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A Nonparametric Approach to Measurement of Efficiency and Technological Change: The Case of Large U.S. Commercial Banks

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Abstract

The purpose of this paper is to derive the efficiency measures and the rate of technological change for a sample of large U.S. commercial banks by employing a nonparametric technique. This technique is used to construct a multiproduct production frontier relative to which the efficiency measures of the banks in the sample are calculated and the displacement of which over time provides a measure of the rate of technological change. The empirical results indicate that the relevant frontier shifted inward between 1980 and 1985 reflecting a high pace of technological advancement achieved by the banks in the sample. The pace varied significantly across the banks with some banks even regressing over time.

1. Introduction

A wave of deregulatory legislation has swept the U.S. banking industry over the last decade, the most important of which is perhaps the passage of the Depository Institution Deregulation and Monetary Control Act of 1980 (DIDMCA). The aim of the Monetary Control Act and similar deregulatory legislation during this period was to bring about a more competitive environment in order to foster a higher degree of technical efficiency and to hasten the pace of technological change in the banking industry.

Although a vast body of research has been directed toward the analysis of scale and scope economies in banking (e.g., Berger, Hanweck, and Humphrey, 1987; Mester, 1987; Gilligan, Smirlock, and Marshall, 1984; Benston, Berger, Hanweck, and Humphrey, 1982), technical efficiency and the nature and extent of technological change in this line of business activity have received inadequate attention.

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The few existing studies of technological change in banking (e.g., Chan and Mountain, 1987; Lawrence and Shay, 1986; and Hunter and Timme, 1986) all use a parametric framework and employ a translog cost function. This approach requires data on input prices which are generally unavailable or highly unreliable in banking. Moreover, the specific production technology imposed by the translog model leaves the door open to misspecification problems, and the output-metric in this model is not well defined whenever any single output takes a zero value.

The existing studies can also be criticized on the grounds that they generally employ a single product model and use highly aggregated data. For example, Chan and Mountain (1987) take the whole financial sector as a unit of observation and use the value added in this *sector* as the measure of output in their average cost function. Hunter and Timme (1986) also construct their output measure as the aggregate of the *total assets and total deposits combined*, and use the data on *bank holding company organizations* rather than the data on individual banks. These features may have confounded the findings of these studies.

The purpose of this article is to derive the efficiency measures and the rate of technological change (RTC) for a sample of large U.S. commercial banks by employing a nonparametric technique. This technique is used to construct a multiproduct production frontier relative to which the efficiency measures of the banks in the sample can be calculated and the displacement of which over time will provide a measure of the rate of technological change. The nonparametric framework adopted here, while avoiding all of the deficiencies cited above for the translog model, is extremely flexible. It can isolate technological change from technical efficiency by measuring the RTC at a given state of technical efficiency. It can also produce efficiency measures for each individual observation rather than an average measure for the sample. Further, it is investigated whether technological change during the period under study has been neutral in nature or biased toward some factors of production.

In what follows, section 2 briefly reviews the literature. Section 3 introduces the nonparametric approach to efficiency measurement; section 4 presents and discusses the empirical results on technical efficiency and the RTC, and section 5 presents the conclusions.

2. Approaches to measuring efficiency and RTC

The traditional approach to measuring efficiency is to use total factor productivity (TFP). In this approach the RTC is defined as the growth rate of TFP and is calculated as the difference between the weighted growth rates of output and input quantities. The weight for each output (input) is its respective share in total revenue (total costs). As explained by Nishimizu and Page (1982), the main problem with this approach is that it cannot separate technical efficiency from technological change. As a result, the RTC estimated in this framework often overstates its corresponding true value.

A second popular approach is to use an average translog cost function. In this approach the RTC is generally measured in one of two manners: either as the elasticity of costs (C) with respect to the technology index (T) which is proxied by time ($RTC = \partial \ell n C / \partial \ell n T$), or as the percentage reduction in costs per period ($RTC = d\ell nC/dT$). Studies adopting the latter measure include the works by Caves, Christensen, and Swanson (1980), Nishimizu and Page (1982), Hunter and Timme (1986), and Lawrence and Shay (1986). Caves, Christensen, and Swanson show that, with this measure, the RTC will still be the difference between the weighted growth rates of outputs and inputs, as is the case when using the TFP measure. The difference, however, is that the weights for outputs in this case will be the cost elasticities with respect to corresponding outputs rather than the output shares in the total revenue. The weights for the inputs will continue to be the respective cost shares.

