107551.0)}{171734.0(MS)} \qquad R^{2} = 0.89$$

where

TC = total cost in 1963 dollars;

PC = number of patient days;

S = number of facilities, services, and programs;

OVP = number of outpatient visits;

NS = existence of a hospital-controlled professional nursing school = 1; otherwise = 0;

N = number of student nurses;

IRP = number of types of internship and residency programs offered;

IR = number of interns and residents; and,

MS = affiliation with a medical school = 1, otherwise = 0.

The estimated coefficients pertaining to the cost-size relationship from equation (1) are used to construct a per capita cost curve for hospital services by city size. The mean number of services (S = 24.5) is assumed for all hospital sizes and other cost-affecting characteristics (e.g., OVP, NS, N, IRP, IR, AND MS) are omitted from the calculations as they are set equal to zero. The omission of these nonsize related variables does not change the shape of the curve but only the level of cost at all hospital sizes. Since total cost for hospital services is expressed in (1) as a function of patient days, the expected number of patient days of hospital care must be determined for each city size. The calculated total costs using the varying levels of patient days are subsequently divided by city size to express per capita costs of hospital services. The approach used in this chapter allows a hospital to increase in size (measured by annual patient days--a figure somewhat below total available beds) until minimum average cost is attained. From that point on, it is assumed that another similar hospital will be built and the average cost curve becomes horizontal for cities greater in size than the minimum population associated with the optimal sized hospital.

The average daily census rate (annual patient days/365) for short-term general hospitals in 1969 was 3.30 per 1,000 population. The figure becomes 1,204.5 per 1,000 population when expressed in annual patient days and this is the figure used to calculate total cost in (1). Figure 15 is constructed from the estimates obtained from (1) after inflating the costs to 1971 price levels using the hospital daily service charge index and 1,204.5 patient days per 1,000 population as the required quantity of hospital facilities. Substantial economies of city size accrue until cities of 40,000-50,000 populations are reached. The minimal point on the cost curve in Figure 15 occurs at city size 100,000.

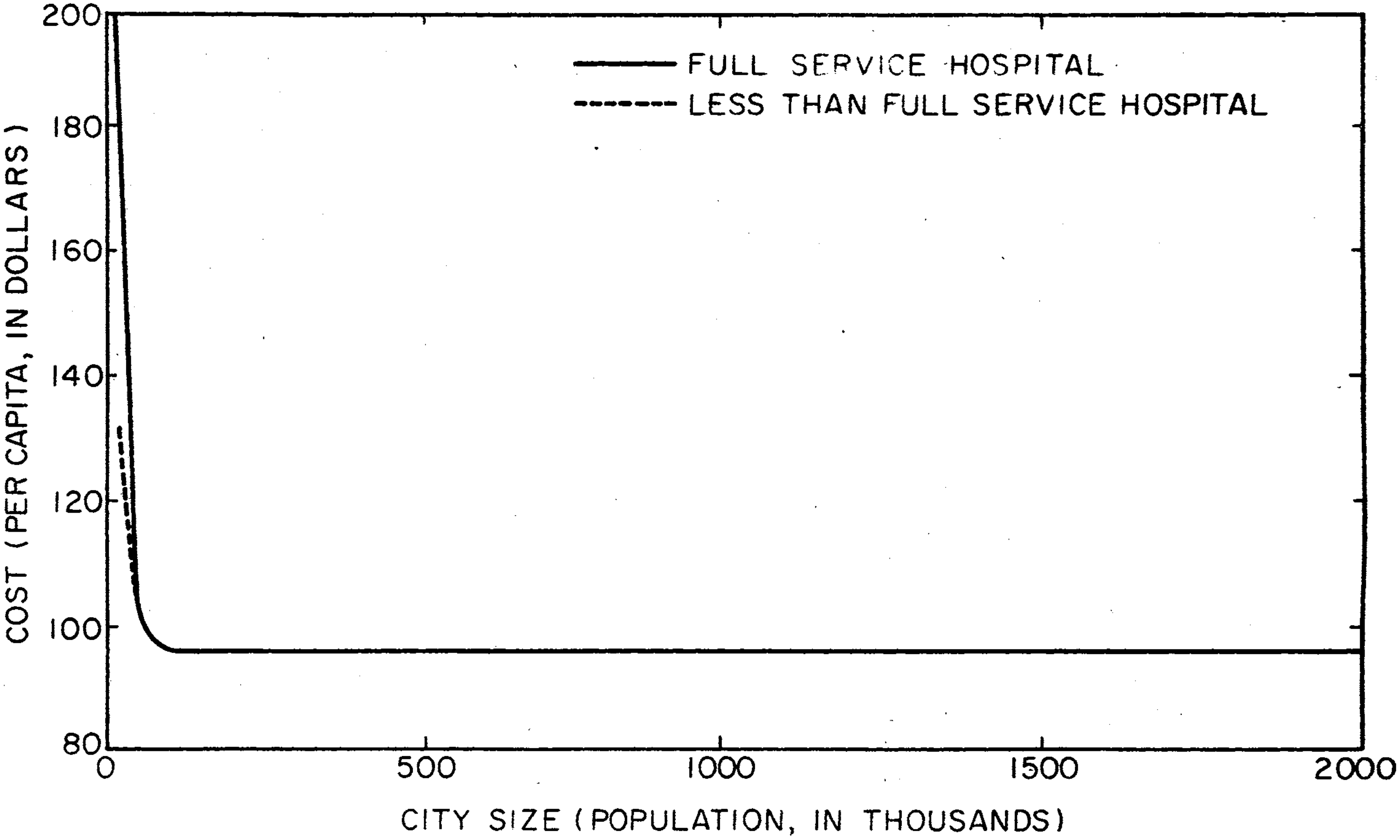


Figure 15. Per Capita Costs of Hospital Care by City Size

The costs of hospital care seem unduly high for the smallest cities in Figure 15. This can be partially explained by the technique of forcing the same quantity of services to be available from hospitals in both small and large cities. An alternative system for providing hospital services would consist of less than full service hospitals near the populace of small cities and full service hospitals in large cities. Residents of cities served by less than full service hospitals would have to travel to full service hospitals when such services were required. The full cost of hospital services to the residents of the smaller cities would include: (1) the per capita cost for the less than full service hospital; (2) per capita transportation charges including direct and opportunity costs; and (3) imputed charges for the possible increase in mortality and morbidity arising directly from transportation time to the full service hospital. Less than full service hospitals would be built in small cities until the full costs (stated above) of the less than full service hospital approached that of the full service hospitals. The city size where the two costs are equal would be the minimum city size for full service hospitals and cities larger than the minimum city size would build only full service hospitals.

Total costs for a less than full service hospital were also estimated by Carr and Feldstein.[2] The per capita costs (1971) for the less than full service hospital (14.15 services) in a city size of 10,000 is $121.00 compared to nearly $200.00 for the full service hospital. This large differential in costs soon disappears as both the full service and the less than full service hospitals attain equal minimum average costs at city size 40,000. Since one hospital is offering nearly twice as many services as the other at identical costs, patients would rationally choose the full service hospital. The largest cost differential occurs for cities in the 10,000-25,000 size category. The dashed line segment of the curve in Figure 15 is for the alternative system for providing hospital care and consists of costs for the less than full service hospital plus a charge for transportation calculated from the frequency of use of services not available from the less than full service hospital and average traveling time to the full service hospital.

