ESTIMATION OF CAPACITY UTILIZATION FOR SELECTED U. S. MANUFACTURING INDUSTRIES

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March 1995

Presented at the
Eastern Economics Association Annual Meeting
March 17-19, 1995
New York, New York

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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ESTIMATION OF CAPACITY UTILIZATION FOR SELECTED U.S. MANUFACTURING INDUSTRIES

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*This research was supported by the Federal Emergency Management Agency (FEMA). We thank Joe Mattey for his help in securing the Survey of Plant Capacity data. We also thank Robert McGuckin, Orman Paananen, and Mark Weimar for helpful comments. Any opinions expressed here are our own and not those of FEMA or the Census Bureau. Any remaining errors or omissions are also ours.
Abstract

This paper reports results from the nonparametric estimation of plant-level capacity and capacity utilization for selected four-digit Standard Industrial Classification (SIC) industries for the years 1972-90. The estimates are constructed using establishment-level data from the Annual Survey of Manufactures (ASM) drawn from the Census Bureau’s Longitudinal Research Database (LRD). This work represents the first broad-scale application of the nonparametric measurement of capacity and capacity utilization to manufacturing plants. Given that the measures are largely untried, we attempt to assess the quality of the reported nonparametric measures.

Keywords: capacity utilization, nonparametric, data envelopment analysis, DEA, technical efficiency, establishment.
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I. INTRODUCTION

The measures of capacity and utilization published in the Census Bureau's Survey of Plant Capacity (U.S. Department of Commerce 1994) are the result of asking manufacturing plants to estimate maximum output assuming no constraints on the availability of inputs. Capacity utilization is taken to be the ratio of actual output to the estimated maximum output.

Since economic theory suggests that it is rare that a plant will operate at maximum output due to cost considerations, it is unlikely that respondents to the Survey of Plant Capacity (SPC) will know with a very high degree of certainty what maximum output is. Nonparametric measures of capacity and utilization developed by Fare, Grosskopf, and Kokkelenberg (1989) may be more accurate than the Census Bureau's measures in that they rely on the observed maximum plant-level output for a given level of capital. There is no guessing as to maximum output with the nonparametric measures of utilization; rather, maximum output is based on observed maximum output.

In this paper we examine the empirical relationship between plant-level responses to the SPC and nonparametric measures of plant-level utilization. Nonparametric measures of plant-level utilization are constructed for 20 four-digit Standard Industrial Classification (SIC) industries using data collected for the
Annual Survey of Manufactures (ASM) (U.S. Department of Commerce 1992). Linkage of plant-level responses to the ASM with plant-level responses to the SPC allow us to conduct a detailed analysis of the empirical relationship between the SPC and nonparametric measures of utilization.

The nonparametric measures of capacity and utilization are largely untried; this work represents the first broad-scale application of the technique to the U.S. industrial sector. In order to assess the quality of the nonparametric measures of utilization, we examine their correlation with the SPC measures at the plant level. While there are differences between the two measures, it might be expected that they are correlated to some extent. A lack of correlation, however, does not imply that the nonparametric measures are mismeasuring utilization; indeed, it may be that the Census Bureau measures are mismeasuring utilization.

It is generally thought that the level of capacity utilization at a plant, in an industry, or in an economy, is correlated with changes in capacity and in investment. High levels of utilization, indicating the need for new capacity, are thought to induce additions to capacity; one of the primary means by which a plant can expand capacity is by investing. In order to assess the relative quality of the measures, we present evidence on their correlation with changes in capacity and investment. A simple test of which of the measures better
estimates utilization is which better predicts changes in capacity and investment.

This paper is divided into three sections. The first section discusses the measurement of capacity utilization. In addition, we discuss the SPC and the relationship between conventional and nonparametric measures of capacity and utilization and measures that have been collected by the Survey.

The second section reports correlations between Census Bureau and nonparametric utilization rates for selected manufacturing industries. We also report on attempts to assess the quality of the nonparametric and Census Bureau measures of capacity by examining how well they predict investment and changes in capacity. The third section draws conclusions based on the empirical results and offers suggestions for future research.

II. MEASURING CAPACITY AND CAPACITY UTILIZATION

A. Conventional Measures of Capacity and Capacity Utilization

Capacity utilization is generally defined as the ratio of actual output to some measure of capacity for a productive unit. Measures of capacity may depend on the type of productive unit considered: whether a plant, a firm, an industry, or an economy. As this paper is concerned with measuring plant-level capacity, the following discussion will be carried out in terms of plant capacity. The discussion, however, could just as easily be
carried out in terms of firm or industry capacity. Most measures of capacity, whether at the plant level or some other level, can be grouped into one of two broad categories: engineering capacity and economic capacity.

**Engineering Capacity**

Engineering capacity is the technical capacity of a plant’s capital stock, ignoring cost considerations and the availability of other factors. It represents the maximum level of output the capital stock is technically capable of producing. There are ambiguities, however, in defining engineering capacity. For example, should the maximum output of a machine be based on operation for one shift, two shifts, or three shifts? Should allowance be made for maintenance? Should the maximum be based on operation at full speed (which may not be sustainable for long)?

Perhaps the least ambiguous application of the engineering definition is to a continuous process industry where the technical capacity of capital is relatively well defined. For example, annual lime plant (SIC 3274) capacity is based on 365 days less the average number of days for maintenance times the average 24-hour capacity of lime production (U.S. Bureau of Mines 1992). Average 24-hour capacity is largely determined by the rated capacity of the plant’s lime kilns which are operated

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There are many issues surrounding the aggregation of plant-level measures of capacity to the firm, industry, or economy level which we only briefly discuss in the following sections. Discussions of the issues surrounding the appropriate definitions of capacity at the level of a plant, firm, industry or economy can be found in Klein (1960) and Morrison (1993).
continuously due to costs of frequent shutdown and startup. Even this definition, however, will lead to two identically configured plants having different capacities if plant operators differ in skill or if the number of days required for maintenance differs across plants.

Further complications arise as engineering capacity assumes that all factors of production but capital are freely available. In fact, there are likely to be limits on the availability of other factors. For example, the availability of skilled labor may be limited in the short run. As another example, the costs of hiring and firing workers may partially fix the labor force in the short run. Furthermore, engineering capacity is likely to be a function of prices; the cost of maintaining capital may determine the number of days operation is interrupted for maintenance and, hence, in part, determine capacity.

Economic Capacity

Two economic definitions of capacity have been proposed. The first corresponds to the output at which the long-run and short-run average total cost curves are tangent. The second corresponds to the output at which the short-run average total cost curve (SRATC) reaches its minimum. The relationship between the measures depends on the degree of scale economies for the plant in question. Both definitions, however, recognize that there is an optimum output from the economic point of view that

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will, in general, differ from engineering capacity. Empirical implementation of the economic measures generally depends on the econometric estimation of a cost function.\textsuperscript{3}

Plant capacity in the economic sense is determined by the availability of inputs in the short run. Available levels of inputs may be constrained due to constraints on adjustment or due to scarcity. Unlike the engineering definition of capacity, which allows for the fixity of only capital, the economic definition allows for any combination of factors to be fixed. If capital is not the only fixed factor, then it is important to distinguish between capital utilization, the extent to which capital is utilized, and capacity utilization, the extent to which actual output falls short of or exceeds capacity output.

