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Benchmarking and the Measurement of Best Practice Efficiency: Evidence from Electricity Generation

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I. INTRODUCTION

> "The reduction of power costs is a problem of permanent importance to the industrial world . . . ."
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> (Howard S. Knowlton 1909, p.833)

> "While, for example, we look at the cost of power as a number of 'analysed' items such as coal, water-rate, ash removal, drivers' and stokers' wages, etc., it will probably be a long time before it dawns upon us that all this expenditure can be reduced to a horse-power-hour rate, and that such a factor, once known, may turn out to be a standing reproach. The burning of 200 tons of coal per week may mean anything or nothing, but the cost of a horse-power hour can be compared at once with standard data . . . . the publication of figures based on them would reveal amazing inefficiencies that under present conditions are unsuspected and unknown because no means of comparison exists."
>
> (A. Hamilton Church 1909, p.190)

> "The competitiveness of Australian enterprises in international markets is determined, in part, by the costs of inputs and services of Australian infrastructure. The provision of infrastructure in Australia is dominated by government business enterprises, many of which have not been directly subject to competitive pressures . . . . The international benchmarking of infrastructure performance by the Bureau of Industry Economics (BIE) between 1991 and 1996 did much to focus attention on the need for change. The BIE examined the performance of eight infrastructure industries relative to international best practice: electricity, rail freight, telecommunications, the waterfront, road freight, coastal shipping, aviation and gas supply. The world's lowest observed electricity charges . . . in 1995, those of Transalta Canada, were 22 per cent lower than Australia's lowest charges, those for Victoria."
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> (Denis Lawrence, John Houghton and Anna George, 1997)

The process of benchmarking has long been used by private enterprise, and its use in the public sector is spreading now as well.[1] The essence of benchmarking is the selection of quantitative measures, like Hamilton Church's horse-power hours in the above quote, that facilitate comparisons among establishments, or over time for the same

[1] On public sector efforts in Canada, we call attention to the Improved Reporting to Parliament Project of the Treasury Board Secretariat which aims to improve the Expenditure Management information provided to the Canadian Parliament (information and reports for phase two are available electronically from the Treasury Board Secretariat Internet site: http://www.tbs-sct.gc.ca/tb/key.html); the June 1996 report of the government of Alberta on performance in that province; and the April 1996 report of the Auditor General of British Columbia. See also Nakamura and Warburton(1997). Australia's "microeconomic reform" benchmarking efforts are summarized by Lawrence, Houghton and George(1997). Murray(1992) reports on a massive performance measurement study of the Swedish public sector.

establishment, for important aspects of performance.[2] Ideally, the selected measures should be ones for which observations can be cost effectively obtained, and that accurately reflect reality. They should also provide insight into how progress can be made toward productivity goals. Reports of flagging productivity and of the productivity paradox have caused managers and others to become far more concerned about finding ways to improve productivity.

Businesses use both financial and nonfinancial performance measures. The financial ones include total and unit costs, revenues and profits, and multifactor productivity measures with price weights. The nonfinancial ones include input-output ratios and their reciprocals which are often called single factor productivity measures. Based on a field study of Canadian businesses funded by The Society of Management Accountants, Armitage and Atkinson (1990) note a tension arising from the lack of an accepted framework for integrating financial and nonfinancial performance measure information.[3] This tension is evident as well in public sector benchmarking efforts.

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[2] Lawrence, Houghton and George(1997, p.2) write: "Firstly, before comparisons can be made it is necessary to come up with a set of key performance indicators. If comparisons are to be objective and transferable between staff, they must be readily quantifiable. This process helps to identify the factors that are critical to the success of the firm and facilitates a thorough understanding of the organisation's strengths and weaknesses."

[3] Armitage and Atkinson report that businesses typically use non-financial and financial performance measures for different purposes:

> "The non-financial systems are used for day-to-day operations control. These non-financial systems are detailed, rely on operational data, and are microscopic. These systems take strategy, objectives, and goals as given and deal with what is essential to control in the short run to achieve these goals.
>
> The financial systems seem to serve as an aggregate test of the efficacy of the operational control systems in achieving their objectives. The financial systems provide a basis by which to make strategic comparisons of the organization's performance to the performance of the world-class competitor. The financial systems also appear to provide the aggregation and summary necessary to reduce complex operations data to comprehensible scores of performance" (Armitage and Atkinson 1990, p. 141).

In this paper, we show that the *best practice efficiency measure*, which is the overall efficiency measure proposed by Farrell(1957), can provide a meaningful, intergrative framework for utilizing nonfinancial input-output efficiency measures together with unit cost financial information. This approach requires no information on output prices. Hence it is relevant for the government as well as for the private sector, and for enterprises that are regulated or face oligopolistic or monopoly conditions in output or input markets.

We explain and demonstrate this best practice efficiency approach in the context of an empirical study of the efficiency of electric power generating plants in a number of countries. It is an example with parallels to a large number of other infrastructure and public sector service production situations.[4]

We begin in section II by introducing the motivations and the data for the electric power plant application. Further details concerning the data set are provided in appendix A, and the adjusted measure of physical capital that we use is explained in appendix B. Single factor efficiency measures for the power plants are examined in section III, and unit costs in section IV. The best practice efficiency measure is introduced and discussed in section V, and is applied in section VI. Section VII concludes.

Public sector benchmarking makes substantial use of nonfinancial as well as financial measures for comparative as well as for control purposes. Reasons for this include the frequent lack of competitive market price information for the public sector outputs. There have been other attempts to provide an integrative framework for nonfinancial and financial performance measures, including the APC Performance Measurement System (see Kendrick 1984), but none of these have been widely adopted.