Services at the less than full service hospital are adequate for approximately 80 percent of the admissions. Specialized surgery and special treatment facilities, for instance, among other services are required for the remaining admissions. The choice of an average traveling time to the full service hospital is very subjective and for this study is assumed to be one hour. Approximately a 100 mile radius from the full service hospital is covered by an average of one hour's driving time. For some geographic locations, this radius will be too large or too small depending on the spatial distribution of cities in the area under question. Nonetheless, a 100 mile radius should approximate a norm and is used in calculating a cost of transportation for specialized hospital services. The costs of transportation are assumed to equal $50 for an average trip--a figure including direct and indirect costs. No charge for mortality or morbidity was included due to the difficulty of quantifying such a charge--especially in the case of a mortality.

The per capita transportation charge based on an average trip of $50 and a 20 percent frequency rate was added to the Carr and Feldstein cost estimates for a less than full service hospital. For a city size of 10,000, the costs of providing hospital services by the alternative system is $133.04 per capita, a saving of $66.96 per capita compared to the full service hospital. Granted that the true cost of a given quality of hospital care is represented by the solid line in Figure 15, the dashed line segment showing the cost of less than full service hospital care is deemed the appropriate and more functional cost curve for use in this study. The diseconomies of size for a full service hospital are of such magnitude that these hospitals are economically infeasible for small cities as well as sparsely settled rural areas.

Primary and Secondary Education Costs by City Size

The per capita costs for primary and secondary education services used in this study were obtained from a comprehensive study by White (1972).[3] The White study also contains a comprehensive review of previous work dealing with the costs of education. White, using Oklahoma school district data, estimated production and cost functions for an educational system and combined them to find the most efficient method of producing a given quality of education.[4] The cost estimates were originally estimated in terms of average daily attendance (ADA); for the purposes of this chapter, the costs will be converted to a per capita basis using the percent of the population currently enrolled in primary and secondary schools. Each 100 ADA is assumed to be composed of 28.2 secondary schools and 71.8 primary school ADA's. The education cost estimates used in this chapter include the following cost components: administration, plant operation and maintenance, annual charge for buildings and equipment, principals, guidance counselors, texts, and instructional materials.

The estimated coefficients and standard errors of the various equations used by White are presented below:[5]

$$AD = 311.743 + \underset{(.312)}{.528ACH} - \underset{(4.730)}{26.391PTR} + \underset{(.097)}{.513(PTR)^2} \qquad (2)$$

$$+ \underset{(6.697)}{6.694(1/ADA)} \qquad R^2 = .937$$

$$POM = 32.073 + \underset{(.380)}{1.612ACH} - \underset{(8.591)}{16.516PTR} + \underset{(.179)}{.298(PTR)^2} \qquad (3)$$

$$+ \underset{(.193)}{.338ADA} + \underset{(3.617)}{12.839(1/ADA)} \qquad R^2 = .852$$

$$CON_E = 1{,}428.944 - .057(ADA_E) + 22{,}488.895(1/ADA_E) \qquad (4)$$

$$CON_S = 1{,}909.770 - .234\,(ADA_S) + 1{,}845.033(1/ADA_S) \qquad (5)$$

$$EQP_E = 238.520 - 4{,}404.357(1/ADA_E) \qquad (6)$$

$$EQP_S = 406.735 - 7{,}919.032(1/ADA_S) \qquad (7)$$

where

AD = administrative costs per student in average daily attendance;

ACH = average eleventh-grade composite achievement score;

PTR = pupil-teacher ratio;

ADA = average daily attendance in 1,000 units;

POM = average cost of plant operation and maintenance per pupil;

CON = construction cost for buildings per ADA;

E = elementary school;

S = secondary school; and,

EQP = equipment cost per ADA.

Equation (2) expresses administrative expenditures--salaries, contractual services, and other expenses--as a function of average pupil-teacher ratio, average daily attendance and average achievement score. Equation (2) is a long-run average cost curve as are equations (2) through (7). School plant operation and maintenance cost per pupil (3) was expressed as a function of the same variables in (2). Construction costs for buildings in Oklahoma per ADA (4) and (5) were estimated for both elementary and secondary schools--both functions of school district size. The construction costs were subsequently put on an annual basis that included depreciation, insurance, and interest on investment. Equations (6) and (7) depict the average cost of equipment for elementary and secondary schools.

Instructional costs--including salaries of secretarial and clerical assistants, and costs of textbooks, school libraries, audiovisual materials and teaching supplies--were estimated for a standardized course offering. For the purposes of this chapter, an average cost per ADA ($50) for transportation was included in the cost estimates.

The costs derived from equations (2) through (7) were combined with the instructional and transportation costs to form the long-run average cost of educational services per ADA for a given quality education. The minimum cost school district size was 2,500 ADA. This school district size can be converted to a population base rather than ADA by using the percent of the population attending primary and secondary schools (25.49). The optimal city size for providing educational services is 9,800; as cities grow in size beyond 9,800, additional optimal size schools will be built rather than building larger schools. The curve showing the per capita cost of providing primary and secondary education services, for the purposes of this chapter, is a horizontal line for all city sizes--neither diseconomies or economies of city size are realized after city size 9,800 is attained. The per capita cost is $141.52 based on Oklahoma cost data. The average educational expenditure per ADA in Oklahoma public schools for 1971 was 26.92 percent below the national average. The cost estimate from White was inflated by 26.92 percent to correct for the lower spending levels on education in Oklahoma. The per capita cost of providing education services used in the current study was $179.62.

Summary

The costs of providing hospital and education services were reported in this chapter. Substantial economies accrue until city size 100,000 is reached for providing hospital services. Costs of a given quality of hospital services were so high for small cities that an alternative method of providing these services was examined. The alternative method allowed a less than full service hospital to be built in the small cities and when services not available in this hospital were required, the patient would have to travel to the nearest full service hospital. The per capita costs under the alternative method were still substantially higher for the smallest cities. Neither economies nor diseconomies of size existed in providing educational services in cities over 10,000.

FOOTNOTES

[1] W. John Carr and Paul J. Feldstein, "The Relationship of Cost to Hospital Size," <u>Inquiry</u>, Vol. IV (June, 1967), pp. 45-65.

[2] <u>Ibid</u>., p. 56.

[3] Freddie Cad White, "A Quantitative Analysis of Factors Affecting Elementary and Secondary Schooling Quality in Oklahoma, with Economic Application for Rural Areas," (Unpublished Ph.D. dissertation, Oklahoma State University, 1972).

[4] Ibid.

[5] Ibid., pp. 78-96.

CHAPTER VI

THE COST OF PROVIDING UTILITY SERVICES

Analysis in this chapter concentrates on utility services--a group of services where the disassociation between social and private costs, if any, is small. The analysis in this chapter implicitly assumes that the quality of a given quantity of service is constant for all city sizes. For example, one would expect 500 kilowatt-hours of electricity in a city with a population of say 25,000 to be the same quality as in a 1.5 million population city.

The purposes of this chapter are to:

1. Estimate the per capita cost of electricity services by city size.

2. Report previous estimates of the per capita cost of sewage services by city size.

3. Report previous estimates of the per capita cost of refuse collection and disposal services by city size.

4. Report previous estimates of the per capita cost of public water services by city size.

Electricity Costs by City Size

The Model

The cost to the consumer, expressed on a residential basis, for a representative quantity of electricity is hypothesized to be a function of city size, type of ownership, and geographical location in the following econometric model:

$$E = f(S, O, R_i) \tag{1}$$

where

E = annual charge for residential electrical services;

S = city population;

O = type of utility ownership (private = 1, public = 0); and,

R_i = set of dummy variables corresponding to U. S. Bureau of the Census division (see Figure 1).

O, the type of utility ownership, is included to measure the effect of different pricing policies between publicly and privately owned electric companies. The publicly-owned utilities may follow one of two pricing policies: (1) assessing a tax on electricity usage and subsidizing other public services, or (2) undercharging for electrical services and using other revenue sources to make up the difference. Privately-owned utilities can be expected to charge the full amounts for production and distribution. The problem of excessive profits built into the charges of privately-owned utilities is assumed minimal due to the public regulatory bodies.

