Efficient Heat Rate Benchmarks for Coal-Fired Generating Units

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B.F. Roberts, Economic Sciences Corporation
Lessly Goudarzi, OnLocation, Inc.

Introduction

The objective of this study was to analyze the potential for heat rate improvement among coal-fired generating units in the United States. The notion that heat rate improvements may be likely with the emergence of retail competition in electricity generation is prompted by: the broad range of coal-fired heat rates reported for regulated units; and the key role of heat rates in determining generation variable cost and plant profitability under competition. Our analysis shows that a reasonable expectation for potential coal-fired heat rate improvements under retail competition is about 8%.

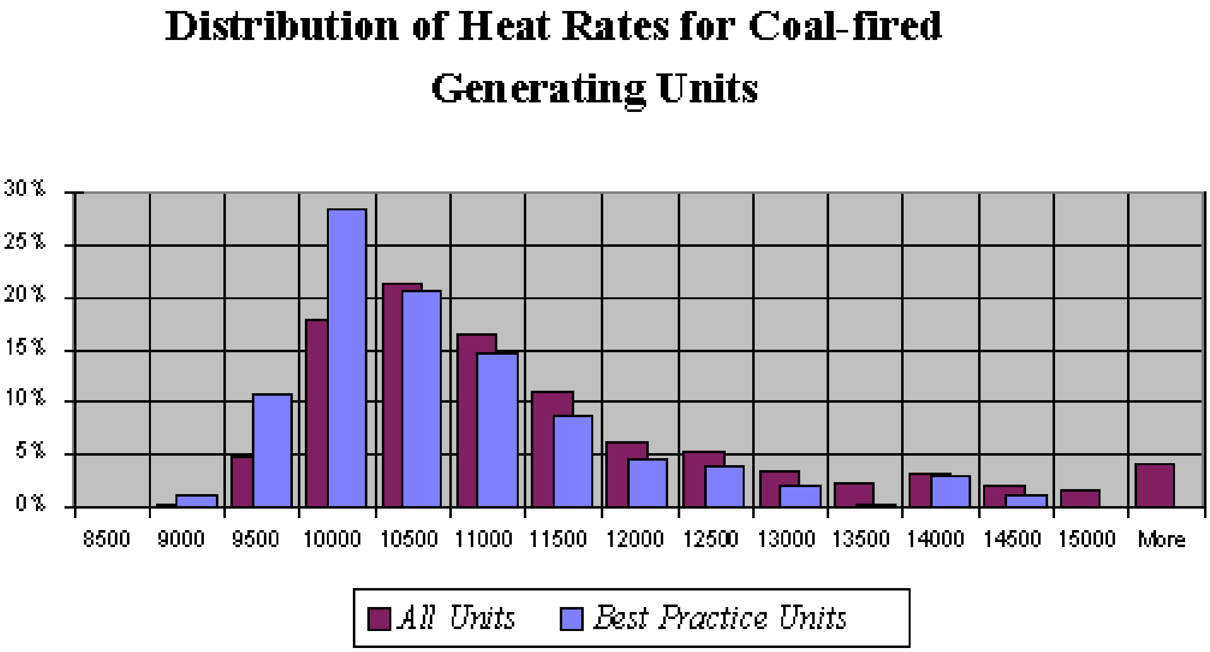
The methodology utilized for this study was to develop empirically based heat rate efficiency benchmarks for coal-fired generating units consistent with the size, age, and other characteristics of the individual generating units. This was accomplished by developing and simulating statistical benchmark models that take explicit account of the differing characteristics of the generating units and facilitates normalization and reasonable comparison across all units.

The Data Set

Data were provided describing approximately 300,000 megawatts of coal-fired generating capacity. For each generating unit, the data included measures for: heat rate, summer capacity, primary fuel type, date brought on-line, scrubber type, NOX control type, firing type, boiler bottom type, and capacity factor. On inspection, the data for 130 generating units was eliminated because of incomplete and/or inconsistent reporting. For example, some units reported non-coal primary fuels. Others reported heat rates that were unreasonably low relative to reported age and/or capacity factors. Additionally, all units with reported capacity factors of less than 10% were removed from the data set. Finally, the data for jointly owned units (but reported by ownership share) were aggregated to obtain unit totals. The final data set included data for 1,098 generating units.