Economic capacity is generally less than engineering capacity. Given actual output, this implies that capacity utilization based on an economic measure of capacity will generally be greater than that based on an engineering measure. As output approaches engineering capacity, a plant may face higher marginal costs for all factors including capital. Increased variable costs such as added wear and tear on capital equipment, overtime and shift wage premiums, and limits on the ability of a fixed labor force to work extraordinary hours for a sustained period as output approaches engineering capacity.

\textsuperscript{3}See Morrison (1993) for discussion of the estimation of capacity and utilization using via the estimation of a cost function.
probably make it optimal for production to remain below engineering capacity.

**A Graphical Exposition of Engineering and Economic Capacity**

Figure 1 illustrates the relationship between the two economic measures of capacity and engineering capacity, assuming capital is the only fixed factor. The first economic measure of capacity, the point of tangency between the SRATC and the long-run average total cost (LRATC) curve, is $Q^*_{t}$; the second economic measure of capacity, the minimum of the SRATC curve is given by $Q^*_{m}$; and the engineering measure of capacity is given by $Q^*_{e}$. As drawn, $Q^*_{m} > Q^*_{t}$. The relationship between the economic measures of capacity, however, will depend on returns to scale at the tangency point. If tangency occurs on the downward sloping portion of the LRATC curve, then $Q^*_{m} > Q^*_{t}$. If tangency occurs on the upward sloping portion of the LRATC curve, then $Q^*_{m} < Q^*_{t}$. If tangency occurs at the minimum point of the LRATC curve, then $Q^*_{m} = Q^*_{t}$. The engineering measure of capacity might be thought of as an upper bound on the SRATC curve. As drawn in Figure 1, the SRATC curve approaches but does not exceed $Q^*_{e}$.4

Note that the economic measures of capacity utilization can be less than, greater than, or equal to unity. In the case of utilization based on engineering capacity, as drawn in Figure 1,

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4 Whether or not the SRATC curve extends beyond engineering capacity depends on the definition of engineering capacity used. If, for example, the engineering definition accounts for normal maintenance, the short-run averaged cost curve may extend beyond engineering capacity as normal maintenance can be deferred resulting in actual output exceeding engineering capacity. It seems reasonable to believe, however, that it is the technical capacity of capital that ultimately sets an upper bound on production.
capacity utilization will be less than one. In general, engineering utilization may be less than, greater than, or equal to unity, depending on the definition of maximum capacity used. For example, in the case of a lime plant, maintenance may be deferred during periods of high demand resulting in fewer than average days for maintenance and possibly greater-than-capacity production. So long as the level of engineering capacity exceeds the economic level of capacity, however, utilization based on economic capacity will exceed utilization based on engineering capacity.

A. A Nonparametric Measure of Capacity

Fare, Grosskopf, and Kokkelenberg (1989) develop measures of capacity and capacity utilization based on the construction of a nonparametric nonstochastic production frontier, given a fixed level of capital. Fare, Grosskopf, and Kokkelenberg (referred to hereafter as FGK) allow for a plant to be technically inefficient in the sense of Farrell (1957): plants may be operating within the production frontier. Technical inefficiency is adjusted out of the FGK measure of utilization; that is, utilization is based on maximum observed output and the level of output the plant

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5While Fare, Grosskopf and Kokkelenberg (1989) consider only the case of fixed capital, their nonparametric technique can easily be extended to consider more than one fixed factor. In addition, the technique can be extended to consider the production of more than one output. See Fare, Grosskopf, and Lovell (1994) for a detailed exposition of nonparametric techniques used in the construction of production frontiers and the measurement of efficiency.
would have produced had it not been inefficient, given a fixed capital stock.\(^6\)

Figure 2 illustrates the FGK measure of utilization in the two input, one output case assuming variable returns to scale and strong disposability of inputs.\(^7\) In Figure 2, a single homogeneous output, \(u\), is produced using a single fixed input, \(x_f\), and a single variable input, \(x_v\). For observations on three plants (points A, B, and \(j\)), given fixed capital input \(x_f\), a piecewise linear production frontier, which envelops the three plants from above, is constructed.\(^8\) Plants A and B lie on the frontier and are technically efficient; since plant \(j\) lies within the frontier, it is technically inefficient.

**Output Efficiency**

Plant \(j\) produces \(u^j\) with variable input \(x_v^j\) and fixed input \(x_f\). Given variable input \(x_v^j\), plant \(j\) could produce \(\phi(x_f, x_v^j)\) as determined by the production frontier. Farrell output efficiency is defined as the ratio of frontier output to actual output; for plant \(j\), Farrell output efficiency, \(e\), is defined as

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\(^6\)Fare, Grosskopf, and Kokkeleberg (1989) use a single output version of this measure of capacity to examine utilization among a sample of Illinois electric utilities in 1978. Fare, Grosskopf and Valdmanis (1989) use a multioutput version to compare capacity utilization and efficiency of hospitals in Michigan across different competitive environments in 1982.

\(^7\)See Fare, Grosskopf, and Lovell (1994) for a discussion of alternative assumptions regarding returns to scale and disposability.

\(^8\)This technique for constructing a production frontier's often referred to as data envelopment analysis or DEA.
KO is clearly greater than or equal to one; the greater is KO, the less technically efficient is a plant.

**FGK Capacity Utilization**

The observed maximum output, given fixed input \( x_f \), is \( \phi(x_f^j) \); this will be referred to as FGK capacity. For plant \( j \), FGK define capacity utilization, \( CU \), as

\[
CU^j = \frac{\phi(x^j)}{\phi(x_f^j)}
\]  

(2)

This will be referred to as FGK capacity utilization or simply FGK utilization. FGK utilization is the ratio of output that could be produced in the absence of inefficiency, given actual variable input, to observed maximum output, given fixed input. Note that FGK utilization, unlike the engineering and economic measures of utilization discussed above, is always less than or equal to unity.

Consider the ratio of \( \phi(x_f^j) \) to observed output, \( u^j \), i.e.,

\[
K_0(x^j, u^j) = \frac{\phi(x_f^j)}{u^j}, \quad j=1, \ldots, J
\]  

(3)

With (1) and (2), (3) implies

\[
K_0(x^j, u^j) = K_0(x_f^j, u^j) \cdot CU^j
\]  

(4)

This provides an alternative way of calculating \( CU^j \):
As noted above, $K_0$ is Farrell output efficiency based on actual variable input. $K_0$ is the Farrell output efficiency measure based on an unrestricted level of the variable input. Equation (5) serves as the basis for the capacity utilization rates reported below. The linear programming models used to calculate $K_0$ and $K_0$ are detailed in Appendix A.