The set of divisional dummy variables is included to reflect differences in proximity to fuel sources such as coal and oil deposits or large man-made dams and power generating plants.

The net effect of city size on the cost of residential electrical services can be analyzed by correcting equation (1) for type of ownership and regional location. The cost of residential electrical services will be converted to a per capita basis from average household size data.

The Data

Annual typical residential electric bills in 1970 for consumption of 9,000 kilowatt-hours were obtained from the Federal Power Commission for the sample of 509 cities used in this study.[1] The sample of 509 cities consists of all cities over 100,000 population (114) and a random sample of cities with populations between 10,000 and 100,000 (395). Population and geographical data are from the U. S. Bureau of the Census.[2]

The Results

The estimated parameters for equation (1) using ordinary least squares regression on the sample data of 509 cities are presented in Table VIII. The ownership dummy variable 0 has a significant coefficient at the .10 level and indicates that privately-owned electric utilities charge $4.26 a year more per residence than publicly-owned electric utilities. The coefficients on the geographic dummy variables indicate a range of $68.12 per residence from the lowest cost division (East South Central) to the highest cost division (New England). The coefficient for city size is significant at the .01 level and positive in sign though the magnitude is not large. Nonlinear functions were also estimated but did not improve the results.

The relation between city size and electricity service costs corrected for type of ownership and geographical differences is presented in Figure 16. Figure 16 shows per capita cost, computed by dividing the per residence electric bill by 3.17--the average size of household, of electric services for a publicly-owned electric utility

TABLE VIII

ESTIMATED COEFFICIENTS AND STANDARD ERRORS OF ELECTRIC RATE EQUATION (1) WITH THE ANNUAL 9,000 KILOWATT-HOURS CHARGE E, THE DEPENDENT VARIABLE, A FUNCTION OF THE INDICATED INDEPENDENT VARIABLES

Independent Variable		Regression Coefficient	Standard Error
Constant		160.6348*	2.7793
City Size (Population in 000's)	S	0.0114*	0.0026
Ownership (Public in constant)			
Private	O	4.2606**	2.5821
Division (East North Central in constant)			
New England	R_1	23.2631*	4.1223
Middle Atlantic	R_2	3.5994	2.2576
West North Central	R_3	21.2740*	3.4118
South Atlantic	R_4	-14.9342*	3.1626
East South Central	R_5	-44.8649*	3.8502
West South Central	R_6	-12.4905*	3.2539
Mountain	R_7	4.3114	6.0850
Pacific	R_8	-31.0281*	3.5568
R^2		.50	

Source: See text.

*Significant at .01 level.

**Significant at .10 level.

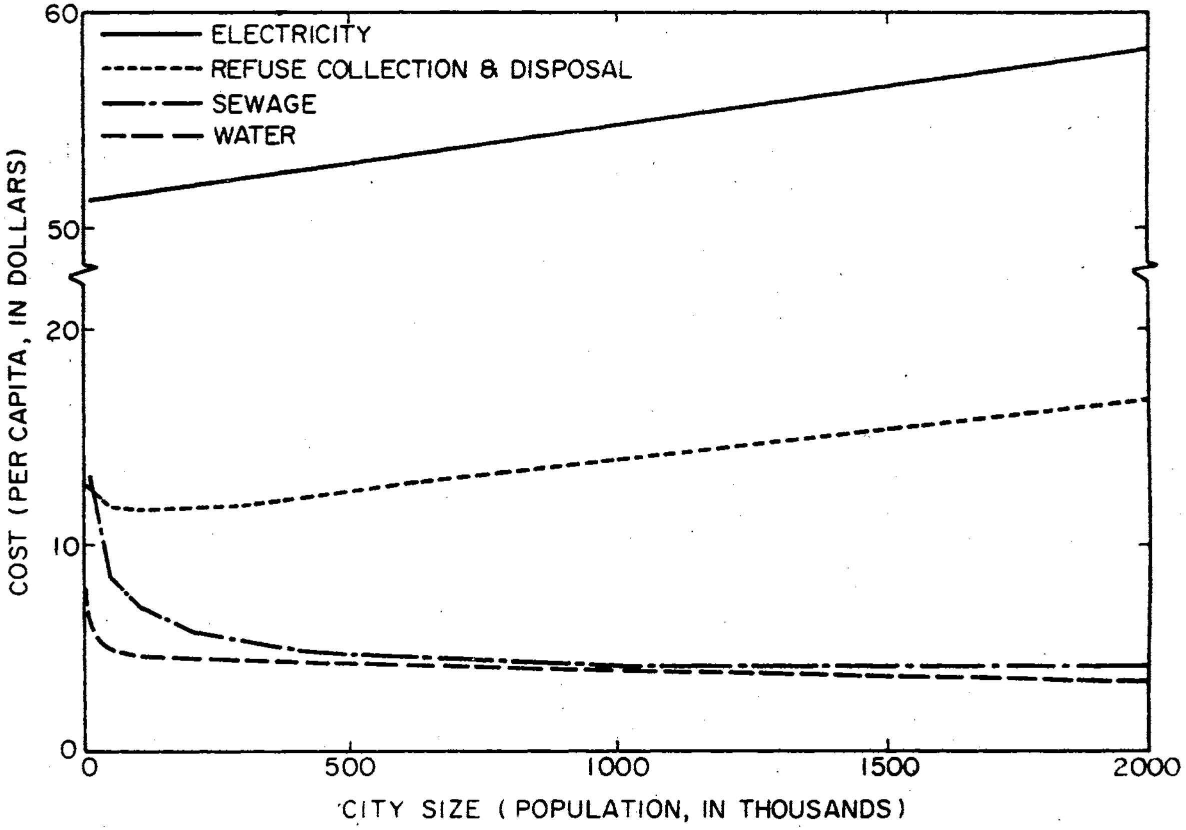


Figure 16. Per Capita Costs of Utility Services by City Size

in the East North Central division. Another geographical division or ownership type can be analyzed by adjusting the intercept according to the sign and magnitude of the coefficient of the appropriate variable. The estimates show diseconomies of city size of $7.15 per capita as the size of city increases from 10,000 to 2 million. The region in which a city is located influences electric charges more than city size. For example, a 2 million population city in the East South Central division has an annual per capita electric bill of $7.00 less than a city of population size 10,000 in the East North Central division.

Sewage Plant Costs by City Size

The per capita costs for sewage services used in this study were derived from two previous works. Rowan et al. estimated construction costs for sewage treatment plants from data furnished to the Public Health Service by agencies receiving financial assistance for construction of sewage treatment plants under the Federal Water Pollution Control Act.[3] A follow-up study, also by Rowan et al., estimates the sewage treatment plant operation and maintenance costs on a per capita basis.[4] The particular type of treatment facility was chosen to be a trickling filter plant because this plant is the most prevalent type in new construction starts.

Construction Costs

The per capita cost of sewage plant construction was hypothesized by Rowan et al. as a logarithmic function of city size.[5] The estimated equation using least squares regression is presented below:

$$\log 10Y = 2.7953 - 0.2800X \tag{2}$$

$$R^2 = .47$$

where

Y = per capita construction costs in 1913 dollars; and

X = city population.

