# THE COST-OUTPUT RELATIONSHIP IN MISSISSIPPI WATER SYSTEMS

by

Wayne E. Boyet, Kenneth W. Hollman and Wayne L. Sterling
Bureau of Business and Economic Research
University of Mississippi

## ABSTRACT

A cross section analysis of cost data for 72 Mississippi water systems reveals that there are economies of size in these utilities. Multiple regression analysis was used to relate total cost to volume of water produced for these systems for the operating year 1973. Even though the results obtained were statistically significant and theoretically consistent, the lack of uniform reporting procedures creates a need for further study and refinement of the model.

## INTRODUCTION

Natural monopolies are typically defined as industries which experience decreasing long-run average costs of production over a wide range of output, enabling the firm to produce sufficient output to supply the entire market at a price covering full cost. Hence, natural monopolies can deliver the product to the consumer at a lower price if they are able to maintain their positions as monopolists than would be the case if competing firms entered the market. Public policy, therefore, tends to discourage or even prevent competition in those industries which are characterized as natural monopolies.

The unique characteristic of natural monopolies is the existence of economies of scale. It has often been assumed that this describes the cost-output relationship for most public utilities, including water distribution systems. This underlying assumption has become so widely accepted that it is seldom, if ever, questioned. However, it must be recognized that it may not always be valid even though there are many reasons why one would expect the per-unit cost of delivering water to decline as a particular system's output is increased.

The purpose of this paper is two fold. First, a theoretical explanation of the cost-output relationship for water systems will be presented. Second, preliminary empirically derived estimates of the cost-output relationships for Mississippi's water systems will be presented.

## THEORETICAL COST-OUTPUT RELATIONSHIPS

For purposes of decision making and planning, both short-run and long-run costs must be considered. The short run is defined by economists as a time period in which output can be varied but the size of the plant can not be altered. The long run is a time period sufficiently long to vary everything. In practical terms, all operating decisions are made in the context of the short run, while planning decisions are made in the context of the long run. For example, a decision pertaining to the number of maintenance personnel to hire and to their pay scale is an operating decision and does not influence the size of a particular water system's production, treatment and distribution facilities. Such a decision is of a short-run nature and can be modified at virtually any time. On the other hand, a decision to begin a search for new sources of water is a planning decision, and as such it does influence the size of the system's facilities.

In the short run, the quantity of water which a system produces must be produced from the existing facilities. Therefore, total operating costs may be broken down into two major categories. First, certain costs remain constant as the quantity of water delivered by the system varies. These costs are called fixed costs. When viewed on a per-unit or average basis, fixed costs must decrease as the volume of water produced increases. Second, some expenses are directly related to the volume of water produced. These are called variable costs. Unit variable costs may exhibit virtually any relationship to volume, depending upon the technology being used to produce, treat and distribute water.

Fixed cost constitutes a substantial portion of a water system's total operating cost. Some of the more important components of total fixed cost are (1) administrative wage and salary expense, (2) maintenance related to a system's age, such as repairs of broken mains, and depreciation, (3) debt service costs, including interest on capital indebtness, (4) customer billing and general accounting, and (5) the cost of developing new water sources because old sources have become depleted or polluted, and the total volume of water produced remains stable. Obviously, these costs vary considerably from system to system. However, they tend to remain unchanged as a particular system varies its volume during a given period of time. For example, there is little if any reason to expect these cost components to be different at the time of the peak summer production from what they would be at any other time during the year.

Variable costs of producing and distributing water include (1) power for transporting water from its source to the ultimate consumer and for operating the treatment plant, (2) treatment supplies, and (3) use-related maintenance. On the surface, it seems reasonable that power costs would vary in direct proportion to volume. However, some systems may have several alternative sources of water, with the added sources being utilized only as the volume of water produced increases beyond a minimum level. In such a case, per-unit power cost may increase with output if the costs of the standby sources are greater than the costs of sources regularly used. Generally, one would also expect treatment supply costs to be proportional to volume except in those cases where the water quality at the basic source declines as the amount withdrawn increases. Thus there is good reason to assume that these two components of per-unit variable cost remain constant as output varies. Use-related maintenance depends largely upon the type of equipment which the water system operates and is also expected to be proportional to volume.