**Frontier Capacity Utilization**

An alternative measure of capacity utilization, which does not adjust for inefficiency, $CU_u^j$, may be constructed as the ratio of actual output to maximum output allowing variable input to vary freely, i.e.,

$$CU_u^j = \frac{u^j}{\hat{u}(x^j)}$$

(6)

where the subscript $U$ indicates that this measure is unadjusted for technical efficiency. In order to distinguish this measure from FGK utilization, we will refer to it as frontier capacity utilization, or simply frontier utilization. Since both measures of utilization are measured relative to a nonparametric frontier, we will refer to them as nonparametric measures of utilization.

**Decomposition of FGK Utilization**

Substituting (3) and (6) into (5) yields an expression relating FGK capacity utilization, frontier utilization, and output efficiency:
Equation (7) shows that FGK utilization can be decomposed into the product of output efficiency and frontier utilization. It is clear that the greater is output efficiency, all else equal, the greater is FGK utilization. It is also clear that the greater is frontier utilization, all else equal, the greater is FGK utilization. The FGK measure of utilization allows one to identify the extent to which output falls short of capacity due to inefficiency in the use of factors of production.

Note that the frontier relative to which capacity utilization is measured is based on observed variable input and observed output in a given period. Maximum output is not determined by engineering capacity. It is not determined by the minimum of the SRATC curve; nor is it determined by tangency between the SRATC and the LRATC curve. Maximum output is observed maximum output, given fixed input. It is impossible to say, however, what the relationship between observed maximum output and the economic measures of capacity output is. As a result, it is impossible to say, a priori, what the relationship is between the FGK measure of capacity utilization and conventional economic measures of capacity utilization; whether greater than, less than, or equal to economic measures of capacity.
Shifts in the Frontier over Time

It seems likely that the position of the frontier will vary from period to period due to several factors. We discuss three factors here: technological change, the business cycle, and the misclassification of fixed and variable inputs.

As disembodied technological change occurs, a given level of inputs will yield a greater level of output; as a result, the production frontier will shift upward over time. In the case of Figure 2, if the effect of disembodied technical change is to increase the amount of output that plants A and B can produce with inputs \((x_f^A, x_v^A)\) and \((x_f^B, x_v^B)\), then the frontier will shift upward. The extent to which technological change affects plants on the frontier relative to plants inside the frontier will determine whether industry average output efficiency increases or decreases. If plants on the frontier are affected by disembodied technical change to a greater extent than plants inside the frontier, then industry average output efficiency will increase. Plants on the frontier remain there while plants inside the frontier are now further from the frontier. In Figure 2, if plants A and B find output increasing due to disembodied technical change, but plant j is unaffected by disembodied technical change, then plant j will lie further from the production frontier. That is, its Farrell output efficiency measure will have increased (indicating a decrease in technical efficiency), and the average of Farrell output efficiency
measures among the three plants will have increased (indicating a decrease in average technical efficiency).

It seems likely that the position of the frontier will vary from period to period over the business cycle. Consider a temporary increase in demand for output. A plant may temporarily find it profitable to produce beyond its ordinary output level. The plant will increase use of variable input to produce a greater level of output, given fixed input. In the case of Figure 2, plant B might increase its use of variable input to produce a greater level of output with its fixed input; i.e., the frontier aABb would shift upward. Again, industry average output efficiency will depend on how the frontier shifts relative to plants inside the frontier.

Finally, consider the case where fixed factors of production are misclassified as variable. In this case, with a decrease in production, the same level of variable input will be associated with a lower level of output, i.e., the frontier will appear to shift down. Faced with a temporary decrease in demand for output, plant B in Figure 2 will continue to employ the same level of variable input, while reducing output. This results in a downward shift in the frontier of Figure 2. Differences across plants in the "fixity" of variable inputs will determine whether industry average output efficiency increases or decreases.

A shortcoming of the FGK approach to measuring utilization is that utilization is a relative concept. It is measured relative to capacity as determined by observed maximum output for
a given level of capital. As noted here, observed maximum output, and, hence, measured utilization, may change due to factors other than the technical capacity of capital in place. Engineering capacity is, in theory, fixed; engineering utilization is measured relative to this fixed standard. The FGK approach, alternatively, measures capacity based on observed maximum capacity given a level of fixed input.

C. The Survey of Plant Capacity

The Survey of Plant Capacity (SPC), conducted by the Census Bureau since 1974, collects manufacturing plant estimates of capacity and actual output in the 4th quarter. The sample for the SPC is a subsample of the ASM, also conducted by the Census Bureau. The survey has collected a measure of capacity that appears to be a hybrid of the engineering and economic definitions of capacity outlined above. Until 1988, this measure was referred to as practical capacity; since 1988, it has been referred to as full production capacity.9

Practical Capacity

Until 1988, plants responding to the SPC were asked to provide estimates of practical capacity in the 4th quarter of the year. Practical capacity was defined as the maximum level of production that an establishment could reasonably expect to attain using a realistic employee work schedule and the machinery

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9 In addition, beginning in 1990, the Survey also attempted to account for seasonal factors in 4th quarter production by asking plants whose output varies substantially to report full-production capacity based on peak quarterly production during the year.
and equipment in place during the time periods covered by the
survey. Respondents were instructed not to consider overtime
pay, added costs for materials, or other cost increases to be
limiting factors in estimating practical capacity. The Census
Bureau did not offer a definition of a realistic work schedule;
rather, respondents were left to interpret the phrase as they saw
fit. Assuming a realistic work schedule, however defined,
imposes a constraint on capacity not imposed on engineering
definitions of capacity. Practical capacity as defined by the
Census Bureau would seem to be biased downward relative to an
engineering definition of capacity.

**Full Production Capacity**

After 1988, plants responding to the SPC were asked to
additionally assume that the number of shifts and hours of plant
operations under normal conditions was no higher than that
attained by the plant in the last five years in estimating their
practical capacity. This is referred to by the Census Bureau as
full-production capacity. Full-production capacity, then, is
biased downward relative to practical capacity, and full-
production utilization is biased upward relative to practical
utilization. Both full production and practical production are
biased downward relative to engineering capacity.

In summary, the nonparametric measures of capacity and
utilization differ sharply from the economic and engineering
measures in their theoretical structure and empirical
implementation. Economic capacity is determined by the minimum
point on the SRATC curve or the point of tangency between the SRATC curve and the LRATC curve. It is estimated in practice by estimating a cost function. Engineering capacity is determined by the technical capacity of capital in place regardless of the cost of production. It is estimated by examining the rated technical capacity of capital in place.

The FGK and SPC measures do not correspond identically with either the economic or engineering definitions of capacity, though both seem to be closer to the engineering definition as neither takes account of the cost of production. FGK capacity is determined by the observed maximum level of output given a fixed level of capital, assuming no constraints on the use of variable inputs. It is estimated in practice by the construction of a production frontier enveloping observed data on inputs and output. SPC capacity is determined by asking survey respondents to estimate maximum output based on capital in place, assuming a realistic work schedule.

III. NONPARAMETRIC ESTIMATES OF CAPACITY UTILIZATION: 1972-90

Estimates of capacity utilization were constructed for the industries listed in Table 1 for the years 1972-1990. For certain industries, redefined in the revision of the SIC classification system in 1987, estimates were made only for the years 1988-1990. The measures of inputs and output used in construction of the capacity utilization measures are described
in Table 2; further detail on their construction can be found in Appendix B.

