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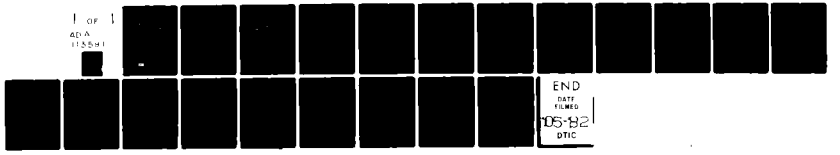

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AN EMPIRICAL STUDY OF PRODUCTION INEFFICIENCY IN THE PRESENCE OF ERRORS-IN-THE-VARIABLES

James Jondrow
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ABSTRACT

The concept of a frontier production has been attacked on the grounds that mismeasurement of output makes it impossible to separate efficient from inefficient firms, i.e., what looks like inefficiency may actually be mismeasurement of output. In this paper, we illustrate one method for estimating a frontier production relation when output is poorly measured--leading to errors-in-the-variables. The technique, based on Goldberger's ~~(1974)~~ factor analysis model, is meant to avoid not only spurious findings of inefficiency but also an overestimate of scale economies. Our empirical example involves a military application: U.S. Naval Bases. In this example, our taking account of the errors-in-variable problem does not decrease the indicator of average inefficiency. It does, however, substantially reduce the measured economies of scale.

I. INTRODUCTION

A controversial feature of frontier production models is that some firms are labeled "inefficient." The controversy centers on the source, nature, and even the existence of the inefficiency. Liebenstein (1966) argues that some firms operate below their own frontier and uses the phrase X-efficiency to mean less-than-efficient operation. Aigner, Lovell, and Schmidt (1977) write of technical efficiency in much the same way. Stigler (1976) and Maddala and Fishe (1979) argue that there is no such thing as inefficiency; what looks like inefficiency is actually the result of unmeasured differences in the capacity of different entrepreneurs, the taste for leisure, etc.

In econometric terms, the Stigler argument is that what is usually called inefficiency is actually the result of errors-in-variables. Inputs and outputs are measured poorly. Errors-in-variables could create two problems: (1) a biased estimate of the degree of inefficiency, (2) a spurious finding of scale economies. To see (2), suppose that production technology is summarized with a cost curve. Errors in measuring output will bias downward the measured effect of output on cost and, hence, bias upward the measured economies of scale.

In this paper, we apply Goldberger's (1974) technique for reducing errors-in-variables and examine the effect on the measured degree of efficiency and the measured economies of scale. The data are drawn from a military application: costs, and "outputs" for a large cross-section

of U.S. Navy bases. Both efficiency and economies-of-scale are of major interest to the Navy. Measured efficiency of different bases is an aid in cost control; economies-of-scale are one (of many) considerations in base consolidation.

II. A FRONTIER COST CURVE AND ERRORS-IN-VARIABLES

Consider a log-linear multiple-output cost equation of the form

$$c = \alpha + YB + \varepsilon \qquad (3)$$

where c is a $N \times 1$ vector of the natural log of costs at different cross-sectional units, Y is a $N \times L$ matrix of outputs (each measured in logarithmic terms) and ε is a $N \times 1$ vector of error terms. Variation in input prices was suppressed because all measures are at the same point in time. The error term ε is composed of two parts, (1) the type of random noise usually termed statistical error (v_i) and (2) inefficiency (u_i). The inefficiency error includes technical inefficiency (deviation from the production function) and allocative inefficiency (inappropriate response to factor prices).

In addition to the two components of ε, there are errors-in-the-variables. What the researches have on hand is not really Y, but rather $X = Y + W$, where W is an $N \times L$ matrix of disturbances.

There is standard advice on how to handle errors-in-variables: to replace the OLS estimator of B

$$\hat{B} = (X'X)^{-1}X'c$$

with

$$\bar{B} = [X'X - \hat{E}(WW')]X'c \ .$$

For example, see Theil (1971, pp. 610). An obvious alternative is to use

$$B^* = (\hat{Y}'\hat{Y})^{-1} Yc$$

where $\hat{Y} = X - \hat{W}$. Both alternatives have remained useless: There has been no way to estimate $\hat{E}(WW')$ or $\hat{W}$.

