IV. THE USES OF THE INDEXES OF DRILLING AND COMPLETION COSTS

A. The Uses of the Individual Price Index Series.

Each individual price index series for items purchased directly by the operator, as shown in Table VII, may be used as an indication of the trends in the prices of the goods and services included in that index. Projections of individual series into the future should not be made without observing proper caution, however, particularly in the light of the relatively short period of time covered by these series, to say nothing of the other pitfalls of statistical trend projection. For those who nevertheless wish to risk such projections, it may be possible for them to devise a set of weights appropriate to their own particular operations (if their own cost data appear to show relative expenditures differing from that of the industry taken as a whole) and to project their own relevant composite price index into the immediate future.

B. The Use of the Index of Direct Operator Cost Unadjusted for Depth Changes.

The index of direct operator cost unadjusted for depth changes, computed in the form of a composite price index, is an attempt at a measure of pure price change. It purports to measure the differences in the cost of purchasing an identical composite set of drilling inputs (goods and services) from year to year, any cost changes it may indicate being therefore solely due to changes in the prices of these inputs. This composite price index is therefore a measure of price change for a certain composite of inputs. A different weighting of the component series of inputs will result in a measure of price change for a different composite of inputs. In conjunction with an index of actual expenditures, this composite price index can be used as an indirect measure of the effect of technological change and other factors affecting total costs, although it cannot measure the effects of such factors individually. If we assume that the efficacy in well drilling of a certain base-year composite outlay is the same from year to year, and that the average depth of wells remains the same, then the cost per foot drilled and the cost per well drilled should remain the same, in the absence of price changes. Under these circumstances a composite price index would measure pure price change, and in doing so would also measure changes in cost per well and cost per foot. If, however, technology improves, new processes are developed, and new inputs are introduced, the cost per foot and per well may decline as drilling efficiency increases. If, on the other hand, wells must be drilled deeper, on the average, each year, and in more inaccessible locations with more resistant geological formations, the real outlay costs per well and per foot may increase.

If we then compare the composite price index for a given year with the index of cost per foot or cost per well for the same year, the cost index will be lower than the composite price index if technological progress has predominated over elements of increasing real cost, and higher than the composite price index if increasing depth of wells, increasingly resistant formations, increasingly inaccessible locations (such as offshore drilling) and other elements of increasing real cost have offset technological improvements. For 1961, the composite price index (1947-1949 = 100) is 152.0 while the index of drilling and completion cost per foot is 173.6, and the index of drilling and completion cost per well is 204.3. We may interpret these results along the following lines: the cost per foot is 114.2 per cent of the composite price index. Despite considerable technological improvement, other factors affecting the cost per foot have acted so as to increase the cost per foot of drilling 14.2 per cent above the increase which would be expected on the basis of price increases alone. However, the cost per well is 134.4 per cent of the composite price index. Increasing real costs of drilling, and other related factors, have acted so as to increase the cost per well drilled 34.4 per cent above the increase which would be expected on the basis of price increases alone.

How are we to relate changes in prices, and in costs per foot and per well? Let us first assume that technological improvements had been sufficiently great to reduce the index of drilling and completion cost per foot below the composite price index by X per cent. Had technological improvements served only to decrease the cost per foot of drilling at a given depth, while the effect of increasing real costs were confined to factors which would increase the cost of drilling per well but not per foot *(e.g.,* increasing average depth of well), then the effects of technological improvements and increasing real costs could be roughly separated. Technological advances could then be said to have cut costs by X per cent, but increasing real costs would have more than counteracted this, increasing costs by X + 17.7 per cent (117.7 per cent being the ratio of cost per well to cost per foot, or 204.3 to 173.6, which, given the simple assumptions here adopted as to the relationship of per foot and per well costs, is merely the per cent increase in average well depth). Actually, such is not likely to be the case. Increasing real costs, for example, will increase not only the cost of drilling per well as average depth increases, but will also increase the average cost of drilling per foot, at the greater depths. There is no reason to suppose that cost changes owing to the action of one factor will be limited to per foot or per well statistics, and therefore all that can be done is to compare cost per foot and cost per well separately with the composite price index, in order to determine the joint effect of all factors concerned on each cost index.