[4] The extension of this approach to multiple output cases involves linear programming techniques which are straightforward but beyond the scope of the present paper.

II. AN ELECTRIC POWER PLANT CONTEXT

> " The broadest definition of services corresponds to the nontangible, noncommodity notion: everything except agriculture, mining, construction and manufacturing. This notion defines the scope of this volume but also . . . is troubled by the fact that electricity is tangible."
>
> (Zvi Griliches 1992a, p. 6)

Productivity in the electricity industry is of interest partly because it has been subject to change over time.[5] Also, there are still important regional differences -- even in North America -- in the costs, quality and availability of electricity service.[6] For many developing countries, the importance to economic growth of reliable and sufficiently abundant electric power is paramount, which is why the World Bank has provided funds for the construction of electric power plants.

The main service sector productivity measurement issues for electric power generation have to do with the practical limitations on market sales. Electric power must typically be purchased from regional providers granted monopoly rights by governments. Also, some governments use subsidized power as a way of attracting businesses. Thus, the prices for electric power unsually should not be treated as competitive market prices.

This study is based on information for 77 plants in 28 countries (both developed and developing). The number of plant-year observations is 198.[7]

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[5] Based on a U.S. historical study, Dean and Kunze(1993, p.91) report that the electric utilities had one of the fastest rates of productivity growth for 1967-73 but one of the poorest for 1973-79. Similarly, in introducing their study of the U.S. electric power industry, Klein, Schmidt and Yaisawarng(1992, p.207) note that: "The slowdown in productivity growth in the U.S. economy which began in the 1960s has been extensively documented, and electric utillities appear to be among the worst hit by the slowdown."

[6] This is sometimes forgotten in discussions of regional economic development. The plight of the unemployed in some of the isolated resource industry communities illustrates this point. Some critics have suggested that if the government would provide computer training, these people could escape from dependence on public income support by finding work over the electronic highways, without abandoning their communities. But the electronic highways only stretch where the way has been forged by power lines.

[7] The data set was assembled by Erwin Diewert for the 1993 study referred to in the lead footnote.

For each plant-year, we have values for net electric power output and for five categories of inputs. The *output quantity* of a plant in a given year, denoted by Y_i, is measured in megawatt hours (MWh). The *input quantities* are for: (i) liters per plant-year of diesel fuel, denoted by F_i ; (ii) liters per plant-year of lubrication oil, U_i ; (iii) personhours per plant-year of labour, L_i ; (iv) materials, including spare parts, rags, detergents, and other nonlabour and nondurable inputs,[8] measured in 1987 U.S. dollars of expenditure per plant-year and denoted by M_i ; and (v) the capital stock measured in kilowatts (kW) of installed operable generating capacity, K_i. As explained in appendix B, the capital stock variable K_i was used to create a new interest rate and depreciation adjusted measure of physical capital, denoted by KA_i, which is used in our efficiency computations. For each plant-year, we also have compiled values for the unit prices of the input factors, denoted respectively by PF_i, PU_i, PL_i, PM_i and PK_i. For convenience, we sometimes omit the plant-year subscript i .

The sample averages of the unit input prices are given in table 1 along with the coefficients of variation and the sample minimum and maximum values.

TABLE 1
Sample averages for prices and adjusted capital efficiencies

Variable name	*Sample mean*	*Coefficient of variation*	*Minimum*	*Maximum*
PF	.265	.42	.069	.705
PU	1.151	.38	.084	2.990
PL	5.261	.85	.147	23.540
PM	1.026	.064	.838	1.129
PK	1148.4	.17	838	1580.6

[8] In the case of some sorts of spare parts, it might in fact be more appropriate to treat these as durables rather than nondurables, but that is not what was done in this study.

III. SINGLE FACTOR EFFICIENCY MEASURE FINDINGS

Values were computed for five *single factor efficiency indicators* for each year of available data for each plant. These indicators are F / Y, the fuel efficiency measured in liters per MWh of net power output; U / Y, the lube oil efficiency measured in liters per MWh of output; L / Y, the labour efficiency measured in personhours per MWh of output; M / Y, the materials efficiency measured in 1987 U.S. dollars per MWh of output; and KA / Y, the adjusted capital stock efficiency, measured in kilowatts of operable adjusted installed capacity per MWh of output produced.

The sample averages for plant output and for the single factor efficiency indicators are listed in table 2, along with the coefficients of variation and the sample minimum and maximum values. There is considerable dispersion about the sample averages. In fact, no single plant-year or plant has the best, or worst, single factor efficiency in more than one of the five categories. These results suggest some method is needed for combining the single factor efficiency measures into an overall measure.

TABLE 2
Sample averages for plant output and partial efficiencies

Variable name	*Sample mean*	*Coefficient of variation*	*Minimum*	*Maximum*
Y	46,383	1.52	374	417,601
F/Y	252	.22	143	417
U/Y	3.35	.57	.88	12.38
L/Y	7.35	1.26	.31	78.37
M/Y	13.5	3.61	.55	650.50
KA/Y	.0324	.44	.0069	.1201

The installed capital efficiencies were expected to be, and are, quite variable. New plants are constructed and major equipment purchases are made infrequently, often based on predictions of higher future power demand. Also, some plants face particularly pronounced peak load demand fluctuations. Others must supply power to isolated resource sector production sites or meet other mandated objectives that adversely affect the capital efficiencies. The most efficient plant with respect to its utilization of capital was the Vieux Fort plant in St. Lucia in 1987 with KA/Y = $.0069/kWh, while the least efficient plant was the Baidoa plant in Somalia in 1988 with KA/Y = $.1201/kWh.