Factor Analysis

Under specified assumptions, factor analysis can be used to make the necessary estimate of $\hat{W}$. This is the essence of Goldberger's (1974) multiple indicators model.* In the context of our problem,

* It has long been recognized that the errors-in-variables problem can be reduced by averaging. One interpretation of the multiple indicators model is as a means of putting different explanatory variables in comparable units--so they can be averaged.

Goldberger's model can be written as equations (4) to (7).

$$c = \alpha + YB + \varepsilon \tag{4}$$

$$X = Y + W \tag{5}$$

$$Y = F\Lambda \tag{6}$$

so

$$X = F\Lambda + W \tag{7}$$

$$E(FW') = 0 \quad E(WW') = \Psi \text{ diagonal}$$

where X is an $N \times K$ matrix of indicators, Λ is an $L \times K$ matrix of factor loadings, and W is an $N \times K$ matrix of error terms.

In our application, we will assume that the many dimensions of output can be represented by three latent variables, distilled from 15 potential indicators. We investigate two strategies for estimating the three latent variables: (1) to choose three of the indicators and enter them as explanatory variables in an OLS regression and (2) to extract three factors from the 15 indicators and enter them in a regression as explanatory variables. Strategy (1) makes no correction for errors-in-variables; strategy (2) does make the correction.

Using the factors themselves involves a well-known indeterminacy, usually associated with factor "rotation." As Goldberger (1978) notes, the product $F\Lambda$ can also be written $[FH][H^{-1}\Lambda]$. Thus, if F is a matrix of factors, so is FH, where H is any $L \times L$ nonsingular matrix. Since F is unobservable, it has no natural units. The choice of H can be viewed as putting F into convenient units. We chose to put F, which involves three variables, into the units of the three indicators used in the OLS version, since this makes the comparison more intuitive. It turns out, however, that the R^2 and individual errors would be unchanged if the factors were multiplied by any nonsingular matrix.

III. THE APPLICATION TO NAVAL BASES

The data base involves expenditure for base operation at 144 naval bases in 1979. The relationship to be estimated is log linear

$$c = \alpha + Y\beta + \varepsilon$$

where

c is the natural log of expenditure at base i for operating support (building maintenance, medical services, and other) costs of base operation, as opposed to, say, direct pay to pilots or fuels for naval planes)

Y is a matrix of unobservable latent "outputs" in logarithmic form.

We start with 15 indicators for outputs:

1. Energy consumption of the base in 1979 measured in BTUs; includes electricity, coal, natural gas, and fuel oil
2. Energy consumption in 1978
3. Building area in square feet in 1979
4. Land area of the base in acres
5. Civilian personnel in 1979 (number of persons)
6. Civilian personnel (1978)
7. Active military personnel in 1979 (number of persons)
8. Active military personnel (1978)
9. Dependents of military personnel: dependents located off the base (number of persons)
10. Dependents on base (1979)
11. Current value of physical plant (dollars)
12. Retired personnel associated with the base (e.g., who use the base hospital), 1979 (number of persons)
13. Active personnel in 1979 (FDR)
14. Civilian personnel in 1979 (FDR)
15. Reserve personnel who use base (FDR).

Except those noted, all of the data for this study come from the Domestic Base Factors Report (DBFR). This is a survey of a sample of

naval bases to obtain information on base support costs, acreage, building area, and a variety of other base characteristics. The survey has been given since 1977. The one used primarily in our study is 1979. The sample for the survey is chosen to include all the largest naval installations in the U.S. Our sample of bases included 144 of the bases in the DBFR. To arrive at our sample of bases, some bases from the DBFR sample were eliminated because of missing data or because they seemed one-of-a-kind.

The other source of data, the FDR (force distribution report) is a listing of billets or slots assigned to particular bases.

Of the 15 indicators, the three chosen for the OLS run were

X_1 is the natural log of 1979 energy consumption in BTUs (taken as a measure of activity at the base)

X_2 is the natural log of building area in square feet

X_3 is the natural log of civilian employment.

Choosing only these three ignores the information in the other 12 indicators, but avoids the massive collinearity that would result from using all 15 indicators.

The factor analytic regression replaced X_1, X_2, X_3 by $\hat{X}_1$, $\hat{X}_2$, $\hat{X}_3$—the appropriate columns from the estimated FA. As noted earlier, these are just the factors, put into appropriate units. Results are shown in table 1.