The industries listed in Table 1 are largely involved in the production of defense-related goods and come primarily from three major industries: fabricated metal products (SIC 34), electric and electronic equipment (SIC 36), and transportation equipment (SIC 37). Also included among these industries are several for which capacity and capacity utilization are relatively well-defined concepts.

Pulp mills (SIC 2611), paper mills (SIC 2621), cement (SIC 3241), steel (SIC 3312), and aluminum (SIC 3334) are all industries for which measures of plant- and industry-level capacity and utilization are widely available. These industries are generally considered to be continuous process industries; that is, industries for which start-up costs are large enough to make stoppage of the production process infrequent. Plants in these industries generally operate 24 hours a day.

In addition, these industries are also among the most homogeneous manufacturing industries in terms of output. This serves to reduce the impact of product-mix effects on the measurement of capacity and utilization in these industries relative to other industries.

A. **Components of FGK Capacity Utilization**

Equation (7) shows that FGK utilization \( CU^j \) is the product of output efficiency \( K_0 \) and frontier utilization \( CU_0^j \). To illustrate the decomposition of FGK capacity
utilization, Table 3 presents total employment-weighted means and standard deviations of the components of FGK utilization, and Figure 3 graphs the means of the components of FGK utilization. Figure 4 graphs total employment-weighted mean FGK utilization and frontier utilization against SPC utilization.

**B. Correlation Between Utilization Measures**

**Simple Correlations**

Table 4 reports the simple correlation between plant-level capacity utilization as reported for the SPC and the two nonparametric measures of capacity utilization. Inasmuch as the Census Bureau redesigned the questions asked on the 1989 and 1990 SPC, correlations are reported for the full 1974-90 period for which FGK estimates were made, as well as for the subperiods, 1974-88 and 1989-90, during which the SPC questions were unchanged.

Examination of correlations during the full 1974-90 period shows that 16 of the 20 industries had positive correlation coefficients for both FGK and frontier utilization. Twelve of the 20 industries had correlation coefficients that were positive and significantly different from zero at the .10 level for both nonparametric measures; 9 had correlation coefficients that were positive and significantly different from zero at the .05 level. Four of the nine industries with significant coefficients at the .05 level were continuous process industries (SIC 2611, SIC 2621, SIC 3312, and SIC 3334).
The range of correlations appears to be wide: among the industries with significant correlations at the .05 level, the range for the full period 1974-90 is from .20 (SIC 3731) to .62 (SIC 3812) for FGK utilization. This suggests that industry-specific factors may be important in determining the correlation between SPC and the nonparametric measures of utilization.

Results are similar for the subperiod 1974-88 during which respondents to the SPC were asked for estimates of practical capacity. The lack of significant correlation between the SPC and FGK measures during the subperiod 1989-90 may be the result of relatively few observations.

Regression Analysis

While simple correlations are useful in examining broad correlations between plant-level measures of utilization within an industry, there may be year-specific or plant-specific factors that affect the relationship between the measures. For example, it was noted that the position of the production frontier relative to which FGK and frontier utilization is measured may shift with the business cycle. Year-to-year changes in demand within an industry will affect industry output and possibly the position of the deterministic frontier. As an example of a plant-specific effect, it may be that a particular plant produces products with a demand such that significant excess capacity needs to be maintained. In the absence of a multiproduct measure of utilization, such a plant may have a lower than average measured utilization rate. In order to account for such year-
and plant-specific effects, simple regression equations were estimated which controlled for these effects. Table 5 reports results from the estimation of such equations by industry.

Table 5 reports coefficient estimates and t-ratios for the coefficient on either FGK utilization or frontier utilization in an estimated equation which controlled for year- and plant-specific effects. In addition, overall $R^2$ for each equation is reported. For 9 of the 17 industries for which equations were estimated, the coefficient on FGK utilization is significant at the .05 level. For 13 of the 17 industries, the coefficient on frontier utilization is significant at the .05 level.

Recall that FGK utilization adjusts out inefficiency in the use of variable inputs. It decomposes shortfalls in output into that part due to inefficiency, and that part due to failure to use all inputs needed to reach capacity. Frontier utilization makes no such adjustment. It may be that respondents to the SPC failed to make any such adjustment for inefficiency; this is consistent with frontier utilization being more highly correlated with SPC utilization than FGK utilization as reported.

C. Assessment of the Relative Quality of Utilization Measures

This section presents the results of two tests of the relative quality of the SPC and FGK measures of capacity.

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10 The equations estimated were of the form

$$ u_{SPC}^{t} = \alpha + \beta u_{J}^{t} + \sum_{i=4}^{n} \gamma_{1,i} d_{i}^{t} + \sum_{j=1}^{n} \gamma_{2,j} d_{p}^{t} $$

where $u_{SPC}^{t}$ is the log of practical utilization from the SPC, $u_{J}^{t}$ is the log of either FGK or frontier utilization, $d_{i}^{t}$ is a year dummy, and $d_{p}^{t}$ is a plant dummy. The t-ratios reported in Table 5 are for the estimate of $\beta$. 

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utilization. Both the SPC and nonparametric measures of utilization are only estimates of utilization. We would ideally like to know what actual utilization is at each of the plants in our sample so as to judge which of SPC or nonparametric measures of utilization comes closer to measuring, or is more highly correlated with, actual utilization. Given that we do not know true utilization, some other means of judging which of the measures is likely to be closer to, or more highly correlated with, true utilization is needed. We turn here to the expected relationships between utilization and capacity, and utilization and investment.

High utilization rates should lead, other things equal, to plants adding to capacity. High utilization rates should also lead, other things equal, to plants investing more so as to expand capacity. The two tests presented here examine how well the measures of utilization predict 1) changes in plant-level capacity, and 2) plant-level investment. Should the expected relationship between utilization and capacity and investment not hold for any of the measures, we would have reason to question their accuracy.

Utilization and Changes in Capacity

Table 6 reports how well the measures of utilization fared in predicting their own capacity growth rates. The FGK measures of utilization produce an estimate of maximum output given the

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11 These tests are similar to those applied by Perry (1973) in assessing the usefulness of three industry-level indexes of utilization.
level of capital in place and assuming no limit on the availability of other inputs. The SPC asks respondents for the maximum output they could produce using machinery and equipment in place and assuming no limit on the availability of other inputs. Each measure of capacity was used as a dependent variable in a regression equation in which the appropriate utilization rate, lagged one year, and the change in output, lagged one year, appeared as explanatory variables. High utilization rates should, other things equal, lead plants to add to their capacity. The change in output, lagged one year, is included as a way of capturing expected future changes in output.\(^\text{12}\)

As shown in Table 6, the FGK measures of utilization seem to perform better in explaining changes in capacity than does SPC practical capacity utilization based on the estimated equations. While the SPC utilization rate has a t-ratio of greater than 2 in

\[^{12}\text{The capacity equation estimated was}\]

\[c_{t} - c_{t-1} = \alpha + \beta u_{t-1} + \gamma (q_{t-1} - q_{t-2})\]

where \(c\) is the log of capacity, \(u\) is the log of capacity utilization (either SPC, FGK, or frontier utilization), and \(q\) is the log of output. This equation was estimated separately for each of the 4-digit industries listed in Table 5 for all observations available during 1974-88.