As both the Vieux Fort and Baidoa plants use distillate fuel, it is possible to give the following cost interpretation to their adjusted capital efficiencies. Multiply the value of KA/Y by the price of capital (PK = $1,000 and $1,039, respectively, as explained in appendix A) to get the amount that must be added to average variable costs to cover the average capital costs (both depreciation and interest). Thus, the Vieux Fort plant must add $6.80 per MWh and the Baidoa plant must add a burdensome $124.68 per MWh to the respective average variable costs in order to cover the capital costs.

IV. UNIT COST AS AN EFFICIENCY MEASURE

A widely used measure of overall efficiency is average total cost, or *unit cost*, denoted in this paper by C_i. This measure was being recommended for benchmarking even back in 1909, as our opening quote from Church shows. Unit cost can be computed as a price weighted sum of the corresponding input-output coefficients, which are the single factor efficiency measures discussed in section III above:

$$\begin{aligned}(1) \qquad C_i &= [PF_i \times (F_i / Y_i)] + [PU_i \times (U_i / Y_i)] + [PL_i \times (L_i / Y_i)] \\ &\quad + [PM_i \times (M_i / Y_i)] + [PK_i \times (KA_i / Y_i)], \qquad i = 1,2,\ldots,198.\end{aligned}$$

The *variable unit cost*, VC_i, is equal to the unit cost minus the capital cost contribution:

$$(2) \qquad VC_i = C_i - [PK_i \times (KA_i / Y_i)].$$

The sample averages for the unit variable cost VC_i, the unit cost C_i, and for the cost shares for the five input factors are reported in table 3.

From the bottom five lines of column of table 3, it can be seen that the average cost shares were about 48% for fuel, 29% for capital, 13% for labour, 7% for materials, and 3% for lube oil. The large cost share for capital explains our attention in appendix B to the determination of capital costs for durable inputs.

TABLE 3
Sample averages for unit costs and cost shares

Variable name	*Sample mean*	*Coefficient of variation*	*Minimum*	*Maximum*
VC	105.61	.81	22.56	918.19
C	142.26	.64	57.31	1000.60
SF	.481	.22	.160	.767
SU	.029	.55	.0025	.095
SL	.130	.76	.0053	.490
SM	.070	.90	.0036	.650
SK	.291	.41	,067	.677

V. A MULTIFACTOR BEST PRACTICE EFFICIENCY MEASURE

The unit cost of a plant relative to the lowest observed unit cost is not a satisfactory indicator of efficiency because input prices are not controlled for in this measure, and these prices are not under the control of plant managers. A plant may have a relatively low (or high) unit cost simply because the input prices are relatively low (or high). That drawback is overcome by the best practice efficiency measure.

Using the prices for plant-year i together with the input-output coefficients for plant-year j, we can form a hypothetical unit cost denoted by B_{ij} and defined as:

(3)
$$B_{ij} = [PF_i \times (F_j / Y_j)] + [PU_i \times (U_j / Y_j)] + PL_i \times (L_j / Y_j)] \\ + [PM_i \times (M_j / Y_j)] + [PK_i \times (KA_j / Y_j)], \quad i = 1,2,\ldots,198.$$

The <u>"best practice" unit cost</u> for plant-year i is defined as the minimum over all j of the

B_{ij} and is denoted by B_i . Thus, for our power plant data,

(4) $B_i =$ minimum$_j \{B_{ij} : j = 1,2,\ldots,198\}$.

The <u>"best practice" efficiency[9]</u> for plant-year observation i is defined as the ratio of the best practice unit cost for the i th plant-year to the actual unit cost:

(5) $E_i = B_i / C_i, \qquad i = 1,2,\ldots,198.$

The value of E_i must always be greater than zero and less than or equal to one because of the way in which B_i and C_i are defined. If $E_i = 1$, this indicates full efficiency; in this case, the unit cost cannot be reduced by using the technological coefficients pertaining to any other plant-year. If $E_i < 1$, then the unit cost for plant-year i could be reduced to $E_i \times C_i = B_i$ if the plant could adopt the best practice technological coefficients.

A diagram may help to illustrate the concept of best practice efficiency when output Y is produced by combinations of only two inputs, say F and L. The input-output coefficients for plant-year i are F_i / Y_i and L_i / Y_i . The six points labeled 1 to 6 in figure 1 correspond to the input-output coefficients for six hypothetical plants. The dashed line through point 3 (F_3 / Y_3 , L_3 / Y_3) represents the set of $(F / Y, L / Y)$ combinations which attain the observed plant 3 unit cost given by $C_3 = [PF_3 \times (F_3 / Y_3)] + [PL_3 \times (L_3 / Y_3)]$. That is, the dashed line through point 3 is the set of $(F / Y, L / Y)$ values such that $[PF_3 \times (F / Y)] + [PL_3 \times (L / Y)] = C_3$, where PF_3 and PL_3 are the prices facing plant 3.

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[9] The basic concept is due to Farrell (1957, p.255). Farrell called the concept the *overall efficiency*. See also Farrell and Fieldhouse (1962). In the case of a single output, overall efficiency can be regarded as a partial equilibrium counterpart to Debreu's (1951, p.285) general equilibrium *coefficient of resource utilization.* The format in which the measure is expressed in our study will enhance its usefulness in real world benchmarking applications.