Some shortcomings of this approach are noteworthy. First, it requires information on input prices which is not often available in the banking industry with an acceptable degree of reliability. The problem is especially severe for physical capital. In the *Call and Income Report* data, used in many banking studies, the expenditure on capital items is not reported for a great majority of banks. Even for the remaining banks, the reported figures are unreliable in terms of their economic contents.[1]

In addition, the proper measure of cost of inputs such as deposits is the effective rather than the nominal deposit rate, where the former incorporates the effects of compensating balances and services offered by banks to depositors at less than market values. The data on these items, however, are not accessible.

Second, the translog function is not well defined for zero output values; if *any* output takes a zero value, *total* costs will become zero as well. As a result, banks that do not produce nonzero values of *all* of the outputs have to be excluded from the sample. This reduces the degrees of freedom in estimation and makes the sample nonrepresentative.[2] Third, the studies based on the trasnlog model generally use an average cost function, not a production or a cost frontier. It follows that in these studies the efficiency measure, and hence the RTC, of each bank is measured relative to the *average* sample performance, not the maximum potential or "best practice" performance. Finally, the estimation of translog models generally involves the problem of dealing with severe multicollinearity, which makes the estimators and the statistical tests unreliable. In sum, these shortcomings make the nonparametric approach a viable alternative.

3. The nonparametric approach

In this study a nonparametric approach is employed to model the production structure of banks. This approach avoids imposing a specific functional form on the production frontier and allows the RTC to be obtained directly from the production structure rather than its dual, the cost structure. This eliminates the need to input price data.[3] Moreover, unlike the existing models, outputs and inputs are disaggregated according to their market characteristics, and the efficiency index and the RTC are assessed relative to a technology constructed in a multi-output and multi-input space (see Färe et al., 1985; Grabowski and Pasurka, 1988).[4] This removes, or at least reduces, the problems caused by output/input aggregation.

The nonparametric approach is not without drawbacks. First, since this approach is nonstochastic, the possibility of determining statistical significance regarding tests of the production frontier is foreclosed. Second, this approach assumes away any noise in the data. As a result, it cannot separate data shocks and measurement errors from inefficiency, and thus it can misstate measured inefficiencies.[5] These drawbacks must be balanced off against the deficiencies of the parametric approach discussed earlier.[6]

3.1. Measure of efficiency, the RTC, and technological bias

The efficiency concept used here is based on an extension of Farrell's work (1957) by Färe, Grosskopf, and Lovell (1985). In this approach, the level of inefficiency of a firm is defined as the proportional reduction in input quantities that can occur while maintaining the level of output, or alternatively, the proportionate reduction in input that can be achieved when the firm moves from its actual position to a point on its production frontier.

This concept is displayed in figure 1 for a hypothetical single product firm D, with two inputs (x_1, x_2) whose production frontier is depicted, in the input space, by a unit isoquant I_1. The technical efficiency index (TE) for the firm at time t_1 can be computed as the ratio of the efficient input requirement (OM), given by the isoquant I_1, to the actual input utilization (OD): $TE_{t_1} = OM/OD$.

The RTC for a firm between two points in time is defined as the magnitude of the proportionate shift in the production frontier (the unit isoquant) due to technological change, given the state of technical efficiency. For example, suppose that over time, technological progress reduces the input quantities needed to produce the unit output, and hence the unit isoquant I_1 shifts left, to I_2 at time t_2. At this time the technical efficiency of firm D relative to the new isoquant I_2 can be measured as $TE_{t_2} = ON/OD$, and the RTC occurring between the two periods t_1 and t_2 can be measured by the proportional shift, toward the origin, of the isoquant along the ray OD:

$$RTC = (OM - ON)/OM = 1 - ON/OM.$$

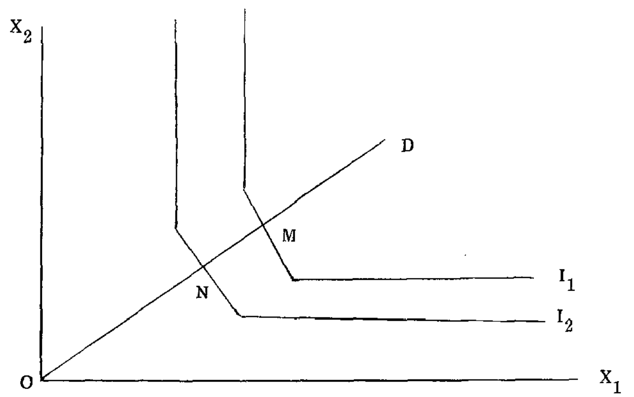

Figure 1

But since $ON/OM = (ON/OD)/(OM/OD) = TE_{t_2}/TE_{t_1}$, the *RTC* for the individual firm *D* can be written alternatively as:

$$RTC = 1 - TE_{t_2}/TE_{t_1}.$$

Technological change between t_1 and t_2 is said to be neutral if it does not alter the relative shares of factors of production. If the share of a factor increases as a result of technological change, the technological change is characterized as biased toward that factor. Therefore, to determine the nature of the bias, the relationship between *RTC* and the factor shares has to be examined. This can be accomplished by running a regression in which *RTC* is the dependent variable and factor shares appear as regressors. A positive relationship between *RTC* and a factor share in this regression would imply a technological bias toward that factor.

The concepts put forward here will be derived for the banks in our sample using a linear programming technique to construct a reference production frontier. A similar approach is adopted in works by other researchers on other sectors of the economy (e.g., Grabowski and Pasurka, 1988; Byrnes et al., 1988).

3.2. Construction of the frontier

The *RTC* for a typical observation *D* in figure 1 can be derived by calculating the efficiency measures for this particular observation relative to the production frontiers I_1 and I_2. To calculate the efficiency measure for firm *D* relative to the frontier I_1, call it β, a linear programming (*LP*) problem is designed that constructs a "hypothetically efficient" firm and computes β as the ratio of the input use by the efficient firm and the actual input used by firm *D*. To construct the efficient firm, the program examines all linear combinations of the firms in the sample that use no more than the input bundle used by *D* and produce output bundles equal to or greater than the bundle produced by that firm. Within this set, the program chooses as efficient the linear combination that minimizes β. The solution to this minimization problem is the efficiency index for firm *D*. The process is repeated for each bank in the sample, and the locus of input use for all the efficient firms so constructed is used as the production frontier. The I_1 frontier is based on the 1980 data set.

To clarify, consider the simple *LP* problem given below for a two-input/two-output firm operating under constant returns to scale (CRTS):

Min β
s.t.
Input Constraints:

$$\sum_{i=1}^{k} M_i^{t_1} \alpha_i^{t_1} \leq \beta M_i^{t_1}$$

$$\sum_{i=1}^{k} L_i^{t_1} \alpha_i^{t_1} \leq \beta L_i^{t_1}$$

Output Constraints:

$$\sum_{i=1}^{k} Y_i^{t_1} \alpha_i^{t_1} \geq Y_i^{t_1}$$

$$\sum_{i=1}^{k} Q_i^{t_1} \alpha_i^{t_1} \geq Q_i^{t_1}$$

In this program $M_i^{t_1}$ and $L_i^{t_1}$ are the levels of inputs utilized by the ith bank in year t_1; $Y_i^{t_1}$ and $Q_i^{t_1}$ are the level of outputs produced by the ith bank in the same year; $\alpha_i^{t_1}$ $(i = 1, \ldots k)$ are intensity variables used in defining linear combinations of banks; and k is the number of banks in the sample. The lefthand side of the first input constraint is the level of input M employed by a "theoretically efficient" bank at time t_1, which is made of a weighted sum of input M utilized by all banks in the sample at t_1. The intensity variables (α's) constitute the weights given to each bank by the LP problem. The M_i on the righthand side of this constraint is the observed level of input M used by a particular bank i at t_1. The inequality signs guarantee that only banks using less than or equal amounts of inputs used by bank i are included in the comparison. The second input constraint can be explained similarly. Now, consider, for example, the output constraint Y. The lefthand side is the output level Y of the theoretically technically efficient firm. The level of output Y_i produced by bank i is restricted not to exceed the output of the theoretically efficient bank on the lefthand side of the constraint. The efficient index β for bank i is derived as the ratio of the input utilized by the theoretically efficient firm to the input actually utilized by bank i. If bank i is technically efficient then $\beta_i = 1$; otherwise it is possible to reduce the input utilization while still producing the same level of output. In this case, the efficiency index β lies below unity.