In the case of the SPC practical utilization equation, \(c\) was the log of practical capacity, \(u\) was the log of practical utilization, and \(q\) was the log of current dollar annual shipments adjusted for changes in inventories and converted to constant dollars by a 4-digit industry shipments deflator.

In the case of the FGK equation, \(c\) was the log of maximum output as determined by the frontier, \(u\) was the log of FGK utilization, and \(q\) was the log of deflated current dollar annual shipments as in the SPC equation.

In the case of the frontier equation, \(c\) was the log of maximum output as determined by the frontier as in the FGK equation, \(u\) was the log of frontier utilization, and \(q\) was the log of deflated current dollar annual shipments as in the SPC and FGK equations.
8 of the 16 industries, both the FGK and frontier rates have t-ratios greater than 2 in 11 of the 16 industries.

Utilization and Investment

Another simple test of the utilization measures is their ability to predict investment. Investment is one of the primary means by which a plant can expand capacity; hence it is expected that the greater is capacity utilization, the greater will be investment so as to expand capacity. Lagged values of each of the measures were used as independent variables in an equation explaining investment. Table 7 reports how well the measures fared in such a test.

All three measures of utilization perform poorly when used to explain investment: fewer than half of the equations estimated have utilization rates that are jointly significant. The FGK and frontier utilization measures perform only slightly better in the sense that 6 industries have coefficients on lagged utilization that are jointly significant at the .05 level, while only 5 industries have jointly significant coefficients on lagged utilization when SPC utilization is used.

---

13 The investment equation estimated was

\[(v_{i,t-k}, k_{i,t}) = c + \beta_1 u_{i,t-1} + \beta_2 u_{i,t-2}\]

where \(v\) is the log of current dollar investment in building and capital converted to constant dollars by an industry new investment deflator, \(k\) is the log of the real capital stock, and \(u\) is the log of utilization rate.

When a third lag of utilization was included, the coefficient on it was negative for at least half the industries; hence it was decided to limit the equation to two lags.

14 When three lags of utilization were included, a similar pattern in the joint significance of the utilization rates resulted: 3 industries had jointly significant utilization rates at the .05 level when SPC utilization was used, 5 industries had jointly significant utilization rates when FGK utilization was used, and 4 industries had jointly significant utilization rates when
IV. CONCLUSION

The SPC and nonparametric measures of utilization appear to be most highly correlated for those industries with relatively well-defined notions of capacity producing a relatively homogeneous output: SPC utilization rates for pulp mills (SIC 2611), paper mills (SIC 2621), steel (SIC 3312), aluminum (SIC 3334), and motor vehicles (SIC 3711) were all significantly correlated with nonparametric utilization rates as reported in Tables 4 and 5.

A lack of correlation between the nonparametric and SPC measures of utilization should not necessarily be interpreted as due to the inadequacy of the nonparametric measures; lack of correlation may also be due to the inadequacy of the SPC measures. The simple tests of the quality of the nonparametric and SPC measures of utilization showed the nonparametric measures to perform at least as well as the SPC measure in predicting investment and changes in capacity at the plant level. Based on these tests, it appears that the nonparametric measures perform at least as well as the SPC measures of utilization. Thus, the nonparametric plant-level measures of utilization may represent a reasonable alternative to the plant-level SPC estimates.

There are two possible advantages to using the nonparametric measures of utilization relative to the SPC measures. First, since the ASM is conducted annually and the SPC is conducted only biennially, it is possible to annually construct plant-level frontier utilization was used.
nonparametric estimates based on the ASM. Second, the SPC is based on a subsample of the ASM. As a result, smaller plants are dropped from the ASM sample to construct the SPC subsample. If smaller plants tend to add capacity over time, the use of the ASM sample to construct nonparametric measures of utilization may be helpful in understanding the evolution of industry capacity.

One important topic for future research concerns the stability of the production frontier over time. While the possible instability of the nonparametric frontier over time was discussed above, we did not attempt to account for instability in our implementation of the nonparametric measures or in our tests of the relative quality of the nonparametric and Census Bureau measures of utilization. It clearly would be desirable to know to what extent the position of the frontier was affected by factors such as technological change, the business cycle, and mismeasurement of inputs.

Another important topic for future research concerns the impact of product mix on the position of the frontier. The measure of plant-level output used in computation of nonparametric utilization was simply value of shipments adjusted for changes in inventories deflated by an industry shipments deflator. As a result, it may simply be that the frontier is determined by those plants producing relatively highly valued output. Whether or not a plant lies on or near the frontier may, in turn, be a function of its product mix rather than the extent to which its capital is utilized.
The nonparametric measures of utilization are highly flexible in the sense that they can accommodate multiproduct output and a variety of assumptions on returns to scale and the disposability of inputs. Further work, allowing for multiproduct estimation under alternative assumptions regarding these factors, might result in more accurate nonparametric measures of utilization.
<table>
<thead>
<tr>
<th>SIC</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2611R</td>
<td>Pulp mills</td>
</tr>
<tr>
<td>2621R</td>
<td>Paper mills</td>
</tr>
<tr>
<td>2821</td>
<td>Plastics materials and resins</td>
</tr>
<tr>
<td>3241</td>
<td>Cement, hydraulic</td>
</tr>
<tr>
<td>3312</td>
<td>Blast furnaces and steel mills</td>
</tr>
<tr>
<td>3334</td>
<td>Primary aluminum</td>
</tr>
<tr>
<td>3482</td>
<td>Small arms ammunition</td>
</tr>
<tr>
<td>3483</td>
<td>Ammunition, not elsewhere classified (n.e.c.)</td>
</tr>
<tr>
<td>3484</td>
<td>Small arms</td>
</tr>
<tr>
<td>3489</td>
<td>Ordnance and accessories, n.e.c.</td>
</tr>
<tr>
<td>3661R</td>
<td>Telephone and telegraph apparatus</td>
</tr>
<tr>
<td>3663*</td>
<td>Radio and TV communications equipment</td>
</tr>
<tr>
<td>3669*</td>
<td>Communications equipment, n.e.c.</td>
</tr>
<tr>
<td>3711</td>
<td>Motor vehicles and passenger car bodies</td>
</tr>
<tr>
<td>3724</td>
<td>Aircraft engines and engine parts</td>
</tr>
<tr>
<td>3728R</td>
<td>Aircraft parts and auxiliary equipment</td>
</tr>
<tr>
<td>3731</td>
<td>Ship building and repairing</td>
</tr>
<tr>
<td>3764</td>
<td>Space propulsion units and parts</td>
</tr>
<tr>
<td>3795</td>
<td>Tanks and tank components</td>
</tr>
<tr>
<td>3812*</td>
<td>Search, detection, navigations, guidance, aeronautical instruments</td>
</tr>
</tbody>
</table>

Notes: * Estimates constructed for 1988-90 only.