A more realistic explanation of the actual relationship among the changes in prices and in costs per foot and per well would proceed along the following lines. Technological improvements have undoubtedly acted to decrease the average cost per comparable foot drilled, but the increase in average well depth, the changes in the offshore-onshore well ratio, the changes in the exploratory-development well ratio, and the change in the depth distribution of wells have more than counteracted the savings in cost made possible by technological advances. The average foot drilled in 1961 was drilled at a greater average depth and typically under otherwise more expensive conditions than the average foot drilled in 1947. The net effect of such cost-increasing factors outweighed the cost-reducing effects of improved technology, increasing the cost per foot drilled 14.2 per cent above the level of the increase which would have been expected from price increases alone. It may be said that in some sense the "real" cost of drilling a foot of hole increased 14.2 per cent from 1947 to 1961.

Costs per well increased 34.4 per cent more than would have resulted from price increases alone. Since the cost per well index is obtained merely by multiplying the cost per foot index by an index of the average depth of wells drilled, this increase of 34.4 per cent can be accounted for entirely as the product of the increase in the real cost of drilling a foot of hole, and the increase in the average depth of well, or as the product of 114.2 and 117.7, which is 134.4.

C. The Uses of the Indexes of Drilling and Completion Costs.

1. The index of drilling and completion costs per well. The index of drilling and completion costs per well shows the net effect of price changes, changes in technology, and changes in real costs on the cost of drilling the "average" well. The index of costs per well can be used to estimate total costs of drilling, given the number of wells drilled per year, and the cost of the average well in the base period, whether expressed as 1959 or as 1947-1949. One use of this index is therefore to estimate the total cost of drilling and equipping wells in the United States, and this method will be illustrated in a later section. Another use of this index is to take the estimated

TABLE X

ESTIMATES OF TOTAL DRILLING AND COMPLETION COSTS, COSTS PER FOOT, AND COSTS PER WELL, 1947-1961, AS COMPUTED BY MEANS OF THE IPAA INDEXES APPLIED TO INDEPENDENT COST ESTIMATES FOR VARIOUS YEARS

Year	Cost per Foot for Drilling and Completing Wells: IPAA Index, Applied to:			Cost per Well for Drilling and Completing Wells: IPAA Index, Applied to:			Total Drilling and Completion Costs (Million Dollars) IPAA Index, Applied to:				Independent Estimates of Total Drilling and Completion Costs (Million Dollars)			IPAA Estimate as a Per Cent of Independent Estimates:		
	1954 Census of Mineral Industries	1958 Census of Mineral Industries	1959 Joint Assn. Survey	1954 Census of Mineral Industries	1958 Census of Mineral Industries	1959 Joint Assn. Survey	1954 Census of Mineral Industries	1958 Census of Mineral Industries	1959 Joint Assn. Survey	1948 Estimates by C.C. Anderson	Census of Mineral Industries	Joint Assn. Surveys	Estimates by C.C. Anderson	Census of Mineral Industries (1954 Basis)	Joint Assn. Surveys (1959 Basis)	C.C. Anderson Estimates (1948 Basis)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1947	$ 8.60	$ 8.74	$ 8.64	$31,016	$32,373	$30,549	$ 961.3	$ 977.0	$ 965.8	$1,150.2						
1948	8.81	8.97	8.86	31,885	33,280	31,405	1,190.4	1,212.0	1,197.2	1,473.9		$1,520.0	$1,473.9		78.8	(100.0)
1949	8.92	9.07	8.97	33,026	34,471	32,528	1,218.7	1,239.2	1,225.5	1,513.8						
1950	9.34	9.50	9.39	35,959	37,532	35,417	1,289.3	1,311.4	1,296.2	1,626.1						
1951	9.84	10.01	9.89	39,924	41,671	39,323	1,680.8	1,709.8	1,689.3	2,160.8			2,040.3			105.9
1952	10.48	10.66	10.54	44,867	46,830	44,191	1,943.1	1,976.5	1,954.2	2,540.1						
1953	10.70	10.88	10.76	45,193	47,170	44,512	2,112.9	2,148.5	2,124.8	2,786.3		2,559.0	2,485.5		83.0	112.1
1954	10.95	11.08	10.95	46,335	48,361	45,636	2,248.5	2,412.9	2,384.6	3,166.4	$2,248.5			(100.0)		
1955	11.02	11.34	11.21	46,388	48,418	45,689	2,481.2	2,553.3	2,524.0	3,370.6		2,600.0	3,037.4		97.1	111.0
1956	11.71	11.91	11.78	49,322	51,479	48,578	2,718.8	2,765.2	2,735.0	3,693.9		2,868.0			95.4	
1957	12.55	12.76	12.62	53,287	55,618	52,484	2,769.0	2,815.3	2,784.4	3,808.1						
1958	12.42	12.63	12.49	51,549	53,790	50,772	2,425.5	2,466.5	3,439.2	3,360.9	2,400.7			101.0		
1959	12.83	13.05	12.90	54,319	56,695	53,500	2,636.7	2,681.9	2,651.1	3,652.0		2,651.0			(100.0)	
1960	13.20	13.43	13.27	56,383	58,846	55,533	2,443.9	2,486.4	2,456.8	3,373.3						
1961	13.38	13.61	13.45	57,415	59,927	56,550										