The technical efficiency measure $TE_{t2} = ON/OD$, calculated (for bank D) relative to the isoquant I_2, is similarly derived from the following programming problem using a total of $k + 1$ observations: k observations from the data for year t_2 (1985) and the data on the single observation D from year t_1 (1980). The process is repeated for every observation.

Min γ

s.t.

Input Constraints:

$$M_i^{t_1} \alpha_i^{t_1} + \sum_{i=1}^{k} M_i^{t_2} \alpha_i^{t_2} \leq \gamma M_i^{t_1}$$

$$L_i^{t_1} \alpha_i^{t_1} + \sum_{i=1}^{k} L_i^{t_2} \alpha_i^{t_2} \leq \gamma L_i^{t_1}$$

Output Constraints:

$$Y_i^{t_1} \alpha_i^{t_1} + \sum_{i=1}^{k} Y_i^{t_2} \alpha_i^{t_2} \geq Y_i^{t_1}$$

$$Q_i^{t_1} \alpha_i^{t_1} + \sum_{i=1}^{k} Q_i^{t_2} \alpha_i^{t_2} \geq Q_i^{t_1}$$

The rationale for inclusion of the single observation (D) from time t_1 in deriving the ratio ON/OD is that efficiency measures of the same observation (D) relative to I_1 and I_2 have to be contrasted in order to derive the RTC for this observation between these two time periods.[7]

The CRTS assumption, though restrictive, need not cause concern because several banking studies have found no significant scale economies for banks. For example, Rangan and associates (1988), using a nonparametric framework, report that almost all banks in their sample were operating at constant returns to scale. The results of Aly and associates (1988) are also consistent with and reinforce the CRTS property in bank production.

4. Empirical analysis

4.1. Data

The nonparametric approach discussed in the previous section merely requires data on input and output quantities. These data are drawn from the *Call and Income Report* tapes published by the National Technical Information Service (NTIS) of the Department of Commerce. To obtain a relatively homogenous data set, only banks with total assets of \$300 million or more, defined in the NTIS tape documents as the large banks, were selected. These banks were matched in 1980 and 1985 tapes, and only those banks which were in operation in both of these years were included in the sample. After the banks with missing values of outputs and/or inputs were dropped, a total of 191 banks remained in the final sample and were used for empirical analysis. The matching of banks in 1980 and 1985 allows a parallel comparison of each bank with itself at two different points in time. This comparison provides us with measures of RTC for each single observation as opposed to measures based on sample averages reached in some other studies.

4.2. Input-output measures

Following the intermediation approach to bank behavior modeling (Mester, 1987), banks are treated as financial intermediaries that combine deposits, labor, and capital to produce loans and investments. Deposits are disaggregated into: (1) saving and time deposits including large (\$100,000 or more) negotiable certificates of deposits (CDs), and (2) total demand deposits. This disaggregation is necessary because demand deposits are checkable, and have a much larger turnover and a much smaller cost per dollar than time deposits. Labor is measured by the number of full-time-equivalent employees. Capital is measured by the item "fixed assets and premises" reported in the *Call Report* tapes. This item includes all fixed machinery, equipment, fixtures, and premises purchased directly by the bank or acquired by means of a capital lease.

A note of caution is in order. The drawback of the book value approach followed by banks in reporting the capital measure is that the machinery and equipments purchased in different years are all reported in the then curremt capital prices. Under this condition, the actual value of capital purchased in previous years is understated, and banks with older machines appear to be more efficient. Unfortunately, however, no alternative source of data on bank capital is available, and stochastic and nonparametric studies alike are subject to this shortcoming.

The loan outputs are broken down into (1) real estate loans, (2) commercial and industrial loans, and (3) other loans, because different types of loans require different operating costs. The use of an aggregate loan measure can confound the efficiency results. The investment output is defined to include all the securities other than those held in the bank's trading accounts.

Table 1 contains summary statistics for the input and output variables for 1980 and 1985. The standard deviations, minima, and maxima reported in this table suggest that there exist substantial variations across the sample in terms of inputs and outputs in spite of the fact that we have excluded all the banks with total assets of less than $300 million.