Table 2
Measures of Inputs and Output Used in Calculation of Nonparametric Capacity Utilization

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description*</th>
</tr>
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<tbody>
<tr>
<td>Capital</td>
<td>Real capital stock constructed using perpetual inventory method.</td>
</tr>
<tr>
<td>Labor</td>
<td>Production worker hours for year.</td>
</tr>
<tr>
<td>Energy</td>
<td>Sum of current dollar expenditures on purchased electricity and fuels for year, deflated by the 4-digit industry energy deflator.</td>
</tr>
<tr>
<td>Materials</td>
<td>Current dollar expenditures on materials for year adjusted for changes in inventories, deflated by the 4-digit industry materials deflator.</td>
</tr>
<tr>
<td>Output</td>
<td>Value of shipments adjusted for changes in finished goods and work in progress inventories for year, deflated by the 4-digit industry shipments deflator.</td>
</tr>
</tbody>
</table>

* See Appendix B for details.
Table 3
Components of FGK Utilization, SIC 3334

<table>
<thead>
<tr>
<th>Year</th>
<th>Industry Aggregate</th>
<th>SPC Capacity Utilization</th>
<th>FGK Capacity Utilization</th>
<th>Output Efficiency</th>
<th>Frontier Capacity Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean (Std)</td>
<td>Mean (Std)</td>
<td>Mean (Std)</td>
<td>Mean (Std)</td>
</tr>
<tr>
<td>72</td>
<td>25</td>
<td>0.82 (0.20)</td>
<td>1.25 (0.28)</td>
<td>0.68 (0.23)</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>31</td>
<td>0.88 (0.15)</td>
<td>1.38 (0.37)</td>
<td>0.69 (0.23)</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>27</td>
<td>0.83 (0.17)</td>
<td>1.31 (0.36)</td>
<td>0.68 (0.23)</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>30</td>
<td>0.81 (0.20)</td>
<td>1.41 (0.38)</td>
<td>0.63 (0.26)</td>
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</tr>
<tr>
<td>76</td>
<td>31</td>
<td>0.73 (0.22)</td>
<td>1.40 (1.85)</td>
<td>0.66 (0.25)</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>30</td>
<td>0.89 (0.13)</td>
<td>1.37 (0.35)</td>
<td>0.70 (0.22)</td>
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<tr>
<td>78</td>
<td>30</td>
<td>0.86 (0.18)</td>
<td>1.20 (0.29)</td>
<td>0.76 (0.23)</td>
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<tr>
<td>79</td>
<td>28</td>
<td>0.81 (0.19)</td>
<td>1.28 (0.36)</td>
<td>0.67 (0.23)</td>
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<td>0.62 (0.23)</td>
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<tr>
<td>81</td>
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<td>1.31 (0.34)</td>
<td>0.63 (0.23)</td>
<td></td>
</tr>
<tr>
<td>82</td>
<td>26</td>
<td>0.78 (0.18)</td>
<td>1.27 (0.33)</td>
<td>0.66 (0.23)</td>
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</tr>
<tr>
<td>83</td>
<td>25</td>
<td>0.77 (0.20)</td>
<td>1.17 (0.26)</td>
<td>0.69 (0.24)</td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>22</td>
<td>0.79 (0.23)</td>
<td>1.06 (0.11)</td>
<td>0.76 (0.23)</td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>26</td>
<td>0.73 (0.18)</td>
<td>1.27 (0.31)</td>
<td>0.62 (0.25)</td>
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</tr>
<tr>
<td>86</td>
<td>24</td>
<td>0.73 (0.23)</td>
<td>1.08 (0.12)</td>
<td>0.69 (0.26)</td>
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<tr>
<td>87</td>
<td>23</td>
<td>0.80 (0.21)</td>
<td>1.09 (0.13)</td>
<td>0.76 (0.23)</td>
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</tr>
<tr>
<td>88</td>
<td>21</td>
<td>0.70 (0.23)</td>
<td>1.16 (0.31)</td>
<td>0.64 (0.25)</td>
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</tr>
<tr>
<td>89</td>
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<td>0.76 (0.20)</td>
<td>1.10 (0.15)</td>
<td>0.71 (0.23)</td>
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<tr>
<td>90</td>
<td>20</td>
<td>0.76 (0.22)</td>
<td>1.20 (0.25)</td>
<td>0.67 (0.25)</td>
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</table>

Note: Means and standard deviations are total-employment weighted.
### Table 4

**Pearson Correlation Between SPC and Nonparametric Measures of Capacity Utilization**

<table>
<thead>
<tr>
<th>SIC</th>
<th>1974-90</th>
<th>1974-88</th>
<th>1989-90</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N FGK Frontier</td>
<td>N FGK Frontier</td>
<td>N FGK Frontier</td>
</tr>
<tr>
<td>2611</td>
<td>183 0.45***</td>
<td>0.44***</td>
<td>151 0.68***</td>
</tr>
<tr>
<td>2621</td>
<td>1148 0.18***</td>
<td>0.21***</td>
<td>1093 0.18***</td>
</tr>
<tr>
<td>2821</td>
<td>587 0.07*</td>
<td>0.09**</td>
<td>532 0.11***</td>
</tr>
<tr>
<td>3241</td>
<td>435 -0.01</td>
<td>0.05</td>
<td>387 -0.00</td>
</tr>
<tr>
<td>3312</td>
<td>1233 0.22***</td>
<td>0.25***</td>
<td>1201 0.22***</td>
</tr>
<tr>
<td>3334</td>
<td>270 0.44***</td>
<td>0.38***</td>
<td>246 0.46***</td>
</tr>
<tr>
<td>3482</td>
<td>68 0.50***</td>
<td>0.49***</td>
<td>58 0.50***</td>
</tr>
<tr>
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<td>120 0.04</td>
<td>0.07</td>
<td>110 0.02</td>
</tr>
<tr>
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<td>120 0.15*</td>
<td>0.26***</td>
<td>99 0.13</td>
</tr>
<tr>
<td>3489</td>
<td>46 0.31**</td>
<td>0.31**</td>
<td>45 0.30**</td>
</tr>
<tr>
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<td>0.21</td>
<td>340 0.13</td>
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<td>40 0.15</td>
<td>0.20</td>
<td>1 -</td>
</tr>
<tr>
<td>3669</td>
<td>24 -0.07</td>
<td>-0.06</td>
<td>0 -</td>
</tr>
<tr>
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<td>840 0.36***</td>
<td>0.32***</td>
<td>803 0.37***</td>
</tr>
<tr>
<td>3724</td>
<td>273 -0.03</td>
<td>-0.02</td>
<td>255 -0.02</td>
</tr>
<tr>
<td>3728</td>
<td>335 -0.02</td>
<td>-0.02</td>
<td>305 0.06</td>
</tr>
<tr>
<td>3731</td>
<td>351 0.24***</td>
<td>0.25***</td>
<td>339 0.25***</td>
</tr>
<tr>
<td>3764</td>
<td>125 0.10</td>
<td>0.13</td>
<td>110 0.01</td>
</tr>
<tr>
<td>3795</td>
<td>54 0.23*</td>
<td>0.27**</td>
<td>49 0.16</td>
</tr>
<tr>
<td>3812</td>
<td>40 0.62***</td>
<td>0.50***</td>
<td>2 -</td>
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</table>