FIGURE 1
Best practice efficiency illustrated

[figure not available for electronic version]

Now, if plant 3 could adopt the technological coefficients that correspond to any one of the other plants, then the lowest possible unit cost with plant 3 prices would result from using the input-output coefficients of plant 2. Geometrically, we move the dashed line through point 3 in a parallel fashion towards the origin until we hit the lowest possible input-output coefficients, which correspond to plant 2 in this case. The ratio of plant 3's best practice cost to its actual cost is *OE/OD* , or equivalently *OA/OC* which is the *best practice efficiency* of plant 3.

Note that if the price of *F* increased dramatically relative to the price of *L*, then the dashed lines would become more steeply sloped, and plant 1 would have the lowest possible unit cost. Figure 1 illustrates the important point that, in general, there will be no single set of input-output coefficients that will be efficient under all circumstances. As input prices change, the best practice plant will generally change. In contrast, an engineer's concept of efficiency usually postulates a single set of technical standards or engineering norms for the efficient operation of a plant, though there is an underlying implicit assumption of a standard set of input prices.

In his 1957 paper, Farrel seeks to isolate the technical versus price related aspects of efficiency. To do this, the frontier of the input requirements set must be determined. One approach to doing this termed the pure programming approach involves using a sequence of linear programs to construct the transformation frontier. Technical and allocative (or price) efficiencies are then defined using this frontier. These efficiencies can be illustrated using figure 1.[10]

The polyhedral figure bounded from below by the lines emanating from observations 1 and 2 is the convex, free disposal hull of the observations for plants 1 through 6. It is the smallest convex set S containing the observations that also has the free disposal property that if x belongs to S and $y \geq x$ componentwise, then y also belongs to S. A set S is convex if for every point (x, y) belonging to S and scalar μ between 0 and 1, we have $\mu x + (1-\mu)y$ also belonging to S. An observation is technically efficient if it lies on the boundary of this convex, free disposal set S. It can be seen that only observations 1 and 2 are technically efficient.

A measure of the degree of technical inefficiency of, say, observation 3 is OB/OA, where OA is the distance of point 3 to the origin and OB is the distance of point B to the origin O. Since B is the point where the line OA just intersects the set S, technically efficient points will have $OB/OA = 1$. Farrell (1957, p. 255) defines the allocative efficiency (or price efficiency) of observation 3 as the ratio OC/OB. Thus, if the plant is facing the input prices that plant 3 is facing, the point B is on the surface of the set S and thus is technically efficient. However, the point B is not allocatively

[10] Our discussion follows that of Farrell(1957, pp. 254-256).

efficient since input costs could be lowered by moving to point 2. The proportion by which costs could be reduced by moving from point B to point 2 is OC / OB.

Farrell's technical efficiency measure has the attraction of being independent of prices. Also, it is the inverse of the distance function for the input requirements sets, which has facilitated research concerning the theoretical properties of this measure (see Färe and Lovell 1978). However, it treats the input mix as given, and efficiency as simply a matter of making the best use of the given mix of inputs.

In contrast, as Färe, Grosskopt and Lovell (1985, p.64) explain, the overall best practice efficiency measures "the extent to which the production unit succeeds, by adjusting its input vector in light of the input prices it faces, in minimizing the cost of producing a certain output vector." This seems to us to be the relevant decision problem to focus on in measuring power plant efficiency, and also the efficiency of other productive facilities that are supposed to be responding to input price conditions.

V1. AN ANALYSIS OF POWER PLANT BEST PRACTICE EFFICIENCIES

Best practice efficiencies were computed for the 198 plant-years in our data set. In this section, we present the results of an initial exploratory examination of how these best practice efficiences vary depending on the following plant-year characteristics: (i) the size of the plant, (ii) the year of operation, (iii) whether the plant uses heavy or light fuel, and (iv) whether the plant is privately or publicly owned.

1. *Efficiencies by Size of Plant*

There are many reasons why larger power plants may be more efficient than those with only one or two diesel generators. For example, staffing requirements per machine may tend to decrease as the number of machines increase. On the other hand, with larger plants there may be greater problems of over capacity and coordination.

We divided our sample observations into four plant size classes. Tiny plants are those having an installed capacity of 0 to 1 MW, small plants have 1 to 10 MW, medium plants have 10 to 50 MW, and large plants have 50 to 100 MW of installed capacity. The results of table 4 seem clear: average efficiency increases as we move from tiny sized plants (average efficiency equals .414) to large plants (average efficiency equals .725).

TABLE 5
Efficiencies by size of plant

Size of plant	*Average efficiency*	*Minimum*	*Maximum*	*Coefficient of variation*	*Number of observations*
Tiny	.414	.155	.598	.27	26
Small	.553	.211	.873	.24	80
Medium	.678	.359	1.000	.21	72
Large	.725	.441	.898	.17	20
All	.597	.155	1.000	.27	198

The tiny plants were all relatively inefficient when compared against plants in other size categories. The highest tiny plant efficiency was .598 which is just barely above the average efficiency for all of the 198 plant-years of .597. On the other hand, for the small, medium, and large plants, the maximums of the efficiencies in each of the categories are high (.873, 1.000, and .898 respectively). These results suggest that for analysis purposes it may be acceptable to pool observations for the small, medium and large plants, but not for the tiny ones.

2. Other Hypothesized Determinants of Best Practice Efficiencies

It is probably obvious that some of the input-output combinations used by larger plants would not be feasible for the tiny ones. There may also be important institutional constraints affecting plants in different countries. Thus, in the remainder of this section we show separate results for one developed and two developing country groupings of the observations, with no tiny plants included. [11]

Engineers believe that newer machines are more fuel efficient. If this is so, then the best practice efficiencies for more recent years should be higher on average if recent year observations have a higher proportion of new diesel generators. Over time, we would also expect plant managers to discover more efficient ways of undertaking operations in their plants. So, for this reason as well we would expect the observations for more recent years to exhibit higher efficiencies on average.