Unit Heat Rate Statistics

The following diagram shows a histogram of the average annual heat rates for the 1,098 coal-fired generating units using heat rate increments of 500 BTU/KWh (red bars). This visual presentation makes clear the broad range of thermal efficiencies that have been recorded for coal-fired generating units. Even excluding some of the extreme observations as described above, this data set shows a heat rate range exceeding 100%. Clearly, most of the heat rates are concentrated in the range of 9,000 - 12,000 BTU/KWh. However, over 22% of the units show heat rates in excess of 12,000 BTU/KWh. This diversity of thermal conversion calls for questioning whether efficient operation is being achieved. The implications of this diversity of thermal conversion for power costs and emissions are huge. At issue is whether it will be feasible and economic under retail competition to shift and/or distort the distribution of heat rates to reduce average fuel consumption and emissions per KWh of coal-fired generation.



Factors Affecting Heat Rate Performance

The *optimal marginal heat rate* for an individual generating unit can typically be described by a downward sloping curvilinear function of the level of output (KW). This curve is derived from the technical input/output specifications of the plant, which are dependent on: existing thermal combustion/generation technology, type and quality of fuel, and certain operating conditions such as temperature and emission controls. The input/output relationships for generating units generally show a declining amount of thermal energy required as the level of output increases. Thus, a declining heat rate.

In reality, the *optimal marginal heat rates* may not be realized in plant operation because of: inadequate maintenance, low quality of fuel, inefficient operations practices, and adverse operating conditions. The *annual average heat rate* realized is a function of the marginal heat rates realized and plant scheduling and cycling of output levels during the year.
Marginal heat rates can reduced by: improved maintenance and operations practices, upgrading fuel quality, and the installation of refined technology equipment components[1]. Average annual heat rates can be reduced by reducing marginal heat rates and scheduling plants to operate at high levels of output.

The issue of whether it will be feasible to change the distribution of heat rates depends on whether all of the recorded heat rates were optimal, given existing technology, fuel supply, and operating condition, or whether some of the heat rates were higher than optimal because of inefficient practices, poor quality fuel, and/or other adverse conditions. The issue of whether feasible heat rate reductions will actually occur in competitive markets depends on the economics of competitive markets.

Retail Competition and Heat Rates

Under current regulation, there is limited economic motivation for plant managers to maintain efficient heat rates. In many jurisdictions, fuel costs are simply passed through to ratepayers without significant review. With the emergence of retail competition, heat rates (along with fuel prices) will be key in determining variable cost and plant profitability. Plants with lower variable cost will not only be more profitable when they are dispatched, but will also be dispatched more hours and produce more revenue. As a result, the profit elasticity for heat rate reduction in competitive markets will be very large and will motivate plant management to focus on heat rate reduction.[2]

Methodology - Statistical Benchmark Modeling

The quantitative modeling task is to identify the portions of plant heat rates that result from management inefficiency and can feasibly be reduced through management initiative. The identification of inefficiency is accomplished indirectly by first identifying the portions of heat rates that can be attributed to the plant characteristics and operating conditions for efficient plants and then obtain estimates of inefficiency by residual. The model structure was developed from the conceptual reasoning outlined above. More specifically, the model structure was built on the assumptions that heat rates are determined by the following factors: size of plant, age of plant, type of coal, bottom type, the existence of a scrubber, and the existence of NOX controls.

The first step in the modeling process was to develop an Average Practices Statistical Benchmark Model that would attribute the average effects on heat rate of the various plant characteristics. The purpose of the model are twofold: to explore the extent to which the explanatory variables account for the variations in recorded heat rates and to provide a means of identifying units that operate relatively efficiently, given the plantís specific characteristics. The following variables were evaluated in the analysis:

HRATE	heat rate
SCAP	summer capacity
AGE	age of plant
AGE30	1 if age greater than 30, 0 otherwise NOTE: This variable is intended to separate the possible effects of a technology change that would otherwise be attributed to age.
BIT	1 if bituminous fuel type, 0 otherwise
SUB	1 if sub-bituminous fuel type, 0 otherwise