The discussion contained in the above paragraphs implies that the short-run total cost-output relations for a water system can be described by linear functions which have a positive intercept value. Therefore, when the cost relationship is put on a per unit of output basis, average total cost would decline as output increases. This is consistent with the hypothesis that a water system is a natural monopoly.

As previously indicated, the long run is considered to be a planning period within which water system managers may change any one or every aspect of the particular system's operation. Thus, all costs become variable in the long run and the cost-output relationships may be different from those discussed above. The decisions which must be made with regard to long-run planning include but are not restricted to determining: (1) the source of water which will be tapped, (2) the type of pumping and storage equipment which will be installed, (3) the size and type of treatment facilities, (4) the area to be served by the system, (5) the type and size of distribution mains to install, (6) whether or not meters will be used, (7) the size of administrative staff, (8) other miscellaneous items.

The basic source of water is of vital importance in that it largely determines the type of pumping facilities which will be needed and the extent to which water must be treated. Thus, the water source is of considerable importance in determining costs. As a generality, one can conclude that the greater the expected volume the more difficult and costly it will be to locate and develop a dependable source of high quality water. However, one would not necessarily expect the rate of increase in development costs to exceed the rate of increase in volume added by the source after it has been developed.

The initial cost of pumping, source and distribution facilities does in fact increase as larger units are installed. However, installation costs tend to increase less rapidly than the capacity of each of these facilities. For example, a pump with a capability of delivering 250,000 gallons of water per day will cost more to install than will a pump which has a capability of delivering 125,000 gallons per day, but the cost will not double when the larger pump is used. The same thing holds true for storage facilities and distribution mains. Thus, the larger facilities which are necessitated by higher expected volume tend to result in higher capital outlays but lower unit costs of producing water. In addition, the power to operate the 250,000 gallon per day pump will be less than twice the amount required to operate the pumps with 125,000 gallon per day capacity.

The area to be served by the system greatly influences both the initial capital outlay and the volume of water which the system can be called upon to deliver. As the area increases in size, more miles of distribution mains must be installed and larger mains will be required, at least near the treatment plant. The number of customers served increases with the area served, and this results in a greater demand for water. An exact specification of the relation between area served and per-unit cost depends upon the population density of the area located the farthest from the treatment plant. As population density increases in those areas, the per-unit cost of including additional territory within the system's service area declines. The increased volume generated by including additional territory may even be sufficient to offset the additional capital expenditure and delivery cost associated with transporting water over the greater distances.

The quality of water at its source largely determines the type of treatment needed. Nevertheless, treatment plants which are designed to handle large volumes of water will tend to be more efficient than those designed to handle smaller volumes. For both large and small plants, the amount of treatment supplies used should vary in direct proportion to volume of water treated.

Today, most water distribution systems across the nation use a metering system and bill the individual customer for the actual volume of water used. It is a common procedure for the individual customer to be required to purchase the meter at the time at which the initial service is provided. Such a practice serves as a vehicle for transferring the cost of metering to the customer and thereby reducing the capital investment which the system must incur in order to deliver water to the customer. While metering is necessary in order to have some equitable way of allocating production and distribution costs to individual customers, meter reading costs vary directly with the frequency of reading and the number of customers. Hence, this component of cost is not influenced by volume used by existing consumers.

When all of the above cost components are considered, it seems logical that the long-run total and per-unit cost-output relationships could be represented by ordinary graphical means. It should be remembered that long-run total cost continually increases as the volume of water increases but that the long-run average cost declines throughout the quantity range shown, which is assumed to be greater than the community's total demand for water. This is not meant to imply that the cost relationships may not shift upward over time because of inflation but that long-run average cost does decline as output is increased and that water systems do, at least theoretically, conform to the requirements of natural monopoly.

## EMPIRICAL COST RELATIONSHIPS

Empirically derived long-run cost relationships may be obtained from either of two types of data. Time series data which shows how a firm's cost and output vary from one time period to another may be used. This type of data is the most desirable, but obtaining meaningful estimates from it requires that substantial changes in output be observed during the time period selected. Since output of a water system is expected to increase in approximate proportion to population, and since cost-output data is typically not available for a sufficient number of years, such data cannot generally be used to derive meaningful estimates. Accordingly, the analyst is forced to base his estimates on cross section data which shows the cost-output relationship for a number of firms of varying size during a selected tim period. In order to obtain meaningful estimates from cross section data, there must be substantial firm-to-firm variation in output and cost during the study period. Regardless of which type of data is used, there are certain conceptual problems which the researchers will encounter. A discussion of these problems is not our purpose in that they have been treated in considerable detail by others including Borts,[1] Dean[2] and Johnson.[3]