The construction contract costs exclude the cost of interceptor and outfall sewers, pumping stations not contiguous to the plant structure, and legal, administrative, fiscal, land and engineering costs. However, previous experience with the Federal Construction Grants Program indicates that approximately 80 percent of the total first cost of sewage treatment plants is taken into account. For the purposes of this chapter, these cost estimates are adjusted upwards by 20 percent. To correct for geographic differences in construction costs, Rowan et al. deflated the construction costs using the Engineering News-Record (ENR) Construction Cost Index for the appropriate region to 1913 prices. The ENR Construction Cost Index is published for 20 cities (region of influence) in addition for the United States as a whole. The estimated construction costs for (2) were subsequently inflated to 1971 prices using the ENR Construction Cost Index for the United States in this study. To make the costs of sewage treatment compatible with the other costs in the study, they are expressed on a yearly basis as depreciation plus interest. This is accomplished by assuming a 20 year life of the plant and an interest charge of 6 percent per annum.

Operation and Maintenance Costs

The per capita costs of sewage plant operation and maintenance also was hypothesized by Rowan et al. to be a logarithmic function of city size.[6] The estimated equation using least squares regression is presented below:

$$\log Y = \frac{1}{0.3974 + 0.2490 \log X} \tag{3}$$

where

Y = annual per capita operation and maintenance cost in 1958 dollars for trickling filter sewage plants; and

X = city population.

Costs of central administrative services normally provided by municipal governments such as billing and collection of sewer service charges are not included in the estimates. Unlike the procedure used by Rowan et al. for the construction cost study, neither the wage rates nor the maintenance costs were held constant for all city sizes. This omission will result in the per capita costs for operation and maintenance of sewage facilities to be overstated for the large cities. The Rowan estimates, expressed in 1958 dollars, are inflated to 1971 dollars for use in this chapter utilizing wage rates for nonsupervisory workers in public utilities.

Combined Per Capita Cost Estimates

The per capita costs of providing sewage services in different city sizes--computed by combining the previously discussed construction and operation and maintenance costs--is presented in Figure 16. Economies of size exist throughout the range of city sizes; however, the major economies are realized up to a city size of 500,000. The decline in per capita cost ($6.03) as city size increases to 100,000 from 10,000 is approximately two and one-half times the decline in per capita costs realized as cities grow to 500,000 from 100,000.

Refuse Collection and Disposal Costs by City Size

The cost of providing refuse collection services to residences is analyzed in two segments: (1) costs of collection service and transportation to the disposal site and (2) operating costs of the disposal facility for a sanitary landfill. The landfill disposal facility was chosen as the appropriate type due to ecological considerations arising from public concern over air pollution from the large incineration refuse disposal units.

Collection Service Costs

A report by Stone prepared for the Public Health Service was the source for the refuse collection cost estimates used in this study.[7] A sample of 166 cities was divided into three population classes--10,000 to 100,000, 100,000 to 500,000 and 500,000 and over--and costs per ton of refuse collected was reported for the median city. The costs of collecting refuse includes both operating and overhead expenses. These estimates, crude at best, transformed to per capita costs by using the national average daily refuse per capita, 4.5 pounds. These 1968 estimates were subsequently inflated to 1971 costs before being combined with the landfill costs.

Landfill Operating Costs

The costs of operating sanitary landfills of different capacities is reported in Sanitary Landfill Facts.[8] The cost estimates include wages and salaries, equipment, cover material, administration and overhead. The initial investment is omitted from the cost estimates used in this chapter. The omission does not introduce serious bias because the initial investment outlay is often fully recovered when the completed landfill is salvaged as real estate for high value uses: public use such as a park or golf course or private use such as housing or shopping centers. The costs of landfill operation are combined with the refuse collection costs and are presented in Figure 16. Slight economies of size exist until a city population of 100,000, after which slight diseconomies of size are present (Figure 16).

Water Costs by City Size

Estimated costs of providing public water services were obtained from a recent study conducted in Ohio.[9] The 1968 cost data were collected from 79 Ohio cities with a population ranging from 5,000 to 1.8 million. The cost figures reported were for annual operating costs which include wages, chemicals, electricity, repairs, and maintenance. Analysis on a smaller sample of cities (19) included capital costs. However, because of the small number of observations and problems associated with the capital cost data discussed in the Ohio study, the estimates for only the operating costs will be used in this chapter. The capital costs, including depreciation and interest on investment, for public water systems are very similar to the capital outlays previously discussed for sewer services; hence, the omission of this cost component will not change the shape of the cost curve but will result in somewhat understated costs.

The estimated coefficients and standard errors for the average variable cost function hypothesized by Cosgrove and Hushak is presented below:[10]

$$AVC = 104.31 - \underset{(0.0029)}{0.00110} + \underset{(6655.02)}{27245.43*O^{-1}} + \underset{(3.90)}{18.29*T} \qquad (4)$$

$$R^2 = .52$$

where

AVC = average variable cost per million gallons of water produced in 1968;

O = output--million gallons of water; and

T = number of treatments used by the city water system.

The coefficient of the output variable O is significant (.05 level) only in inverse form. The coefficient of the quality variable T is also significant at the .05 level and positive in sign. Each treatment applied to the water increases costs $18.29 per million gallon.

The per gallon cost of a given quality of water was calculated from (4) holding T constant at the mean value (5.3). The per gallon cost of water was transformed to a per capita cost using the current average water usage of 50 gallons per capita per day. The per capita costs of water supply for different city sizes adjusted for quality is presented in Figure 16. These cost estimates are inflated to 1971 prices. Economies of size exist throughout the range of city sizes; however, the major economies are realized up to a city size of 100,000.

Summary

This chapter contains estimates of the per capita costs of providing utility services by city size. The combined per capita costs of all four utilities--electricity, sewage, refuse collection and disposal, and water--analyzed in this chapter indicate economies of size of $10.19 per capita as city size increases from 10,000 to 30,000 and diseconomies of city size of \$9.06 per capita as city size increases from 300,000 to 2 million population.

This chapter concludes the analysis of the cost functions of individual public services. The following chapter reports results of combining the cost curves previously discussed into a single unit cost curve for the provision of a given quality of public services among city sizes.

FOOTNOTES

[1] Federal Power Commission, *Typical Electric Bills*, (December, 1970) Government Printing Office, Washington, D. C.

[2] U. S. Bureau of the Census, *Census of Population: 1970*, U. S. Government Printing Office, Washington, D. C.

[3] P. O. Rowan, K. H. Jenkins, and D. W. Butler, "Sewage Treatment Construction Costs," *Journal of the Water Pollution Control Federation* (June, 1960), Vol. 32, No. 6, pp. 594-604.

[4] P. O. Rowan, K. H. Jenkins, and D. H. Howells, "Estimating Sewage Treatment Plant Operation and Maintenance Costs," *Journal of the Water Pollution Control Federation* (February, 1961), Vol. 32, No. 2, pp. 111-121.

[5] Rowan, Jenkins, and Butler, p. 601.

[6] Rowan, Jenkins, and Howells, p. 118.

[7] Ralph Stone and Company, Inc., *A Study of Solid Waste Collection Systems Comparing One-Man with Multi-Man Crews: Final Report*, Public Health Service Publication No. 1892 (1969), U. S. Government Printing Office, Washington, D. C.

[8] U. S. Public Health Service, Sanitary Landfill Facts, No. 1792 (1970), U. S. Government Printing Office, Washington, D. C., pp. 22-23.

[9] Michael H. Cosgrove and Leroy J. Hushak, "Costs and Quality of Water in Ohio Cities," Research Bulletin 1052, Ohio Agricultural Reserach and Development Center (April 1972).

[10] Ibid., p. 12.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Analysis in the preceding chapters concentrated on estimation of the per capita costs of individual community services. The costs of a given quality of police protection were estimated in Chapter II. The crime rate was used to measure the quality of police protection. Economies of city size accrued until city size 375,000 was reached. Two methods of reducing the social cost of crime were analyzed: (a) a direct attempt by increasing police numbers and (b) a policy of decentralization of the population to optimal size cities. Since large cities exhibited no evidence of being able to reduce crime by increasing police numbers, the decentralization policy may be the most long-run cost-effective method of reducing the cost of crime.