Sources:

Columns (1), (4), (7), (11), (14): U.S. Department of the Interior, 1954 Census of Mineral Industries, "Crude Petroleum and Natural Gas," Bulletin M-13B. (1954 data multiplied by 1959 IPAA cost per foot and cost per well indexes, converted to the base year 1954 = 100.)

Columns (2), (5), (8), (11): U.S. Department of the Interior, 1958 Census of Mineral Industries, "Crude Petroleum and Natural Gas," Bulletin M-14B. (1958 data multiplied by 1959 IPAA cost per foot and cost per well indexes, converted to 1954 = 100.)

Columns (3), (6), (9): "Joint Association Survey of Industry Drilling Costs," conducted by the American Petroleum Institute, The Independent Petroleum Association of America, and the Mid-Continent Oil and Gas Association (1959 cost per well data multiplied by 1959 IPAA cost per foot and cost per well indexes.)

Columns (10), (13), (16): C.C. Anderson: "Petroleum and Natural Gas in the United States: Relation of Economic and Technologic Trends," Canadian Sectional Meeting, World Power Conference, September 1958. (1948 data multiplied by 1947-1949 IPAA cost per foot index.)

Columns (12), (15): 1953, 1955-1956, and 1959 Joint Association Surveys of Industry Drilling Costs. (Actual data given in Column (12); 1959 data multiplied by 1959 IPAA cost per foot index given in Column (15).)

total yearly drilling cost arrived at above, and to divide it by the number of barrels of new reserves of liquid hydrocarbons discovered (or the B.T.U. equivalent of liquid hydrocarbons and natural gas discovered) in order to arrive at an estimate of the drilling cost of discovering new reserves. There are two difficulties involved in evaluating such a measure. First, it is difficult to estimate how many reserves have actually been discovered by the drilling operations of any given year, since it is generally impossible to estimate with any degree of accuracy the total ultimately recoverable reserves of a newly-discovered oil pool or gas field. Second, it must be recognized that the cost of drilling and equipping wells is only part of the total cost of finding petroleum reserves, and that total costs in the industry include not only finding costs, but also development and production costs. In order to estimate total finding costs per barrel, or per B.T.U. of new reserves found, it is necessary to know, in addition to the cost of drilling and completing wells, such costs as exploratory outlays on geological and geophysical services, the relevant costs of lease acquisition and leasing, and other items of exploratory "overhead." Finally, in order to complete the cost picture for the extractive phase of the petroleum industry, data on development cost and production cost would have to be assembled to accompany the estimates of finding cost.

2. *The index of drilling and completion costs per foot.* The index of drilling and completion costs per foot shows the net effect of price changes, changes in technology, and certain changes in the real costs of drilling wells, insofar as these real costs are reflected in a cost per foot measurement. For this index, the remarks made concerning the index of cost per well are largely relevant. The index of cost per foot can be used to estimate total costs of drilling, given the number of feet drilled per year, and the cost of the average foot drilled in the base period. This index can therefore also be used to estimate the total yearly cost of drilling and equipping wells in the United States, and in conjunction with an estimate of new reserves found during the year, it can be used to estimate the drilling cost of finding new reserves. In this connection, the same difficulties arise as in conjunction with the cost per well estimate, and the same comments are applicable.

D. An Application of the Drilling Cost Indexes For The Measurement of Total Drilling Costs, 1947-1961.

Table X shows the results of an attempt to estimate total expenditures for drilling and equipping wells in the United States, for the period 1947-1961, using as a basis for estimation the drilling cost indexes discussed above. Since these drilling cost indexes are index numbers, it is necessary to determine some absolute (dollar) value to apply to the bases 1947-1949 = 100, and 1959 = 100. There are three sources of industry cost information which may serve to provide such a base. The first is the Joint Association Survey, which gives data on total expenditures for drilling and equipping wells for the years 1944, 1948, 1953, 1955, 1956, and 1959, although the data for the years 1955, 1956, and 1959 are not comparable with the data for the previous years. The second is a study made by C.C. Anderson of the United States Bureau of Mines[4] which includes data on drilling expenditures for 1948, 1951, 1953, and 1955. The third consists of the two most recent issues of the Census of Mineral Industries, which include similar data for the years 1954 and 1958[5].