LIG	1 if lignite fuel type, 0 otherwise
ANT	1 if anthracite fuel type, 0 otherwise
SCRUBBED	1 if the unit is scrubbed, 0 otherwise NOTE: No distinguishing effects of alternative scrubber types were evaluated.
NOX CONT	1 if the unit has NOX controls, 0 otherwise NOTE: No distinguishing effects of alternative control types were evaluated.
WET	1 if bottom type was wet, 0 otherwise

The Average Practices Statistical Model for coal-fired heat rates, in estimated form, is as follows:

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LEAST SQUARES ESTIMATION


FRE C  INT 1 TO 1098

L:HRATE = B0 + B1*L:SCAP + B2*L:AGE + B3*BIT + B4*LIG + B5*SCRUBBED + B6*AGE30


Beta  Variable          Coefficient   Std. Error   T-Statistic

B0    CONSTANT           9.60252501   0.04393963    218.539065
B1    L:SCAP            -0.0932101    0.00278780    -33.434957
B2    L:AGE              0.07325025   0.01228108    5.96448076
B3    BIT               -0.0456100    0.00766903    -5.9473011
B4    LIG                0.06183450   0.01809995    3.41628031
B5    SCRUBBED           0.02935875   0.00834215    3.51932529
B6    AGE30             -0.0702460    0.01009180    -6.9607025


RSQ* = 0.59919700  RBSQ* = 0.59699277    F(6,1091) = 271.839254
DURBIN-WATSON = 1.23943914  STD ERROR = 0.09215019

* R-squared mean adjusted
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The prefix rotation L: implies the natural log of the indicated variable.

The signs of the coefficients are consistent with expectations. Plant size (SCAP) reduces heat rates. Plant age increases heat rates. Bituminous coal produces lower heat rates than does lignite. (Note: the effects of other fuel types are embedded in the equationsí constant term.) Scrubbers increase heat rates.

Bottom type was excluded because no significant impacts on heat rates could be detected.

Capacity factor was initially tested, but was excluded because it was concluded that it is an endogenous rather than exogenous determinant of heat rate. For individual plants, heat rates can be expected to decline at higher levels of output. Annual average capacity factors may not adequately reflect this effect. More likely, annual capacity factor reflects local service area demand and the merit ordering of the generating unit which is largely determined by heat rate, the dependent variable for the model. In addition, many of the reported capacity factor figures do not appear to be consistent with the reported heat rates.

Note that the explanatory variables account for about 60% of the variations in heat rate for the full set of 1,098 generating units. Another 40% of the variation in heat rates is unaccounted for.

The fitted values from this model give the heat rate for each generating unit that the model would predict (from industry average performance), given the characteristics of the generating unit. Units with lower than predicted heat rates perform better than average, those with higher than predicted heat rates perform worse than average, after taking account of each plantís characteristics. This observation suggests the use of the model as a screening device for identifying efficient plants while normalizing for differing plant characteristics.

A set of efficient or "Best Practices" plants is required to develop efficient heat rate benchmarks for evaluating the potential BTU savings and emissions reductions that could be achieved from competitive electricity markets.

To determine the Best Practices Group, the Average Practices Model residuals (actual heat rate ñ estimated heat rate) were ranked in ascending order. The Best Practices group of plants was selected to include the units in the 25 percentile of the ranked list. This comprised 274 units with the largest negative deviations of actual heat rates from the model estimated heat rates. The distribution of the Best Practices units is shown by the blue bars on the diagram.

To obtain the Best Practices statistical benchmark model, the initial model structure was re-estimated using only data for the Best Practices Group of generating units. The Best Practices Model is as follows:

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LEAST SQUARES ESTIMATION


FRE C  INT 1 TO 274

L:HRATE = B0 + B1*L:SCAP + B2*L:AGE + B3*BIT + B4*LIG + B5*SCRUBBED + B6*AGE30


Beta  Variable          Coefficient   Std. Error  T-Statistic

B0    CONSTANT           9.40907889   0.03822112   246.174852
B1    L:SCAP            -0.0747765    0.00189119   -39.539406
B2    L:AGE              0.07703905   0.01136767   6.77702933
B3    BIT               -0.0512741    0.00625900   -8.1920635
B4    LIG                0.07556654   0.03311764   2.28176085
B5    SCRUBBED           0.03778556   0.00777023   4.86286296
B6    AGE30             -0.0645033    0.00734101   -8.7867047