The cost of controlling air pollution was estimated in Chapter III and sizable diseconomies of city size existed for a given quality of air in all city sizes. The amount of pollutants emitted by industry and automobiles was used as the quality variable. The results indicated that, unless a perfectly discriminating program of air pollution control was applied, the costs of controlling air pollution would exceed the costs of allowing it to occur. The full costs--public and private--of fire protection were estimated in Chapter IV with sizable economies of size accrucing until cities of one million population are attained. Chapters V and VI report previous cost studies on the other services included in the bundle of community services under analysis in this study. The analysis of the cost of hospital services revealed economies of size until cities of 100,000 population are reached. Neither economies nor diseconomies of size were found for primary and secondary educational services after a city attains 10,000 residents. Utility services as a whole show economies of size until city size reaches 300,000, after which diseconomies of size are present. The following section combines the individual cost curves into one curve showing the annual per capita costs of community services.

Annual Costs of Providing Community Services

The curve in Figure 17 was constructed by combining the estimated costs for community services from previous chapters. It summarizes the results of the entire study. Economies of city size exist until a city of 300,000 population is attained; diseconomies of city size accrue for cities with larger populations.

The curve in Figure 17 is associated with a given quality of service for each individual service component. The police department expenditures necessary to hold the crime rate equal to 3,000 for all city sizes (see Figure 3) is the cost of police protection used in constructing the curve in Figure 17. The costs of controlling air pollution included in the final analysis are taken from Figure 12 (Curve 1) and are adjusted to central city size. The costs of fire protection are taken from Figure 14. The cost of insurance was calculated so the level of protection remained the same even though the quality of service varied among city sizes. The costs of hospital services (see Figure 15) refer to a hospital offering full services in cities over

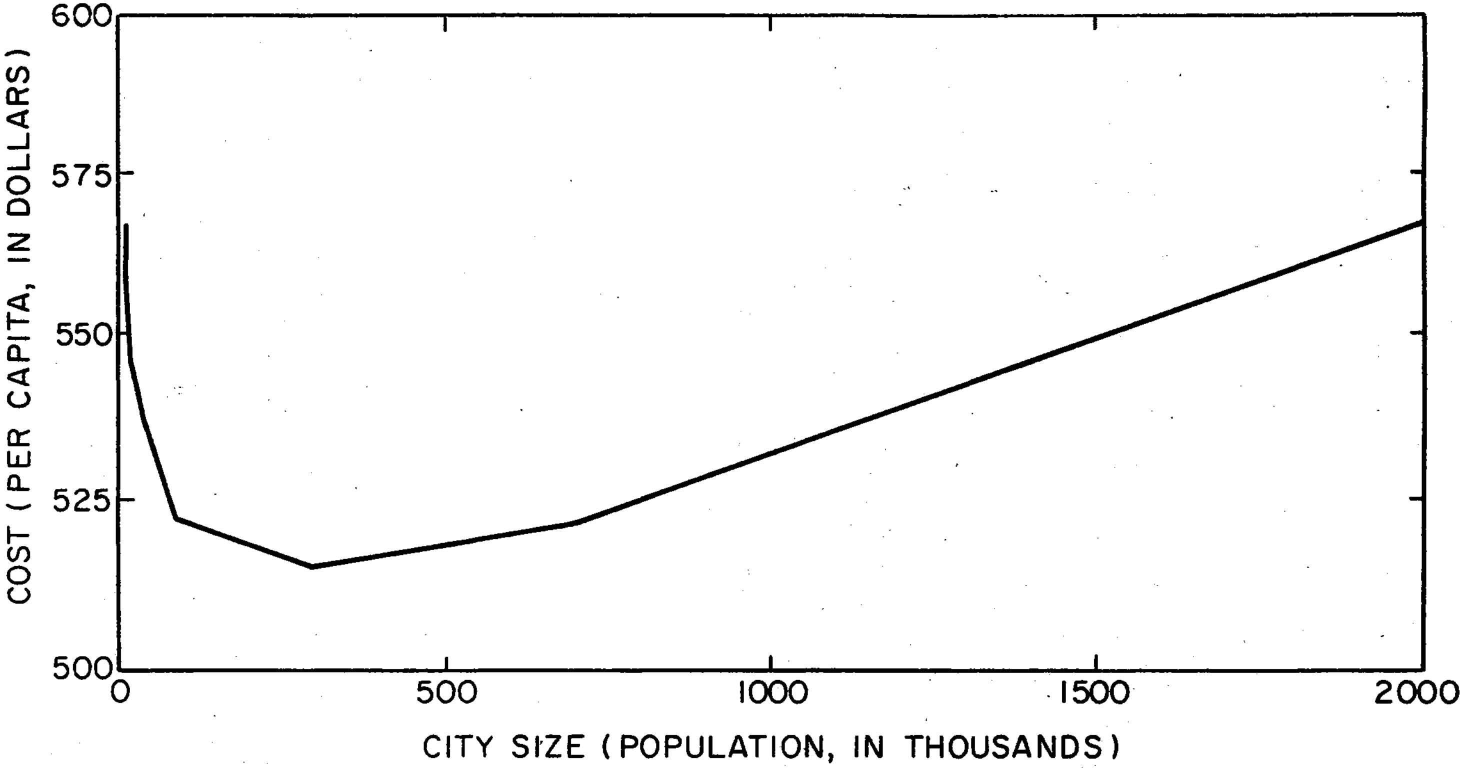


Figure 17. Per Capita Costs of Providing Community Services by City Size

40,000 population and less than full services under 40,000 population cities. The education cost function, adjusted for quality, was specified by White.[1] The cost of utility services--assumed to be of equal quality in each city size--are for the following per capita quantities: (1) 9,000 kilowatt-hours of electricity; (2) 1,642.5 pounds of refuse; (3) 18,250 gallons of water and sewage. The costs of utility services are from Figure 16 and they are the only services where the quality aspect was not accounted for per se.

The cost curve in Figure 17 is a marginal cost curve among city sizes and an average cost curve within city sizes. The total cost of providing community services with alternative population distributions can be compared to the costs of providing community services with all the urban population residing in optimal size cities (300,000 using the curve in Figure 17). If the entire 1970 population residing in city sizes of 10,000 and over were located entirely in cities of 2 million, then the total annual cost of providing community services is $63.82 billion and if located entirely in cities of 10,000 the cost is $64.04 billion. If the entire 1970 population residing in cities of 10,000 and over were redistributed into optimal size cities (300,000), the annual cost is $57.9 billion--an annual saving of approximately $6 billion over either alternative distribution. The savings from an optimal distribution of the population would increase significantly if the urban population residing in cities smaller than 10,000 (36.88 million) were taken into account. Assuming the costs for cities of 10,000 population also apply to smaller cities, the annual savings from an optimal distribution becomes $8.5 billion. Of course, many individuals are tied to land and other immobile resources and cannot be considered as part of a national policy to influence city size. Other individuals may choose to reside in say a small town knowing the quality of services is poorer than other city sizes. A national policy to influence city size should allow the individual a free choice in deciding where to reside. Nevertheless, such a policy, based on results of this study, should not encourage people to reside in either small or large cities.

The quality levels for community services in this study coincide as closely as possible with today's permissible standards. Qualities of services different than those used in this study will alter the shape of the curve in Figure 17. For instance, if the public chooses to increase the quality of police protection, costs would increase for the larger cities. If on the other hand, the public desires better hospital services, then the costs will increase for the smaller cities. A combination of improved quality for several services may materially alter the minimum cost city size. The minimum cost city size is expected to remain in the 50,000 to 1 million range as presented in Figure 17 for a wide range of service quality combinations.