The type of fuel oil used is another factor that is widely believed to affect efficiency. In particular, the heavy fuel plants were expected to have an efficiency advantage over the distillate, light fuel ones.

Finally, both economic theory and other analysts lead us to expect that the privately owned plants would tend to be more efficient than the state owned ones.
In table 5 we show the average best practice efficiency values, the minimum and maximum values, and the coefficients of variation for the private plants and for the public ones in the U.K., the Caribbean countries, and Tanzania. In comparison with the public

[11] These and other empirical issues will be more fully and rigorously investigated in a subsequent empirical study for which a larger data base is being assembled.

plants, we find that the average efficiencies for the private ones are higher for the two developing country groupings of observations, but not for the U.K.

TABLE 5
Average efficiencies by type of ownership

Type of ownership	*Average efficiency*	*Minimum*	*Maximum*	*Coefficient of variation*	*Number of observations*
U.K., private	.614	.423	.776	.164	9
U.K., public	.692	.404	.849	.185	20
Caribbean, private	.760	.572	.919	.152	20
Caribbean, public	.647	.549	.816	.150	6
Tanzania, private	.618	.610	.630	.017	3
Tanzania, public	.472	.379	.557	.114	9

One possible reason why the results in table 5 are not what we had expected for the U.K. could be that the effects of public versus private ownership interact with, or are overshaowed by, the effects of other factors. To explore this possibility the following country group specific regression model that controls for the year and fuel type:

(9) $$E_i = \alpha_1 + \alpha_2 Year_i + \alpha_3 DF_i + \alpha_4 DP_i .$$

In this model, DF_i denotes a dummy variable set equal to one for light fuel use and equal to zero for heavy fuel. Hence α_3 was expected to be negative. DP_i is a dummy variable equal to one for private ownership and equal to zero for public ownership. Hence α_4 was expected to be positive. The coefficient estimates are shown in table 6 (with t values beneath in parentheses). A star on a coefficient indicates (one-sided) significance with a 95% level of confidence.

TABLE 6
Estimated coefficients for private-public regression

Variable	*U.K. plants*	*Tanzanian plants*	*Caribbean plants*
Constant	.699* (13.63)	.652* (9.13)	.618 (6.88)
Year	.008 (.83)	-.037 (-2.63)	.003 (.24)
Light fuel dummy	-.184* (-4.48)	.010 (.37)	.015 (.34)
Private sector dummy	.010 (.23)	.139* (4.33)	.113* (1.99)
Number of plants	29	12	26

From the first column of table 6, we see that for the U.K. the fuel effect is significant (heavy fuel plants had an 18.4% efficiency advantage over light fuel plants), while the year and public-private effects are insignificant. The results in the second column suggest that, on average, the efficiency of privately owned plants in Tanzania exceeds the efficiency of the publicly owned ones by 13.92%. This difference is statistically significant, but the year and fuel type effects are not. Finally, the results in the last column imply that the efficiency of privately operated plants in the Caribbean region exceeds the efficiency of publicly operated ones by 11.3%. This difference is also significant at the .95 level of confidence, but again the year and fuel type effects are not.

These exploratory and partial results on the efficency differences for public versus private owership, controlling for the year and for the fuel type, can be summarized as follows: (i) for developing countries, on average private plant efficiency exceeds public plant efficiency by 11 to 14%; and (ii) for the plants in a developed country, we could not find evidence of a statistically significant private sector efficiency advantage.

VII. CONCLUSIONS

In the first part of this paper, we have defined and discussed a series of measures of efficiency: single factor efficiency measures that are the input-output coefficients, unit cost and unit variable cost measures, and a multifactor “best practice” efficiency measure. The latter of these -- the measure we prefer -- is defined as the ratio of the best practice to the actual unit cost. Best practice unit cost for a plant in a particular year is computed using the actual input prices facing the designed plant in that year and the input-output coefficients from the benchmarking reference sample that result in the smallest hypothetical unit cost figure. This is the overall efficiency measure that was proposed by Farrell(1957). In the form in which we have expressed this measure, it provides an integrative framework for unit cost information and the input-output coefficients which are widely used single factor nonfinancial efficiency measures.

In the empirical portion of our study, we show that, by themselves, the single factor efficiencies for the power plants in our data sample fail to identify best practice in an overall sense. No one plant has the best value for more than one of the five single factor efficiency measures evaluated. The unit cost of electricity production and the unit variable cost are more comprehensive measures that are often used for comparative purposes in actual practice. However, it is inappropriate to judge the performance of the electric power plants by comparing their actual unit costs since the price conditions faced differ greatly. The multifactor best practice efficiency measure has the advantage that it controls for the input price heterogeneity.

If the variability in operating efficiency that we have observed in the diesel electric power industry extends to other service sector industries, then perhaps the main implication of our study is that there are large potential productivity gains to be made from benchmarking exercises that are similar to the one that we have undertaken. The ingredients for a successful benchmarking study are: (i) comparability of outputs and inputs across production units in the comparison set, (ii) detailed price and quantity data on outputs and inputs by production unit, and (iii) a mechanism for the results of the benchmarking studies to be disseminated to the participating production units and investigated to determine the reasons and possible remedies for the low efficiency values.

The bad news that emerges from our study is that so many production units appear to be inefficient. The good news is that these inefficiencies may be the source of future dramatic productivity gains.