TABLE 1

COMPARISON OF TWO REGRESSIONS DESCRIBING
THE DETERMINATION OF OPERATING COSTS

(t-values in parentheses)

Coefficient	OLS on three indicators	OLS on three factors
α	-3.48 (-9.94)	-3.61 (-10.3)
β_1	.178 (4.14)	-.174 (-1.18)
β_2	.303 (5.71)	1.12 (3.52)
β_3	.271 (6.74)	-.053 (.398)
$\Sigma\beta$	.753 (27.6)	.895 (15.4)
$1 - \Sigma\beta$	.247 (9.06)	.105 (1.80)
R^2	.898	.895

A. A Comparison of Results

Table 1 is a comparison of the results of the two methods (table 1). The factor analytic version has a higher indicator of scale ($\Sigma\beta$), .895 versus .753, i.e., the deviation from constant returns is reduced from about 25 percent to about 10 percent. This is consistent with the hypothesis that OLS results are biased from errors-in-variables.

The regressions are similar in terms of R^2, the small difference running in favor of the OLS version. The t-values are somewhat lower in the factor analytic version and two of the three coefficients have an unexpected sign. These are both consequences of increased multicollinearity among the right-hand-side variables. The attempt to purge measurement error has eliminated some of the independent variation among the Xs, which is in accord with the theory of errors in variables (in particular, the diagonality of ψ). What the increased collinearity suggests is that factor analysis is more useful in obtaining the sum of coefficients than individual coefficients. Note also that $\hat{X}_1$, $\hat{X}_2$, $\hat{X}_3$ behave very little like X_1, X_2, X_3. This is not surprising since the $\hat{X}$ variables really include information from all the indicators.

We turn now to the question of whether the technique has changed measures of mean inefficiency for the sample as a whole. Two such measures are discussed in Aigner, Lovell, and Schmidt (1977) and Lee and Tyler (1978). An aggregate measure of inefficiency for the sample observations is the fraction of the total unexplained variation that is

attributed to variations in efficiency:

$$\lambda_1 = \hat{\sigma}_u^2 \; / \; (\hat{\sigma}_u^2 + \hat{\sigma}_v^2) \; .$$

A second indicator of the importance of inefficiency is the estimated expected value of U.

$$\lambda_2 = E(u) = \frac{2}{\pi} \hat{\sigma}_u$$

since the regression is logarithmic, $100\lambda_2$ is approximately equal to a percentage effect of inefficiency.

The estimates of aggregate inefficiency corresponding to the two regressions as listed in table 3.

TABLE 3

MEASURES OF THE IMPORTANCE OF AGGREGATE INEFFICIENCY

Formula	OLS on three indicators	OLS on three factors
$\hat{\sigma}_u^2 = \left[\sqrt{\frac{\pi}{2}}\left(\frac{\pi}{\pi - 4}\right)\left(\hat{\mu}_3'\right)\right]^{2/3}$	.0985	.189
$\hat{\sigma}_v^2 = \hat{\mu}' - \hat{\sigma}_u^2\left(\frac{\pi - 2}{\pi}\right)$	.1152	.0884
$\lambda_1 = \hat{\sigma}_u^2 \; \hat{\sigma}_u^2 + \hat{\sigma}_v^2$	.461	.681
$\lambda_2 = \hat{E}(u) = \sqrt{\frac{2}{\pi}}\, \sigma_u$	.250	.347

As can be seen from the table, the primary effect of the correction for measurement error is to reduce the portion of the error attributable to random noise and increase, both relatively (λ_1) and absolutely (λ_2) the portion attributable to inefficiency. Thus, attempting to correct for measurement error does not necessarily reduce measured inefficiency.

CONCLUSION

We have presented an illustration of how frontier relations change when an attempt is made to reduce measurement error via factor analysis. The results were: (1) The sum of the coefficients (the indicator of scale) moved in the direction expected if measurement error were reduced; (2) the purely statistical properties of the estimates did not improve; and (3) the adjustment for measurement error did not reduce the total error variance; it decreased the amount attributed to randomness and increased the amount attributed to inefficiency. To summarize, we did find evidence of errors-in-variables and that errors-in-variables led to an overstatement of scale economies, but we did not find that errors-in-variables led to an overestimate of inefficiency.

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