Another factor that may alter the shape of the curve in Figure 17 is improved urban design and planning. Figure 17 was constructed from cost estimates using the current state of urban design. The per capita costs of providing community services may well decrease as better urban design is implemented.

Policy Implications

From a policy point of view, a single minimum cost city size is too restrictive; a more meaningful guideline is a minimum cost city size range. Cities with a population range of 50,000 to 1 million are the most desirable for providing community services. Nevertheless, only 36 percent of the 1970 urban populace resided in the minimum cost city size range. Cities smaller than 50,000 population claimed 51 percent of the urban populace, while 13 percent resided in cities over 1 million population. It is of interest that 64 percent of the 1970 urban population resided in cities of other than the minimum cost range (50,000-1 million). In terms of growth, cities in the 50,000 to 1 million range increased in population by 15 percent over the 1960-1970 decade compared to a 19 percent increase in total urban population. The largest growth rate was experienced by cities smaller than 50,000--26 percent--while cities over 1 million in size grew 7 percent. Even though the current urban population is not optimally distributed, there is some indication that the urban population is moving towards a more optimal distribution among city sizes.

Based on the results of previous research on firm profit maximization, the minimum cost city size is likely to remain in the 50,000-1 million range as the results of this study are combined with the private costs of production and distribution.[2] A number of exceptions can be cited, however, such as lumber, agricultural and mining activities best adapted to smaller cities and major financial activities best suited for larger cities than the optimal range specified above. Riots and racial injustices, for the most part, have been concentrated in the largest cities, while anomie is still very much present in small towns and rural areas. The optimal city size determined from a broader framework than employed in this study and which considers real comparative advantage in production as well as attitude should still be in the range of low cost cities in Figure 17 for a large proportion of the population and the policies discussed later should continue to be valid when all aspects of city size are examined.

Since the phenomenon of growth will move cities closer and closer to a city size where diseconomies of size are realized, a growth policy should be directed towards the smaller city sizes (50,000-300,000) rather than cities of 1 million. The optimal city size is useful to city planners either for the development of new cities or renewal and development of existing cities. The results of this study raise serious doubts about the wisdom of spending huge sums of tax dollars, mostly provided by nonresidents, to renew and renovate the largest cities if, as indicated, the cities are uneconomic. Federal outlays might more wisely be directed towards policies to encourage location of people in the minimum cost city size range rather than the largest or smallest cities.

Proximity of cities was not included in the analysis in this study. When reference is made to either a large or small city, the locational aspects should be qualified. For instance, a 20,000 size city near a city of 250,000 is more desirable than a 20,000 size city that is 100 miles from a larger city. Residents of a smaller city near a large city can benefit from traveling a short distance for services at lower costs in the large city, e.g. hospital services and cultural activities.

The results of this study also apply to development policies in lagging rural areas. Growth centers and functional economic areas have been advanced as policies for developing rural areas. These growth centers should ideally be 300,000 size cities; however, many of the depressed areas are not located within an economically feasible distance of the ideal size growth center. In the absence of the ideal city, smaller cities may be exposed as desirable growth centers. The majority of depressed rural areas are located within fifty miles of cities of size 25,000. The cities could be designated as growth nodes--providing sufficient resources or markets exist to make them viable economic areas. A city size of 25,000 is perhaps the lower size limit that should be considered for a growth node because the costs of services are rather high. As the growth node expands and moves closer to the optimal city size, the costs of providing community services will decline. In many instances, a viable economic area might be better structured to include a radius of 75 miles from a growth node city of (say) 300,000 rather than 40 miles from a growth node city of 10,000.

In summary, policies aimed at an optimal growth pattern among city sizes generally should be directed towards cities of 50,000 and 1 million population. Where excess capacity in housing and community services exist in cities of less than 50,000, these too might be encouraged to grow until these services are utilized. The largest public subsidies per capita now are directed to the nonoptimal size cities. The wisdom of this policy is questioned, based on results of this study. People choosing to reside in these uneconomic areas should be charged the full cost of the services used unless a reasonable case for subsidization can be made.

Limitations

Several community services were omitted in this study: employment bureau administration, postal, telephone, welfare administration, doctor, dental, local government administration, transportation and natural gas utility services in addition to outdoor recreation, higher education, and cultural activities. The omission of these services and activities from the analysis is not expected to shift the lower portion of the cost curve in Figure 17 to the right or left. Outdoor recreation activities--hunting, fishing, and skiing, for instance--are more costly in large cities; however, this cost differential would be offset by the cost of providing cultural activities and major league sports in small cities.

If the full costs of postal, telephone, employment and welfare administration services--all substantially subsidized in small communities and rural areas--were included in the analysis, the cost of community services, already high in small cities and open country, would increase even further. In the case of doctor and dental services, all economies should be realized before a city size of 10,000 is attained. Provision of city junior college services is expected to result in economies for large cities. Natural gas utility services were also omitted as the costs reflect transportation charges from the production area to the city and no major economies or diseconomies are expected from the distribution of this service for cities of over 10,000. Inclusion of the costs of local government administration could increase the costs for cities smaller than 10,000 according to results of a recent study.[3] In short, inclusion in the analysis of the services listed in this paragraph would substantially raise costs for cities of under 10,000 but would not be expected to shift the cost curve in Figure 17.

The cost of transportation was also omitted from the analysis--an omission that unlike the other omitted services could substantially affect the optimal range of city size (see Appendix). Ideally, transportation would not constitute a growing social cost associated with centralization in urban areas. Indeed, concentration of the population in large cities may be explained in part as an attempt to minimize transportation costs for firms and people. Rather than choosing a residence near the place of employment to minimize travel time and distance, as was once the case in multi-family apartment buildings and in town houses, urban residents are increasingly fleeing to the suburbs. This trend, which is an outgrowth of social factors such as race as well as economic factors, has created problems of traffic congestion for commuters. Inclusion of travel cost per capita in the cost of community services shifts optimal size markedly toward smaller cities (see Appendix Figure 20). The transportation cost equation is considered to be conceptually and empirically weak, however, though suggestive, it needs more research and is not given serious weight in the conclusions of this study. The costs of commuter travel should be reflected in the private accounts of firms as no rational employee would choose to live in the urban fringe and work in the central city unless the firm was including the increased travel costs in his wages or salary. Transportation costs might be expected to enter into the determination of the optimal city size by being included in the private costs of production and distribution and in the social cost of air pollution.

Another limitation is that the costs of controlling air pollution were estimated on an SMSA basis rather than a central city basis as were the other services. It was necessary to convert the costs for a given size SMSA to a corresponding central city size before these costs could be included in the curve in Figure 17. A simple linear relation was estimated relating central city size to SMSA size for all cities in the sample used for air pollution analysis.[4] This relation between central city size and SMSA size was used to transform the SMSA sizes in Figure 12 to central city sizes. The cost of controlling air pollution in a central city is the cost associated with the corresponding SMSA size. If the central city does not contain the industrial sector and the slow moving traffic networks--both notorious for air pollution emissions--then the costs for controlling air pollution will be biased upwards. This bias toward showing diseconomies for large cities probably is no less than the downward bias of omitting some social costs of commuting (see Appendix) and crime control from Figure 17.

This study analyzes but one part of economies of city size; the cost of providing community services. Combination of the results from this study with future research investigations into private production and distribution costs by city size in addition to data on social attitudes by city size will provide a more complete basis for determining the optimal city size and establishing public policies. Central place theory stresses the hierarchical pattern of city size. The structural pattern from small to large cities is not considered immutable in this study, and city size is assumed to be an instrumental policy than can be influenced within limits by public zoning, taxation and spending policies. The limits within which size can be influenced is a worthy subject for future research.