RSQ* = 0.88844940  RBSQ* = 0.88594265  F(6,267) = 354.422121
DURBIN-WATSON = 1.50280379  STD ERROR = 0.03240578

* R-squared mean adjusted
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Note that the set of explanatory variables account for about 89% of the variations in heat rate for the group of 274 generating units. In comparison with the Average Practices Model, the statistical properties of the Best Practices Model are generally improved, suggesting that the later model should be a more reliable predictor of how heat rates will be determined in competitive markets.

The simulation of the Best Practices Model yields heat rate benchmarks for each of the 1,098 generating units. These benchmarks represent the heat rate that would be expected if each unit were to achieve the average heat rate of the best practices group, adjusted for the specific characteristics of the individual unit. These benchmarks are less stringent than would calculated at the extreme "efficiency frontier" of the best practices group. Efficiency frontier calculations using data envelopment techniques and/or frontier econometric methods would yield larger estimates of heat rate improvement potential. The benchmark of average performance for the 25th percentile of units was selected as a more achievable target. Clearly, different benchmark criteria will yield different estimates of heat rate improvement potential.

The estimated average heat rate savings achievable by moving all generating units to the best practices benchmarks is 7.97%. The total potential BTU savings, given the reported capacity factors for the units is 1,178,605,646 MMBTU per year. The potential BTU savings was calculated as the sum across generating units of the products of the following terms:

- the difference between actual and best practice predicted heat rate
- the summer capacity
- the capacity factor
- the number of hours per year (8,760)

To the extent that the reported heat rates of individual generating units are substantially affected by variables that have not been included in this analysis, then the estimated potential heat rate improvements may be off by the amount of the excluded variablesí effect. The missing effect could increase or decrease the estimated potential for improvement. For example, it is generally understood that coal plants can operate more efficiently in cold climates than in warm ones. Since temperature data were not immediately available for this study, climate differentials have not been included in the analysis. Since some of the most efficient coal plants are in the South, subsequent inclusion of temperature data will probably have the effect of increasing the measure of potential heat rate improvement for generating units in the North.

It should also be noted that the reported heat rates could include the random effects of other unknown factors. If so, then there could be a random element that is being attributed to potential heat rate improvement by the model. Since random effects can be expected to be randomly positive and negative, the net effect on the estimated potential for heat rate improvement should be small.

Finally, it should be noted that variations from these results might be obtained using different functional forms than the one adopted for this study. Linear forms were initially used, but tended to produce unrealistic estimates of heat rate improvement potential for the units at the low and high ends of the heat rate scale. The log-linear form produced more reasonable results, as it so often does in other areas of econometric research.

Summary and Conclusions

- The broad diversity of recorded thermal conversion among coal-fired generating units calls into question whether efficient operation is being achieved.

- Optimal or design marginal heat rates for generating units may not be realized because of inadequate maintenance, low quality of fuel, inefficient operations practices, and adverse operating conditions. Actual annual average heat rates may also be higher than minimum because of greater than optimal marginal rates and scheduling and cycling at less than full operating levels.

- Under current regulations, there is limited economic motivation for generating plant managers to maintain efficient heat rates. In competitive markets, the profit elasticity for heat rate reduction will be very large and motivate management to focus on heat rate reduction.

- After adjusting for the effects of plant size, age, fuel type, and environmental controls, it is estimated that approximately an 8% improvement in heat rate could be achieved if all coal generating units could reach the average thermal conversion performance of the 274 most efficient generating units.

Endnotes:

1. Experience in achieving heat rate reductions through these measures has been documented by the Southern Company and others.
2. See, for example, "Electric Generating Plant Operating Efficiency and Mitigation of Stranded Investment Costs", Lessly Goudarzi and B.F. Roberts, OnLocation Working Paper 97-3, May 1997, for a discussion of the effects of variable cost reductions.

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