**Notes:**
- *** Significant at .01 level.
- ** Significant at .05 level.
- * Significant at .10 level.
Table 5
Regression of SPC Practical Utilization on FGK and Frontier Utilization, 1974-88

<table>
<thead>
<tr>
<th>SIC</th>
<th>N</th>
<th>FGK Utilization</th>
<th>Frontier Utilization</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Parameter estimate</td>
<td>t-ratio</td>
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<td>1093</td>
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<td>2.60</td>
</tr>
<tr>
<td>2821</td>
<td>532</td>
<td>0.15</td>
<td>2.95</td>
</tr>
<tr>
<td>3241</td>
<td>387</td>
<td>0.01</td>
<td>0.14</td>
</tr>
<tr>
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<td>1201</td>
<td>0.27</td>
<td>7.68</td>
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<td>3334</td>
<td>246</td>
<td>0.63</td>
<td>8.83</td>
</tr>
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<td>3482</td>
<td>58</td>
<td>0.40</td>
<td>1.95</td>
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<td>3483</td>
<td>110</td>
<td>0.11</td>
<td>0.96</td>
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<td>0.94</td>
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<td>0.03</td>
<td>0.45</td>
</tr>
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<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>-</td>
<td>-</td>
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<td>805</td>
<td>0.52</td>
<td>6.12</td>
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<td>255</td>
<td>0.13</td>
<td>1.69</td>
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<td>3728</td>
<td>303</td>
<td>0.17</td>
<td>2.27</td>
</tr>
<tr>
<td>3731</td>
<td>340</td>
<td>0.30</td>
<td>2.49</td>
</tr>
<tr>
<td>3764</td>
<td>110</td>
<td>0.21</td>
<td>1.99</td>
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<td>0.29</td>
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</tbody>
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Notes: All regressions included plant and year dummies.
### Table 6
Capacity Growth as Explained by Own Capacity Utilization Rates

<table>
<thead>
<tr>
<th>SIC</th>
<th>N</th>
<th>t-ratio of Utilization Rate Variable in Capacity Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SPC Practical Utilization</td>
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<td>0.59</td>
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<td>832</td>
<td>1.63</td>
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<tr>
<td>2821</td>
<td>351</td>
<td>2.84</td>
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<tr>
<td>3241</td>
<td>267</td>
<td>4.39</td>
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<td>926</td>
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<td>186</td>
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<td>3764</td>
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<td>4.17</td>
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<tr>
<td>3795</td>
<td>22</td>
<td>0.34</td>
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</table>
Table 7  
Investment as Explained by Own Capacity Utilization Rates

<table>
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<tr>
<th>SIC</th>
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<th>$U_{t-2}$</th>
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<th>$U_{t-1}$</th>
<th>$U_{t-2}$</th>
<th>$F$</th>
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<td>8.6***</td>
<td>1.42</td>
<td>0.64</td>
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<td>8.0***</td>
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<td>0.23</td>
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<td>1.34</td>
<td>4.0***</td>
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Notes: $F$ is $F$-test of joint significance of $U_{t-1}$ and $U_{t-2}$.
* Significant at .10 level.
** Significant at .05 level.
*** Significant at .01 level.
Figure 1
Economic and Engineering Capacity

$\text{LRATC}$

$\text{SRATC}$

$Q_t^*$ $Q_m^*$ $Q_e^*$
Figure 2
Nonparametric Capacity and Utilization

CU^j = Φ [x_f^j, x_v^j] / Φ [x_f^j]
K_0 = Φ [x_f^j, x_v^j] / u^j
K_0 = \hat{Φ} [x_f^j] / u^j
Figure 3
Components of FGK Capacity Utilization, Primary Aluminum
(SIC 3334)
Figure 4
Nonparametric and SPC Utilization, Primary Aluminum (SIC 3334)
APPENDIX A. LINEAR PROGRAMMING MODEL

The measures of capacity and capacity utilization were constructed using solutions to the linear programming problems formulated by Färe, Grosskopf and Valdmanis (1989).

Assume there are \( j = 1, \ldots, J \) plants producing a single output \( u^j \) using inputs \( x^j \in \mathbb{R}^N_+ \). Assume further that the input vectors \( x^j \) consist of two subvectors, the fixed factors \( x^j_f \) and the variable factors \( x^j_v \). For plant \( j \), the Farrell output measure of technical efficiency, \( K_0 \), assuming variable returns to scale and strong disposability of inputs, is calculated by solving the linear programming problem

\[
K_0 (x^j, u^j) = \max_{z, \theta} \theta \\
\text{s.t.} \quad \sum_{j=1}^{J} z^j u^j \geq \theta u^j \\
\quad \sum_{j=1}^{J} z^j x_{2n}^j \leq x_{2n}^j, n = 1, \ldots, N \\
\quad \sum_{j=1}^{J} z^j = 1 \\
\quad z = (z^1, \ldots, z^J, \ldots, z^J)
\]

(A.1)

Where \( z \) is the intensity vector that determines the weights with which a given observation of the reference technology is used to determine the maximal \( \theta \).

Following Johansen's (1968) definition of plant capacity, there are no restrictions on the availability of variable factors. This is incorporated by dropping the constraints on variable factors. The Farrell output measure of technical efficiency where variable factors do not restrict output, \( K_0 \),
under variable returns to scale and strong disposability of inputs, is calculated by solving the linear programming problem

\[
R^j(x_i^j, u^j) = \max_{z, \theta} \theta \quad \text{s.t.} \quad \sum_{j=1}^{J} z^j u^j \geq \theta u^j \\
\sum_{j=1}^{J} z^j x_{i^j}^j \leq x_i^j, \quad i = 1, \ldots, I \\
\sum_{j=1}^{J} z^j = 1 \\
z = (z^1, \ldots, z^j, \ldots, z^J)
\]

(Solving (A.1) and (A.2) allows one to calculate capacity utilization, \(CU^j\), using (5). Knowledge of the level of output and the solutions to (A.1) and (A.2) allows one to calculate unadjusted capacity utilization, \(CU_0^j\), using (3) and (6).

Solving (A.2) allows one to calculate optimal input usage using the solution vector of \(z^j\)'s. Denoting the solution vector \(z^*\), optimal input usage of variable input \(i\) is given by

\[
\xi^j_{vi} = \sum_{j=1}^{J} z^* x_{i^j vi}, \quad i = I+1, \ldots, N
\]

Variable input utilization is given by

\[
MV^j_{vi} = x_{i^j vi} / \xi^j_{vi}
\]
APPENDIX B. DATA

Data Sources

The data for this work is drawn from the Longitudinal Research Database (LRD) maintained at the Center for Economic Studies, U.S. Bureau of the Census. McGuckin (1990) describes the LRD and research using the LRD. Among many other variables, the LRD contains current dollar figures on shipments, labor, materials, energy, plant, equipment, asset rentals and inventories for manufacturing plants that were included in the Annual Survey of Manufactures (ASM) in the years 1972-90, and for plants that were included in the Census of Manufactures (CM) for the years 1963, 1967, 1972, 1977, 1982 and 1987.