FOOTNOTES

[1] Freddie Cad White, "A Quantitative Analysis of Factors Affecting Elementary and Secondary Schooling Quality in Oklahoma, with Economic Application for Rural Areas," (unpublished Ph.D. dissertation, Oklahoma State University, 1972).

[2] G. M. Neutze, *Economic Policy and the Size of Cities*, (New York: Augustus M. Kelley, 1967).

[3] Thomas Klindt and Curtis Braschler, *Costs, Revenues, and Simulated Consolidation of Selected Missouri Counties*, Research Bulletin 949, University of Missouri, Missouri Agricultural Experiment Station (March 1969).

[4] $$\text{City size} = 0279438. + \underset{(0.0240)}{0.4786^{**}}\text{SMSA}$$

$R^2 = .93$ ** significant at .01 level

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APPENDIX

THE COST OF TRANSPORTATION

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In the text, transportation costs were assumed to be included in the private accounts of firms and therefore omitted from the calculation of the costs of community services by city size. In this appendix, the transportation costs by city size are reported and the optimal city size is determined with transportation costs included in the calculations. The cost estimates presented in this appendix are only part of the overall cost of transportation--the cost of commuting. Producers are charged for transportation of raw inputs to their plants and this charge should be included for an overall transportation cost analysis. The cost advantages of locating near a source of an input, such as a natural resource or a plant producing the input, may offset the diseconomies of commuting reported in this appendix.

The Model

The model and estimates presented in this appendix were reported by Borukhov.[1] A simple logarithmic relation was hypothesized between city size and both trip length and trip duration of the following form:

$$\log (D) = f(S) \qquad (1)$$

$$\log (T) = f(S) \qquad (2)$$

where

D = average trip length (in miles);

T = average trip duration (in minutes); and

S = city size (population).

The average trip used in the model refers to a home to work trip as the model concentrates on the residential sector of a city in an attempt to explain patterns of commuting. The estimated coefficients of D and T from (1) and (2) can be assigned a charge for distance traveled and time spent traveling to arrive at a cost of transportation by city size. The charges chosen for this purpose are automobile operating costs per mile and average wage rate per hour.

Regression Analysis and Results

The model was applied to data from 34 cities with populations ranging in size from 30,000 to 6,500,000. The average trip length (D) and average trip duration (T) are from Voorhees, et al.[2] The estimated parameters for equations (1) and (2) using ordinary least squares regression are presented below:

$$\log D = -0.77 + \underset{(0.02)}{0.19^{**}}\log S \qquad (3)$$

$$R^2 = 0.75$$

$$\log T = -0.02 + \underset{(0.03)}{0.19^{**}}\log S \qquad (4)$$

$$R^2 = 0.71$$

The coefficient for the common logarithm of city size is significant at the .01 level in both equations. The positive sign of the coefficient indicates increasing travel times and distances as cities increase in size. The relation between city size and trip length and duration is presented graphically in Figure 18. On the average, commuters travel faster and spend more time in transit for larger cities.

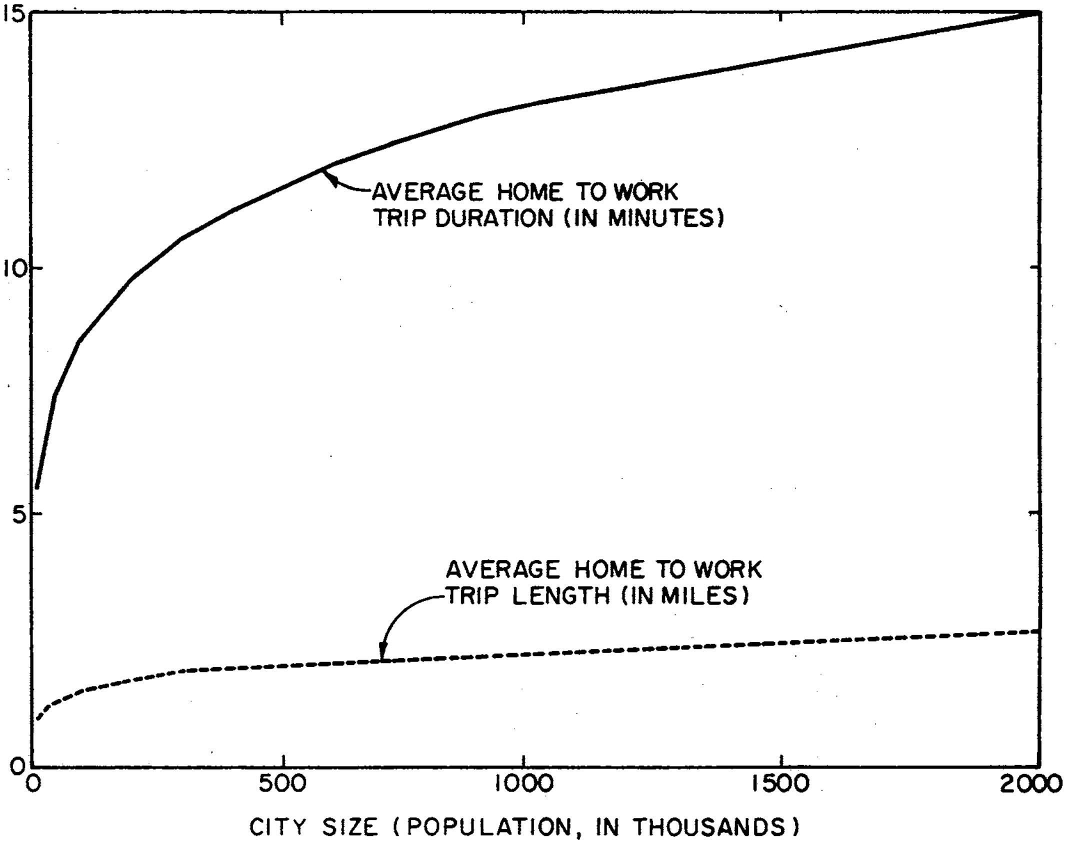

Figure 18. Average Home to Work Trip Length and Duration by City Size

The effects of congestion are apparent in the trends shown in Figure 18 for miles traveled and time spend commuting to work.

Transportation Costs by City Size

The cost of transportation in different city sizes as computed in this study is composed of an opportunity cost of time spent in transit plus the cost for the transportation per se. The gross hourly wage $3.39 in private industry (excluding agriculture) for 1971 was used to measure the opportunity cost of time spend in transit. This particular wage rate is chosen to measure the opportunity cost as it represents the wages of a large number of commuters and is assumed to approximate a median between high salary executives on one hand and minimum wage earners on the other hand. To account for the cost of being transported a charge of $.10 per mile is utilized. This charge is included to cover the fixed and variable costs of operating an automobile--a widely used means of commuting to work.

Not all the population in a city commutes. To calculate the per capita costs of transportation the average proportion of the population that comprises the work force is needed. The Bureau of Labor Statistics reports that the 1970 labor force was 42 percent of the total population.[3] The procedure used to calculate per capita costs of transportation is to first calculate the annual cost of transportation for the average commuter in each city size then multiply the cost for the average commuter by .42--the average proportion of the population in the labor force.