The costs reported for the year 1948 were used as the base-period statistics for the data from Anderson. This was considered permissible since the base period for one of the cost indexes is the period 1947-1949. For the 1954 Census data, however, the base-period statistics had to be obtained by adjusting the 1954 cost data to a 1959 basis by means of the relative values of the relevant cost index for 1947 and 1954. For example, the average cost of a well in 1954 was $46,335, according to the Census of Mineral Industries. In order to convert this 1954 average cost to its 1959 equivalent, the cost of $46,335 was multiplied by 100.0/85.3, the ratio between the value of the index of the cost per well in the base period 1959, and the value of the index of the cost per well in 1954. This procedure yields an estimate of the cost per well in 1959 of $54,319. This method of shifting the base period backward, however, is not without some statistical loss when the present type of index number calculation is employed.

The operation of shifting the base of an index number backward or forward in time is perfectly justified only when the index number is of such a form as to satisfy the time-reversal test[6]. For an index number derived by employing weights, the time-reversal test requires that the product of the index number as computed by its regular formula, and the index number which is computed if the time dimensions (base period versus current period) in the regular formula are reversed, be equal to unity. In other words, the index number derived by interchanging the values of the observations of the base period and the current period in the regular formula should be the reciprocal of the index number obtained by employing the regular formula, with the times of observation unreversed.

As an illustration, let us write the formula for the type of price and cost index constructed by the Cost Study Committee. This index is a weighted index, using base-period weights, and is referred to by statisticians as a *Laspeyres* index. If we refer to prices as p and the quantities by which they are weighted as q, and if we let the subscript o indicate an observation in the base period, and the subscript n indicate an observation in the current period, the formula for the Laspeyres index is:

$$\frac{\Sigma p_o \quad q_n}{\Sigma p_o \quad q_o} \;,$$

where the Σ symbol denotes the summation of all the price-quantity products for the various individual items included in the index. We can see that this index number will not meet the time-reversal test, because the product of the index, and of the expression which results if the base-period and current-period subscripts are interchanged, is obviously not equal to one, except in the very unlikely cases where (1) the quantities of the base period and of the current period are identical, or (2) the prices of the base period and of the current period are identical:

$$\frac{\Sigma p_o \quad q_n}{\Sigma p_o \quad q_o} \times \frac{\Sigma p_n \quad q_o}{\Sigma p_n \quad q_n} \neq 1.00 .$$

In general, then, the Laspeyres index will not meet the time-reversal test. In order to determine whether or not a prohibitively large error may be introduced into our calculations by shifting the base of such an index from 1959 to 1954, as it were, we must compute the time-reversal test for our index, using the years 1959 and 1954, and reversing the time subscripts of the observations for the two years in the formula. Weights of the year 1954 are fortunately available from the Census of Mineral Industries. Using these in conjunction with 1959 and 1954 prices, the time-reversal test yields a product of 1.11 instead of 1.00. It therefore appears that the shifting of the base may introduce an error on the order of 11 per cent in this instance—an appreciable error, but not large enough entirely to invalidate the procedure. (Eleven per cent is merely a measure of the extent to which the computation fails to satisfy the time-reversal test for this particular 1947-1954 comparison. There seems to be no general test available for assessing the significance of deviations above or below 1.00 for the time-reversal test.)

Having obtained total dollar figures for the cost per foot and the cost per well of drilling for the period 1947-1961, for three alternative base-period cost estimates it is now possible to estimate the total cost of drilling and equipping wells by multiplying the cost per foot for each of the three cost estimates by the total number of feet drilled. We, thus, have in Table X, three sets of estimates of total costs of drilling and equipping wells. It is appropriate to ask two questions at this point: how well do the estimates agree with each other, and how do these estimates compare with independent cost estimates for years other than the base year?