APPENDIX A: DATA

The full data base for this study consists of 198 plant-year observations. However, the information sources and the nature of the information differ for the observations 1 through 125 versus 126 through 198.

1. The Institution Data: Observations 1-125.

The first 125 of the plant-year observations are based on information from the Institution of Diesel and Gas Turbine Engineers (1985, 1987, 1988, 1989, 1990, 1991), supplemented by information from the *Caribbean Electric Utility Survey* for 1989 (see de Caires 1989) and from an Electric Power Utlity Efficiency Study (EPUES) project questionnaire. The following information was utilized from the Institution of Diesel and Gas Turbine Engineers publications: (i) owner of the plant; (ii) site rating or capacity in megawatts (MW) for each machine; (iii) hours run since installed for each machine; (iv) hours run this year for each machine;[12] (v) (gross)[13] units of power generated by the plant during the year in megawatt hours (MWh): (vi) the percentage of heavy fuel used; (vii) the consumption of lubricating oil expressed as kilowatt hours (KWh) of (gross) output per liter of oil: (vii) the price of distillate fuel and the price of heavy fuel (if used) in pounds sterling per tonne; (ix) the unit variable cost (excluding capital costs and any

[12] In some cases, instead of individual hours run by machine, we had only average hours run by a group of identical machines.

[13] Since some of the plants in the Institution data base were also in the *Caribbean Electric Utility Survey* data base, and the latter data base distinguished the gross output of the plant from the net output (=gross output minus station losses), we were able to deduce that the Institution output measure was gross output.

overhead costs) in pence per kWh;[14] and (x) the percentages of (variable) cost due to fuel, lubricating oil, operational wages, maintenance wages, and materials.[15]

The information on owner of the plant, item (i) above, was used to determine whether the plant was privately or publicly owned in the given year. Item (vi) is the basis for classifying each plant as utilizing light fuel or heavy fuel.

The physical capital of each plant in each designated year, for plant-years $i = 1, \ldots, 125$, is measured as the sum for that plant-year of the installed capacities in kilowatts of all of the operable machines. The information for item (ii) was used in compiling the figures for K_i. The values for the capital adjustment factor, defined following equation (B3) in appendix B, were computed using the information from items (iii) and (iv). The figures for gross plant output in MWh are based on item (v). The figures for lube oil efficiency are defined as gross plant output in kWh per liter of lube oil used and are based on item (vii). The average fuel price are based on the item (vii) data.

The Institution data permited calculation of the quantities used by each plant-year for the following four classes of inputs: (i) F_i, which denotes diesel fuel measured in liters; (ii)U_i, which is lubrication oil measured in liters; (iii) M_i, which denotes the quantity of materials (spare parts, rags, detergents, and other nonlabor and nondurable expenses) measured in U.S. dollars; and (iv) K_i, the (operable) installed capacity in kilowatts (kW) for each plant-year. The following prices could be computed from the

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[14] In the 1989 publication, the unit variable cost was replaced by the fuel cost (in pence) per kWh of (gross) power produced.

[15] Average annual exchange rates taken from the International Monetary Fund(1992) were used to convert the local currency wage rates and other figures given in sterling into 1987 U.S. dollars.

Institution data: (i) PF_i, the average price of one litre of fuel in U.S. dollars; and (ii) PU_i, the average price of one liter of lubricating oil in U.S. dollars. Information was also available on each plant's total expenditure on labour (including operating, maintenance, and supervisory labour) which, in our notation, is $PL_i \times L_i$. Estimates were arrived at for the average wage rate for plant-year i, PL_i (measured in U.S. dollars per hour), from the publications of the International Labour Office (1988. 1989, 1991), and from the EPUES questionnaire which asked for employment and hours information. Once an estimate for the average wage rate PL_i was determined, an estimate for total personhours worked, L_i, was obtained by dividing labour expenditures for by PL_i.

From the detailed information available in the *Caribbean Electric Utility Survey*, it was determined that the ratio of accounting and administrative employees to the total number of employees in the power plants averaged 23%. Thus, in order to make at least a crude adjustment for overhead expenditures, the total reported or estimated personhours for plant-year i was multiplied by 1.23 to obtain a final estimate for L_i.[16]

The price of materials was taken to be the U.S. GDP deflator with base year equal to 1987. Thus $PM = 1$ for all plants in 1987.

From a limited amount of information on capital costs (taken from the *Caribbean Electric Utility Survey*, various country missions, and other sources), it was found that the average historical cost for all components of a plant's capital stock was about $970 U.S. per installed kilowatt of generating capacity. Based on discussions with manufacturers of

[16] In the World Bank EPUES data gathering missions, an attempt was made to include plant overhead expenditures. For many plants operating in isolated regions, the reported plant expenditures also included overhead expenditures. Our crude overhead adjustment of the Institution of Diesel Engineers' data base was an attempt to make the two data bases comparable.

generating equipment, it was decided to assume that in 1987 a new plant could be constructed and completely equipped for $1,000 U.S./kW for a plant running on distillate (light) fuel and approximately $1,400/kW for a heavy fuel plant. That is, for 1987, we use $PK_i = \$1,000$ for a distillate fuel plant and $PK_i = \$1,400$ for a heavy fuel plant. For years other than 1987, the assumed price of capital is found by using the U.S. GDP deflator to adjust the 1987 figures.