The curve in Figure 19 is constructed by applying a time charge of $3.39 per hour and a distance charge of $.10 per mile to equations (3)

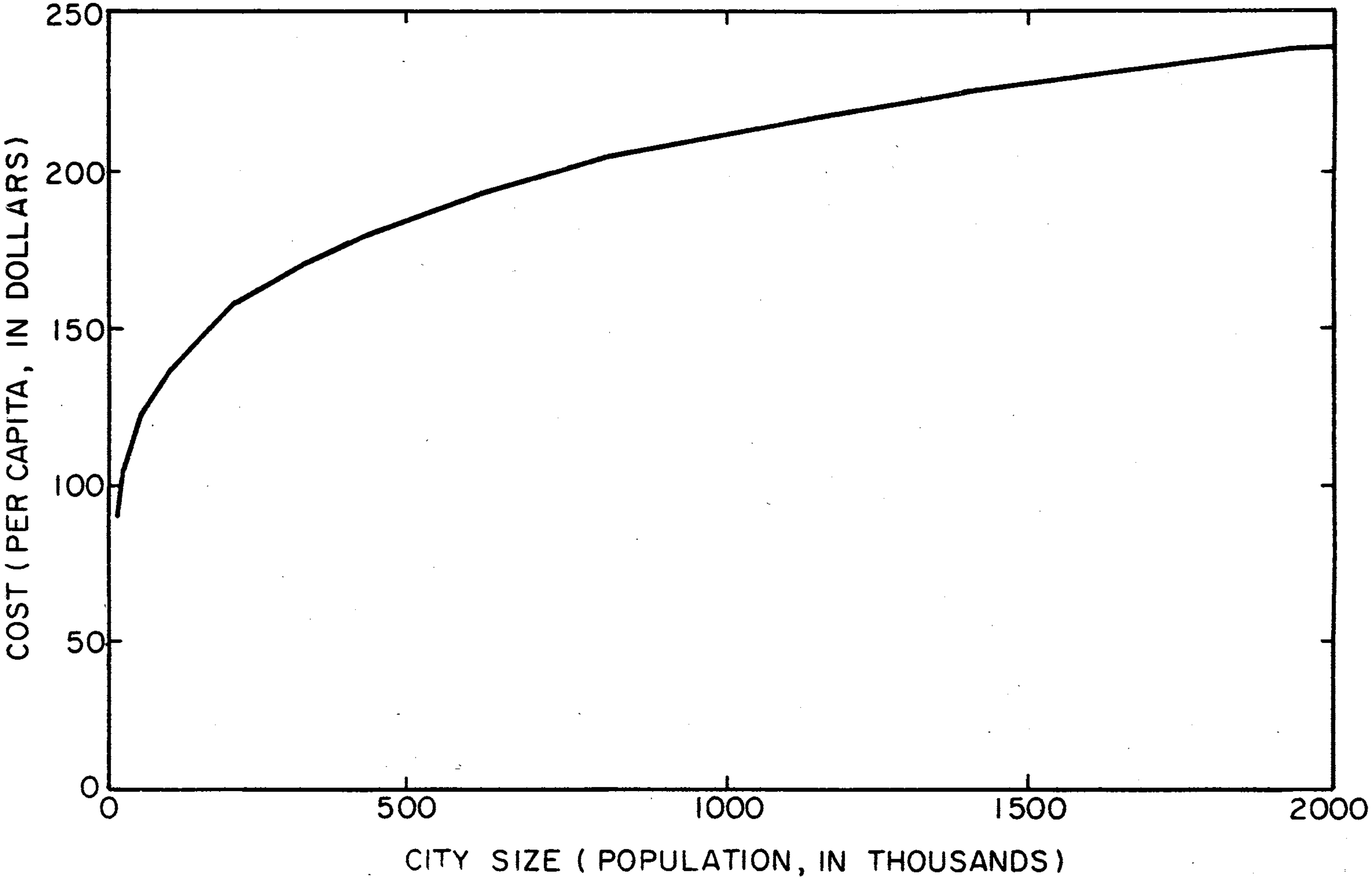

Figure 19. Per Capita Transportation Costs by City Size

and (4) and assuming that 42 percent of the city population is in the labor force and commutes to work. Briefly, the per capita costs of transportation increase rapidly until city size 200,000 is reached; then costs increase at a lower rate. Diseconomies of city size are present throughout the range.

The effects of including the cost of commuting in the costs of community services is evident from Figure 20. Figure 20 was constructed by combining the curves from Figures 17 and 19 and shows a minimum cost city size of 50,000, a city size that was included in the minimum cost range in the text. Inclusion of the transportation costs for firms should result in a larger minimum cost city size than 50,000.

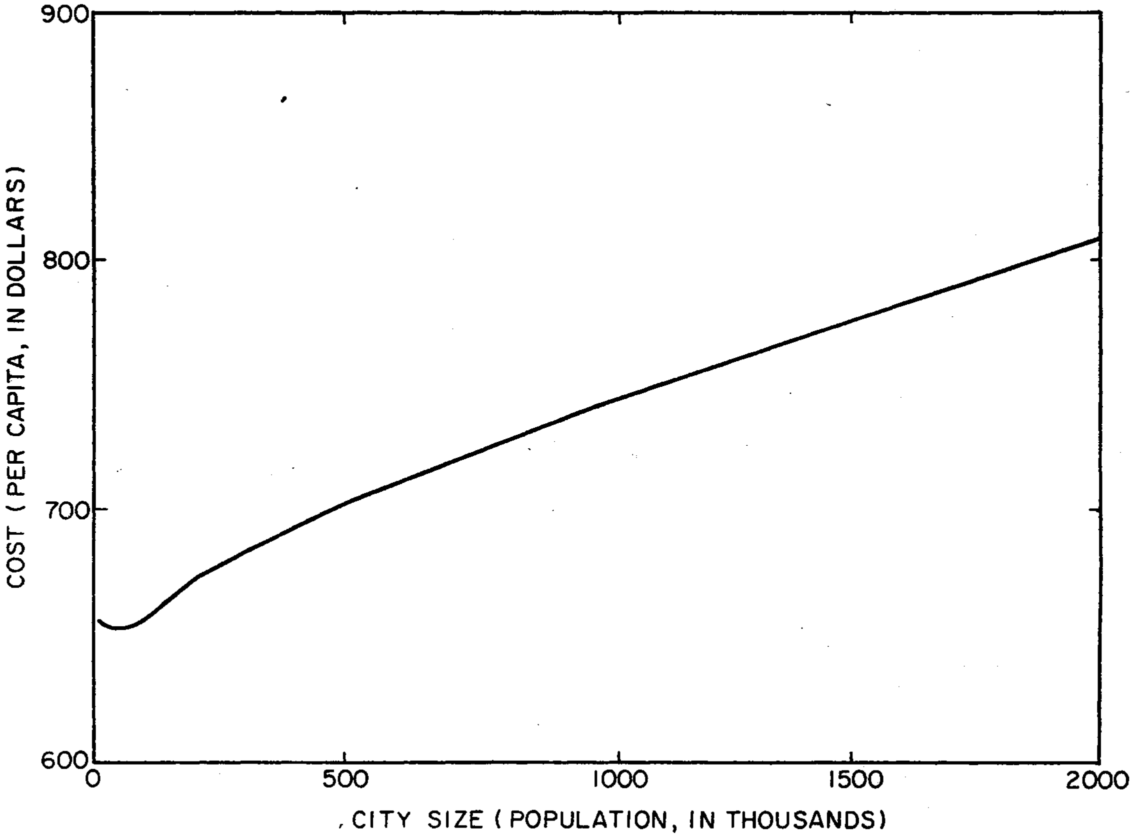

Figure 20. Per Capita Costs of Providing Community Services by City Size (including transportation)

FOOTNOTES

[1] Eli Borukhov, "City Size and Transportation Costs," a paper presented at a meeting of the Econometric Society, (New Orleans, 1971).

[2] Alan M. Voorhees and Associates, "Factors and Trends in Trip Lengths," Highway Research Board, National Cooperative Highway Research Program, Report No. 48 (Washington, D. C., 1968).

[3] Bureau of Labor Statistics, "Projections of the Labor Force 1970-1980," U. S. Government Printing Office, Washington, D. C.

VITA

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