As the LRD contains current dollar figures, it was necessary for parts of the analysis to deflate the current dollar figures. Investment, materials, and energy deflators at the four-digit SIC level were taken from the PCS productivity database maintained by Eric Bartlesman for the National Bureau of Economic Research (Gray 1989).

In the construction of real capital stock series, the costs of rented equipment and building were capitalized using rental prices at the two-digit SIC level taken from the Capital Stocks Database maintained by the Bureau of Economic Analysis (BEA), Department of Commerce. The BEA uses the formula for user cost of capital derived in Hall and Jorgenson (1967) to construct rental prices. Detail is provided in U.S. Department of Labor (1983).
Variable construction

This section describes the construction, from the aforementioned sources, of the variables used in the construction of the nonparametric measures of capacity and utilization. Calculation of the nonparametric measures required measures of capital, labor, energy and materials input.

Capital

A real capital stock series for each plant was constructed using the perpetual inventory method. For real capital stock $K_t$, the perpetual inventory method uses the formula

$$K_{t+1} = (1-\delta)K_t + I_t$$  \hspace{1cm} (A.1)

where $\delta$ is the rate of depreciation and $I$ is investment in new capital. A real capital stock series was constructed for both building and machinery assets; the series were added to produce a measure of total capital stock.

In order to use the perpetual inventory method, an initial value for the real capital stock had to be constructed from the plant-level historical cost book value of capital in the LRD. The method used follows Olley and Pakes (1992). The choice of a starting value depended on the information available for a given plant.

Plants first appearing in the LRD in an ASM year were assumed to be new plants in their first year of operation. Thus it was assumed that all of the book value of assets at the beginning of the period had been installed in the previous year. The starting value of real capital stock was simply book value at
the start of the period deflated by the PAS four-digit new investment deflator.

For plants first appearing in the LRD in CM years, it could not be assumed that their first appearance was their first year of operation since such plants could have begun operation at any time between the prior CM and the CM of their appearance. As a result, two estimates of the real capital stock were made for plants appearing for the first time in CM years after 1967: 1) assuming all assets had been put in place in the year prior to the CM of first appearance, and 2) assuming all assets had been put in place in the year of the prior CM. The starting value was taken to be the simple average of the two estimates.

As an example, consider a plant first appearing in the CM year 1972. The first estimate of the real capital stock at the start of the year 1972, \( K_{72}^{(1)} \), was simply the historical book value of capital at the start of 1972 (i.e., the historical book value of capital at the end of 1971), \( BVE_{71} \), deflated by the PAS new investment deflator for 1971, \( PI\text{INV}_{71} \). The first estimate of the capital stock was calculated as

\[
K_{72}^{(1)} = \frac{BVE_{71}}{PI\text{INV}_{71}}
\]

The second estimate of the real capital stock at the start of the year 1972, \( K_{72}^{(2)} \), was the historical book value of capital at the start of 1972, \( BVE_{71} \), deflated by the PAS new investment deflator for 1967, \( PI\text{INV}_{67} \), depreciated forward to 1972. The second estimate of the capital stock was calculated as
\[ K^{(2)}_{72} = \frac{BVE_{71}}{PINV_{67}} \cdot (1 - \delta)^4 \] (B.3)

The starting value of the real capital stock, \( K_{72} \), was simply the arithmetic average of the two estimates,

\[ K_{72} = \frac{[K_{72}^{(1)} + K_{72}^{(2)}]}{2} \] (B.4)

For plants first appearing in the LRD in either of the CM years 1963 or 1967, and still in operation in 1972, two estimates of the real capital stock were again made: 1) assuming all assets had been put in place in either 1963 or 1967, depending on the CM of first appearance, and 2) assuming all assets had been put in place in 1971. The starting value was taken to be the arithmetic average of these two estimates.

Given starting values for the capital stock, \( K_t \), the previous year purchases of new and used assets, \( NK_t \) and \( UK_t \), were deflated by the PAS new investment deflator and added to the capitalized value of asset rentals and the depreciated capital stock of the previous year. The capitalized value of asset rentals, \( KR_t \), was calculated by dividing current period asset rentals, \( AR_t \), by current period rental price of capital, \( KRR_t \). Thus, the current period real capital stock was calculated as

\[ K_t = K_{t-1} \cdot (1 - \delta) + \frac{(NK_{t-1} + UK_{t-1})}{PINV_{t-1}} + \frac{KR_t}{KRR_t} \] (B.5)

Due to changing samples, not all plants are in the LRD continuously. This meant that there were gaps in the investment data for plants that initially appeared in the LRD but later were
dropped from the ASM sample only to reappear as part of a new ASM sample or in a CM year. When gaps in the investment data were encountered, they were filled in by averaging real investment just before the gap began and real investment just after the gap ended.

Depreciation rates for each of the four-digit industries examined were constructed using BEA physical depreciation rates for various categories of capital assets in 1974 for all manufacturing industries as reported in Table A.1 of Hulten and Wykoff (1981). An expenditure-share-weighted average of the BEA rates was constructed using the 1977 expenditure shares from the input-output tables of the Survey of Current Business, November 1985, for each of the four-digit industries.\(^{15}\)

**Labor**

The labor variable used was production worker hours from the LRD.

**Energy**

The energy variable used was the sum of the cost of purchased electricity and purchased fuels from the LRD, deflated by the PAS energy deflator.

\(^{15}\)We experimented with the use of historical book value of capital in the construction of the nonparametric measures of utilization. We found, however, that plant-level nonparametric utilization was strongly positively correlated with plant age. This suggested that inflation in the price of new capital goods led to an overstatement of the productive capacity in new plants as measured by book valué. Hence, it was decided to construct a real capital stock series for each plant in the sample. See Niefer et al. (1994).
Materials

The materials variable used was current dollar expenditures on materials for the year, adjusted for changes in inventories, taken from the LRD and deflated by the PCS materials deflator.

Output

The output variable used was total value of shipments, adjusted for changes in finished-goods and work-in-progress inventories, taken from the LRD and deflated by the PCS shipments deflator.

Data Editing

Given the number of industries examined in this report, time constraints prevented a detailed screening of the data for outliers. Instead, a simple routine was followed in editing the data for all industries and all years. First, measures of inputs and output were constructed. Any plants with one or more measures of inputs or output equal to zero were deleted from the dataset. Second, plants assigned a weight of zero by the Census Bureau in the construction of industry aggregates were deleted from the dataset. The Census Bureau will assign a zero weight to plants returning unreliable ASM questionnaires; deleting plants with a zero weight eliminates this unreliable data. Third, after deleting plants with zero values for inputs or output and after deleting plants with zero ASM weights, the Andrews and Pregibon (1978) statistic for detecting influential outliers was applied to the data on inputs and output for each industry and year.
Plants in the fifth percentile of the distribution of Andrews and Pregibon statistics were deleted from the dataset.\footnote{We experimented with other data editing routines but found that use of the Andrews and Pregibon statistic was the easiest to use in picking up those establishments likely to exert a strong influence on the position of the frontier. See Niefer et al. (1994).}
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