4.3. Empirical results on efficiency and RTC

As explained in section 3, the linear programming technique is used to construct two production frontiers I_1 and I_2 (figure 1) for the banks in the sample. Let TE_{i80} and $TE_{i80\text{-}85}$ be the technical efficiency of bank i in the sample relative to the two frontiers, respectively. The RTC_i for bank i can then simply be expressed as:

$$RTC_i = 1 - TE_{i80\text{-}85}/TE_{i80}.$$

Table 1. Summary statistics for inputs and outputs*: Large U.S. commercial banks, 1980 and 1985

	Mean		Standard dev.		Min.		Max.	
Variable	1980	1985	1980	1985	1980	1985	1980	1985
Outputs								
Investment	160187.9	260496.4	95245.2	204798.2	0	5506.0	658016.0	1051051.0
Real estate loans	124305.6	218907.1	89810.7	166348.8	1163.0	15444.0	610391.0	1171048.0
Commercial and industrial loans	103042.4	204908.1	74535.1	145126.0	8352.0	10038.0	593889.0	995869.0
Other loans	138603.0	301641.5	211081.2	257932.6	3832.0	16858.0	2854933.0	2697389.0
Inputs								
CD, time, and saving deposits	358119.5	758167.3	225017.8	458597.9	13509.0	162559.0	1829187.0	2537174.0
Total demand deposits	186911.3	240966.9	109464.1	179142.4	7691.0	16370.0	644720.0	1211025.0
Capital	12454.5	20785.0	8376.4	16638.2	1256.0	1573.0	57359.0	106553.0
Labor	699.4	885.8	455.9	672.9	49.0	100.0	3451.0	5073.0

*All variables, except labor, are in thousands of dollars. Labor is measured in number of full time-equivalent employees.

Table 2 includes means, standard deviations, minima, and maxima of the two efficiency indices, and the RTC for banks in the sample. According to the results in this table, the average efficiency for banks in the sample was .8955 when assessed relative to the frontier I_1 ($\overline{T}E_{80}$ = .8955) and was .7771 relative to the frontier I_2 ($\overline{T}E_{80\text{-}85}$ = .7771), where a value of unity implies efficient operation. This indicates that the production frontier for the banks in the sample shifted inward between 1980 and 1985 as a result of technological advancement. The figure .8955 shows that had the banks in the sample been fully efficient in 1980, they could have produced the same level of output with 89.55 percent of the inputs they actually utilized in that year. The figure .7771 implies that for the same banks to be fully efficient relative to the more advanced technology, represented by the I_2 frontier, they must be able to cut their 1980 input use by as much as 22.29 percent.

Although the results presented in table 2 suggest that the frontier for the banks in the sample shifted between 1980 and 1985, this proposition has to be tested for statistical significance. In order to do this, a parametric test (ANOVA) and two nonparametric tests (Wilcoxon and Kruskal-Wallis) are carried out. Table 3 contains the test statistics for these tests. These statistics indicate that, according to all these tests, the shift in the frontier between 1980 and 1985 is indeed statistically significant.

The next issue is the extent of technological change between 1980 and 1985, which is defined as the percentage shift in the unit isoquant between these two period, or $RTC = 1 - TE_{80\text{-}85}/TE_{80}$. A positive *RTC* value implies that technological progress occurred between 1980 and 1985, shifting the frontier toward the origin. A negative *RTC* suggests technical regression. The mean value of the *RTC*, 12.98 percent, reported in table 2, indicates that between 1980 and 1985 the commercial banks in the sample enjoyed a relatively high pace of technological advancement on the average. The minima and maxima values for the *RTC* also show that *RTC* varied significantly among banks in the sample. In fact, some banks were found to have regressed technologically between 1980 and 1985 while some others were rapidly advancing the state of their technical efficiency.

Technological change is said to be neutral if it does not alter the relative shares (intensities) of factors of production in total cost. An increase in the relative shares of two factors—for example, share of labor relative to the share of capital—as a result of technological change, indicates a labor using technological bias.

Table 2. Descriptive statistics for efficiency indexes and RTC: Large U.S. commercial banks

Sample	Variable name	Mean	Standard dev.	Minima	Maxima
1980 data	TEi80	.89553	.08282	.62760	1.000
1980–1985 data	TEi80–85	.77710	.12880	.40780	1.000
	RTC	.12982	.13429	−.24227	.54351

Notes:

TE_{i80} = Technical efficiency of bank *i* relative to the frontier constructed based on data of 1980.