In order to measure the degree of agreement among the indexes for a given year, it is expedient to compare the total range of estimates obtained for that year, and to check the relationship of the estimated total cost on the basis of cost per foot for a given base cost estimate (*i.e.,* Joint Association Survey, Anderson, or 1954 Census) to the estimated total cost on the basis of cost per well for the same base cost estimate. As far as the total range of estimates for a given year is concerned, the relative estimates are consistent in their rank order. On a per well basis, the total cost estimate employing the 1959 Joint Association Survey cost base is the lowest, followed closely by the 1954 Census Data Series, and separated by a slightly larger gap from the 1958 Census-based estimate. For each year, the Joint Association Survey estimate is about 5.6 per cent below the 1958 Census estimate, and about 1.4 per cent below the estimate based on the 1958 Census data. The cost per well estimates for 1961 are as follows: as based on the 1959 Joint Association Survey, $56,550; as based on the 1954 Census data, $57,415; as based on the 1958 Census data, $59,927. It is worth noting that the lowest estimate is only 5.6per cent below the highest.

If we compare the estimates of cost per foot, the cost estimate employing the 1954 Census data is the lowest estimate, followed very closely by the 1959 Joint Association series, with the series based on the 1958 Census data again being the highest estimate in each year. Here, however, the gap is much smaller. For each year the 1954 Census-based estimate is about 1.7 percent below the 1958 Census-based estimate, and the estimate based on the 1949 Joint Association Survey is about 1.2 per cent below the 1958 Census-based estimate. The cost per foot estimates for 1961 are as follows: as based on the 1954 Census, $13.38; as based on the 1959 Joint Association Survey, $13.45; as based on the 1958 Census, $13.61. The range of only 1.7 per cent between the highest and the lowest estimates is noteworthy.

As a final test of the reliability of these indexes as estimates of total drilling costs, we can compare the estimates obtained by their use with the total drilling cost data released by the Census of Mineral Industries, by the Joint Association Survey and by Anderson for years other than the base year of 1948: *i.e.,* 1958 for the Census; 1953, 1955, 1956, and 1959, for the Joint Association Survey; and 1951, 1953, and 1955, for Anderson. These comparisons are shown in Table X. The 1954-based estimate of the 1958 Census is only 1 per cent above the actual 1958 Census total. The estimates made in connection with Anderson's 1948 cost figure are also reasonably close to Anderson's later estimates. For 1951, the 1947-1949-based IPAA estimate is 105.9 per cent of Anderson's total cost estimate. For 1953 the discrepancy increases somewhat, to 112.1 per cent of Anderson's estimate. For 1955, however, the discrepancy is lower than in 1953, being 11.0 per cent above Anderson's data. With regard to the Joint Association Survey (using 1959 = 100 as the basis for comparison), we see that in 1956 the IPAA estimate is 95.4 per cent of the Joint Association estimate, and in 1955, 97.1 per cent. For 1953 and 1948 the discrepancy increases considerably. In 1953 the ratio is 83.0 per cent, and in 1948, 78.8 per cent. Much of this, however, may be due to a change in estimating techniques employed by the Joint Association Survey, which has the effect of decreasing estimated costs in 1955, 1956, and 1959, relative to those reported in 1944, 1948, and 1953. It is to be suspected that the discrepancy would be considerably reduced if the 1955, 1956, and 1959 costs of the Joint Association Survey were to be reported on a basis comparable with that employed in 1944, 1948, and 1951.

In briefly appraising the relative value of the three sources of cost estimates, it seems likely that those of the Joint Association Survey are clearly preferable to those of Anderson, and possibly preferable to those of the Census of Mineral Industries, although owing to the lack of the relevant data needed to form a conclusive judgment, it is impossible to be sure that this is the case. Although it is not made clear in the published data, the 1954 Census does not seem to have defined drilling costs as comprehensively, nor to have included as many drilling cost categories as the Joint Association Survey, this difference, perhaps, accounting for its lower total estimates. Comparing the Joint Association Survey data with that of Anderson, we find that the former source carried out a much more complete and detailed study of drilling costs, involving a comprehensive industry survey. Anderson, on the other hand, estimated the total cost of drilling directly by multiplying the total number of feet drilled by the total cost per foot of drilling, as reported by the American Association of Oilwell Drilling Contractors.

The accuracy of the AAODC data is not known, but at all events one may infer from this procedure that the only difference between the current IPAA cost per foot total cost estimates and Anderson's total cost estimates is the extent to which the current IPAA cost per foot indexes differ from the AAODC index of total cost per foot drilled. Consequently, if the use of a single cost estimate is desired, it seems preferable to use the 1959 Joint Association figure as the base of the index, although it does not make any real difference (for the computation of total costs of drilling and equipping wells) whether the cost per well or the cost per foot index is employed in making the estimate.