From the *Caribbean Electric Utility Survey*, it was found that gross station output was on average four percent higher than net station output. Hence, the information in item (v) above (for gross output) was divided by 1.04 to obtain an estimate of net station output: the definition of Y_i in the rest of this paper. For example, for plant-year 1, $Y_1 = (30,633/1.04) = 29,455$. Also, to obtain the lube oil consumption-output ratio figures (U_i / Y_i) measured in liters per MWh of net output, the reciprocals of the lube oil efficiency figures measured in kWh of gross output per liter were multiplied by 1,000 and then by 1.04. For example, for plant-year 1, $U_1 / Y_1 = 3.07$ is computed as $(339)^{-1} \times 1000 \times 1.04$.

2. Observations 126-198

The information for plant-year observations 126 through 198 is from various consultants' reports from studies financed by aid agencies associated with the Electric Power Utility Efficiency Study.[17]

[17] Observations 126 to 130 were constructed using very detailed accounting data that were kindly provided by Mr. Jim Roberts of the Cordova Electric Cooperative, Inc. The data for observation 157 used information provided to us by the Clark Kincaid Co. (which constructs diesel engines). Institution data were used in constructing observations 158 through 169.

Full input price information was available for observations 126 through 198, while for observations 1 through 125 unit price information was available for labour but cost share rather than price information was given for fuel, lube oil, and materials, and no information was provided concerning the capital cost share or unit price. For comparability, the same basic simplifications and procedures were used in compiling the estimation data for observations 126 through 198 as for observations 1 through 125.

APPENDIX B: THE USER COST OF CAPITAL

1. General Definitions

For a given plant in a given year, it is reasonably easy to calculate the *variable cost* (i.e., the cost of the nondurable inputs used) for producing a given quantity of a single output. To do this, we multiply the quantity of each input used during the year by the relevant average unit price and sum these input factor costs over all the inputs. However, in order to calculate the full cost of the power produced, a value is also needed for the cost of the durable inputs: things such as machines, tools, furniture, inventory items, structures, holding tanks, and special access roads and docks.

The defining characteristic of a durable input is that it is not used up completely within the year when it is purchased or produced. Because of this, the original cost of a durable capital input should not be allocated entirely to the year of purchase or production. Rather, this cost should be distributed over the useful life of the input. This distribution is often accomplished by specifying depreciation rates that decline according to a preset pattern: usually a sequence of fixed positive fractions (one for each year of useful life of the capital input) which sum to unity. These depreciation rates imply a sequence of annual *depreciation costs.*

A second cost item for a durable input is the interest rate, or opportunity cost, per dollar of financial capital, denoted by r. The *opportunity cost of capital* could correspond to an average of interest rates that are actually paid on debt financing, or to the cost of raising an additional dollar of equity capital.

A small amount of notation is needed for clarifying the relevant definitions. Let P be the *beginning of the period initial value* for a durable input of a certain type, and let

$(1+\eta)P$ be the end of the period value for the same type of input with all the same characteristics *and in the same condition*.[18] Then η is a one year *inflation rate* for the given type of durable input. Suppose that the durable input had the initial, beginning of the year market value P and was used over the course of the year.[19] By the year's end, its condition will have depreciated. Its *end of period value* will be $(1-\delta)(1+\eta)P$, where δ is the relevant *depreciation rate* which is a fraction between 0 and 1.

The total cost for using the durable input for a year is the sum of the opportunity cost plus the change in the value of the input from the beginning to the end of the year.

This total cost, termed the *user cost of capital*, is given by:

$$
\begin{aligned}
p &= [\text{opportunity cost}] + [\text{initial value} - \text{end of period value}] \\
&= [rP] + [P - (1-\delta)(1+\eta)P] \\
&= (r-\eta)P + \delta(1+\eta)P.
\end{aligned}
\tag{B1}
$$

In the second line of (1), *rP* is the opportunity cost of capital, P is the initial beginning of the year value, and the remaining product term is the end of year value of the capital asset taking account of both depreciation and inflation. In the third line of (1), $(r-\eta)$ is the per dollar opportunity cost of capital minus the inflation rate, so this is a *real interest rate* for the durable input, and $\delta(1+\eta)$ is an *inflation adjusted depreciation rate.*

[18] If the durable input was purchased and new at the beginning of the accounting period, then P and $(1+\eta)P$ can be viewed, respectively, as the *list prices* for the same durable input (in the same new condition) at two points in time: that is, P is the list price at the beginning of the year and $(1+\eta)P$ is the list price at the end of the year.

[19] The firm could have purchased the (new or used) durable input for price P at the beginning of the year, or P could be the beginning of the year value of a previously acquired durable input.

If the inflation rate is taken to be zero (so $\eta = 0$)[20], then (B1) simplifies to:

(B2) $p = (r + \delta)P.$

This user cost formula (B2) was derived many years ago by Walras (1954, p.269).[21]

2. The User Cost of Electric Power Generating Machines

The concepts developed above were used in evaluating the annual total cost for the durable inputs for electricity production.

With no inflation and with durable inputs for which the depreciation rates are given constants that are not affected by the production activities, formula (B2) can be applied directly for calculating the user costs of the durables. This is generally the case for inputs such as land, structures and inventories. However, for the power generating machines, the relevant depreciation rates are machine and also period specific; in particular, the appropriate value of δ for a given machine and year depends on how many hours the machine was run in the year and on its expected total lifetime (in hours). Let T be the lifetime for a machine. Let h be the number of hours the machine was operated during the given year. Then the depreciation rate for the machine in that year (i.e., the proportion of the useable life of the original new machine that is to be written off in that year) is $\delta \equiv h / T$. Hence, the depreciation cost of the machine for the period is $\delta PK = (h / T) \times PK = (h \times PK) / T$, where PK is the assumed original purchase or

[20] This was approximately true for the U.S. dollar inflation rate during the time period spanned by our data sample for this study.