$TE_{i80\text{-}85}$ = Technical efficiency of bank *i* relative to the frontier constructed based on data of 1985 and the data of bank *i* ($i = 1, \ldots, 191$) of 1980 data.

RTC = Rate of technical change = $\%TE_i$ over time.

Table 3. Statistical tests for differences between TE_{80} and $TE_{80-85}{}^{*}$

ANOVA[a]	Wilcoxon[b]	Kruskal-Wallis[c]
F-value	Z-value	Chisq-value
114.26**	9.1210**	83.20**

*See the note given in table 2.
**Significant at 1 percent level of probability.
[a]The null hypothesis is that the means of efficiency indices calculated relative to I_2 and I_1 are equal.
[b]The null hypothesis is that the medians of efficiency indices calculated relative to I_1 and I_2 are equal.
[c]The null hypothesis is that the distributions of efficiency indices calculated relative to I_1 and I_2 are identical.

In order to determine the nature of technological change, a regression model was estimated with *RTC* as the dependent variable and factor shares as independent variables. Based on the results presented in table 4, none of the estimated coefficients other than the coefficient for the share of labor is significantly different from zero. The results indicate that the *RTC* is positively correlated with labor intensity. Hence technological advancement of the commercial banks included in the sample during the period under study can be classified as *nonneutral* and labor biased in nature.

5. Conclusions

In order to avoid difficulties involved in estimation of functional form-specific production frontiers, and in contrast to other studies, a nonparametric approach is employed here to measure technical efficiency and the rate of technological change. The sample consists of 191 large U.S. commercial banks (total assets equal to or more than $300 million), for which all input-output data are available for both 1980 and 1985.

The empirical results suggest that had the banks included in the sample been fully efficient in 1980, on the average, they could have produced the same level of output with 89.55 percent of the inputs they actually utilized. Unfortunately, these results cannot be reasonably compared with those of some other studies, such as Rangan and associates (1988) and Ferrier and Lovell (1989), which also employ a nonparametric technique to measure bank efficiency. The reasons are threefold. First, the aforementioned studies concentrate on banks smaller than those included in the sample of this article. Second,

Table 4. The results of factor intensity regression equation

Variable	Estimate coefficient	*t* value
CD, time, and savings deposits intensity	.07343	.83
Total demand deposit intensity	.02042	.43
Capital intensity	−.19682	−.49
Labor intensity	.51708	2.68*

R^2 = .499807.
F = value 46.71.
*Significant at 1 percent level of probability.

Ferrier and Lovell adopt the "production approach" in which the number of accounts, rather than the number of dollars of loans, is employed as the measure of output. Finally, the present article is based on the data for the year ends 1980 and 1985, while Ferrier and Lovell use the 1984 data, and Rangan and associates emlploy the data for the year ending 1986.

According to the results of the present study, the production frontier for the banks in the sample shifted inward between 1980 and 1985, reflecting a significant rate of technological progress between these two periods. This is consistent with the finding of Hunter and Timme (1986). Further analysis, based on regressing RTC on a set of factor intensities, indicated that the technological change, over the sample period, was nonneutral and essentially labor biased.

Notes

1. In order to avoid this problem, for example, Benston, Hanweck, and Humphrey (1982) use the rental cost of office buildings in nine U.S. geographical regions as a proxy for the cost of capital. This proxy takes only nine values for all the banks in the United States and is likely to have distorted the results because of measurement errors.
2. A Box-Cox specification allows zero output values, but this model is more difficult to trace and cumbersome to estimate.
3. The data on output and input quantities needed in this approach are much more reliable than those on input prices, especially the cost of physical capital.
4. See section 4.2 for details on output-input disaggregation.
5. Note that although the translog model is an approximation to a general cost structure, the approximation is local, and the function still imposes a specific technology and a specific error distribution on the data set. To the extent that this model misspecifies the true cost structure and error, the *RTC* obtained in this framework, too, will be distorted.
6. For a comparison of stochastic and programming techniques and the extent to which the efficiency measures derived by these techniques may differ, see G.D. Ferier and C.A.K. Lovell (forthcoming). We would like to thank a referee of the journal for bringing this article to our attention.
7. We would like to thank Richard Grabowski for discussion and helpful suggestions on this approach.

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