Frey, Gamble and Sauerlender conducted a study of the cost-output relationship for a sample of 86 water systems which were scattered over 12 Northeastern states. They used cross section data and only concerned themselves with variable cost. Hence, their estimates constituted only a portion of the short-run operating costs of the sample water systems. The basic statistical model used in their study is given by equation 1. Their analysis produced a negative coefficient for the linear term and a positive coefficient for the quadratic term.

$$AVC = a + b_1 V + b_2 V^2 \qquad (1)$$

where

AVC = average variable cost

V = volume expressed in millions of gallons per day

The values of the coefficients were of such magnitude (.045 and .002) that the predicted average variable cost decreased with output up to 13.3 million gallons per day. The minimum average variable cost occurred at a volume which was less than the volume produced by any of the water systems included in their study. Furthermore, the quadratic equation explained only 24.4 percent of the variation in average variable cost. They attribute the low explanatory power of the equation to the exclusion of variables other than size which influence cost. The inclusion of "per capita withdrawal" and "proportion of losses" as additional variables increased the explained variation to 33.9 percent.

In order to obtain a true measure of long-run costs all expenses must be included in the analysis, not just the variable cost components. In a study conducted by the authors, a series of regression analyses of total cost data on 72 Mississippi water systems revealed the results shown by equation 2. The basic model used was that introduced by Frey, et. al., but with the substitution of total cost for average variable cost as the dependent variable, the equation explained 71 percent of the variation in total cost among the systems.

$$TC = 27.0532 + .3259\ (GPY) + .0001\ (GPY)^2 \qquad (2)$$

The coefficient of the linear term is significant at the five percent level but the coefficient of the quadratic term is not significant at any reasonable

---

[1]G. H. Borts, "The Estimation of Rail Cost Functions," Econometrica, V 28, 1960, pp. 108-131.

[2]Joel Dean and R. W. Jones, The Long-Run Behavior of Costs in a Chain of Shoe Stores, University of Chicago Press, Chicago, 1942.

[3]J. Johnson, Statistical Cost Analysis, McGraw-Hill, New York, 1960.

significance level. This suggests that the long-run total cost relationship is in fact a linear function of output and that average cost declines as volume increases. If the nonsignificant squared term is deleted then the model yields results which are theoretically consistent with the hypothesis that water producing systems can be classified as natural monopolies, since average cost declines as volume increases.

Borts has suggested a procedure for stratifying firms according to size when attempting to obtain long-run cost functions from cross section data.[4] This is accomplished by the use of dummy variables where the smallest size class serves as the base. Thus his procedure yields a different cost-output relationship for each size class. These differences can be attributed to different techniques of production which are used by the different size firms. In Bort's study of the rail industry, these variables were significant. However, when we attempted to include such variables in our regression analysis we found that their inclusion failed to improve the explanatory power of the equation and even reduced the significance of the coefficient of the linear volume term and did not change the significance of the quadratic term. In addition, none of the size terms were significant.

## CONCLUSION

The primary purpose of this study was to derive long-run cost-output relationships for the water industry in Mississippi. The total cost function which was derived meets minimal tests. However, additional testing and refinement is needed. A cost relationship which can be used to implement policy decisions is still not available. If additional research supports the hypothesis of economies of size, then there would be ample justification for encouraging some consolidation of existing systems and the construction of systems with larger capacities when new systems are built.

---

[4] G. H. Borts, "The Estimation of Rail Cost Functions."

# REFERENCES

1. Borts, G. H., "The Estimation of Rail Cost Functions," Econometrica, V 28, 1960.

2. Dean, Joel and Jones, R. W., The Long-Run Behavior of Costs in a Chain of Shoe Stores, University of Chicago Press, Chicago, 1942.

3. Frey, John C., Gamble, Hays B. and Sauerlender, Owen H., Economics of Water Supply Planning and Management, Institute for Research on Land and Water Resources, The Pennsylvania State University, University Park, Pennsylvania, 1975.

4. Johnson, J., Statistical Cost Analysis, McGraw-Hill, New York, 1960.