[21] See Jorgenson (1963) for various extensions of this basic formula. A more indepth discussion of this definition of user cost, and a survey of related concepts and literature, are provided in Diewert (1996).

production unit cost for the machine.[22] Therefore, δPK is the depreciation component of the user cost of the generating equipment, with this user cost defined as in (B2).

The opportunity cost component of the user cost for a plant's physical capital is the product of the going interest rate times the initial value of the capital input at the start of the year. To represent this initial value of the generating equipment we need some more notation. Let H be the total number of hours a machine had run from when it was purchased to the beginning of the current year. If $H < T$, then the fraction of the usable life of the machine that had not yet been written off, as of the start of the year, is $(T-H)/T$, and the initial value of the machine at the start of the year can be represented as $PK(T-H)/T$. Hence, the opportunity cost of the machine for the period under consideration is $r[PK(T-H)/T]$.

The user cost of the generating equipment, which is the sum of the opportunity and depreciation costs that should be charged for the year, is

$$\text{(B3)} \qquad \begin{aligned} p &= [r \times PK(T-H)/T] + [(h \times PK)/T] \\ &= [r(T-H)+h](PK/T) \equiv A \times PK. \end{aligned}$$

In the first line of (B3), r is the interest rate, T is the expected total machine lifetime in hours, H is cumulative hours of machine use as of the beginning of the accounting year, h is hours of use during the year,[23] and PK is the current (new) replacement cost of the capital equipment. In the second line of (B3), the term $A = [r(T-H)+h]/T$ is an adjustment factor that consists of an interest rate component, $r(T-H)/T$, and a depreciation component, h/T.

[22] With no inflation, PK is also the current new replacement unit cost of capital.

3. The Adjusted Capital Input

Our data set includes values for h and H for all plant-years. An interest rate of 5% (i.e., $r = .05$) was assumed. It was also assumed that the normal lifetime of a diesel generating engine is $T = 80{,}000$ hours. However, for plants where it was known that the engines did not always last as long as $80{,}000$ hours, the values of T were adjusted downward to approximate the average ages of retirement for machines in those plants. The lowest assigned machine lifetime values for our sample were for the Timbuktu plant, with $T = 30{,}000$, and the Musoma and Bissau plants with $T = 40{,}000$.[24]

For each plant-year, a depreciation rate for the generating machines was determined as discussed in subsection 2 above. In 1987, the Garrison Hill, Barbados plant had the lowest depreciation rate in the sample with δ_5 = .61%. The Timbuktu plant in 1988 had the highest depreciation rate with δ_{153} = 14.7%. Of course, the plant manager can partially control the plant specific capital depreciation rate δ_i ; extra care and attention to proper maintenance will extend the life of a plant's generating machines and reduce the depreciation rate. This fact, and the large observed variation in depreciation rates, raise questions about using K / Y as the measure of capital stock efficiency.

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[23] In the empirical work for the project, for plant-years with $H \geq T$, the user cost p was set equal to zero. On the other hand, for plant-years with $H<T$ but $H+h>T$, the difference $T-H$ was used in place of h in (B3).

[24] Since each plant contains from 2 to 20 machines, the user cost p is a weighted average of the individual machine user costs. Suppose the jth machine in the given plant had run H_j hours at the beginning of the period and ran h_j hours during the period. Denote the capacity of machine j in KW as K_j. Then the average depreciation rate for the plant is defined as $\delta \equiv (\sum_{j=1}^{J} h_j K_j) / (T \sum_{j=1}^{J} K_j)$ and the plant user cost is defined as $p \equiv \delta PK + [\sum_{j=1}^{J} (T - H_j) K_j rPK] / [\sum_{j=1}^{J} K_j]$. In some cases, insufficient information made it necessary to approximate δ_i by $1400 Y_i \ / \ TK_i$, so that 40% of the time, the engine was supposedly running but not generating power. To calculate the capital cost in these cases, we assumed that $H = .5T$.

Hence, an interest and depreciation rate adjusted measure of capital has been substituted for the original capital stock variable in the remaining portions of this study. The adjusted capital input is given by:

(B4) $KA = (p \times K) / PK = A \times K$.

In the first expression for KA in (B4), p is the user cost of capital for the given plant-year, as defined in equation(B3); K is the installed operable capacity in kW; and PK is the assumed purchase price of capital per kW of installed capacity (which is assumed to have a 1987 value of $1,000 U.S. if the plant used distillate fuel and of $1,400 U.S. if the plant used heavy fuel oil, with these values indexed for other years using the U.S. GDP deflator). In the second expression for the adjusted capital variable , recall that A consists of an interest rate, $r(T-H)/T$, and a depreciation component, h/T.

Note that $p_i \times (K_i / Y_i)$ is equal to $PK_i \times (A_i K_i / Y_i) = PK_i \times KA_i$ where KA_i is the adjusted capital input.

Note that in definition (B3) in the text we use the asset price of capital, PK_i (set equal for 1987 to $1,000 or $1,400 depending on whether the plant uses distillate or heavy fuel, and indexed for other years by the U.S. GDP deflator), and the adjusted input-output coefficient for capital, KA_j / Y_j, rather than the user cost of capital, p_i , and the unadjusted input-output coefficient for capital, K_j / Y_j . This is because we regard the adjustment factor component of the user cost, A_i, as a partially controllable variable for the plant manager. PK_i is treated as a truly exogenous variable for plant-year observation i and the adjusted capital input KA_i defined by (B4) is treated as an endogenous variable.

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