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David C. Wheelock
Paul W. Wilson

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FEDERAL RESERVE BANK OF ST. LOUIS
Research Division
411 Locust Street
St. Louis, MO 63102

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TECHNICAL PROGRESS, INEFFICIENCY AND PRODUCTIVITY CHANGE IN US BANKING, 1984-1993

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ABSTRACT

Numerous studies have found that US commercial banks are quite inefficient, and we find that, on average, banks became more technically inefficient between 1984 and 1993. Our analysis of productivity change, however, shows that technological improvements adopted by a few banks pushed out the efficient frontier, and that, on average, commercial banks experienced productivity gains. For banks with assets less than $300 million, however, technological improvement was insufficient to offset increased inefficiency, and thus productivity declined over the period. Our findings suggest that increasing inefficiency is reflective of an industry undergoing rapid technical change and adjustment of average firm size, but not necessarily a long-term decline.

KEYWORDS: banks, productivity, efficiency, technical change, Data Envelopment Analysis

JEL CLASSIFICATION: G2, C6, L8

David C. Wheelock
Senior Economist
Federal Reserve Bank of St. Louis

Paul W. Wilson
Associate Professor
University of Texas at Austin

1. INTRODUCTION

The U.S. banking industry has had a tumultuous decade. Although large numbers of bank failures during 1985-91 have since given way to record profits, researchers continue to debate whether the industry faces long-term decline (e.g., Wheelock, 1993; Boyd and Gertler, 1994; Berger, Kashyap and Scalise, 1995). From a post-World War II high of 15,126 banks in 1984, failures and acquisitions reduced the number of U.S. commercial banks to 10,323 by the end of 1995. Much of this decline can be attributed to the disappearance of very small banks, *i.e.,* those with assets of less than $100 million. Historically, small banks have been more profitable than large banks. As recently as 1982, average profit rates (return on average assets) were inversely related to bank size.[1] By 1995, however, this pattern had completely reversed, with a positive association between size and profit rates for banks of under $15 billion of assets.

In their comprehensive review of the ongoing transformation of the U.S. banking industry, Berger, Kashyap and Scalise (1995) describe the technological and regulatory changes driving consolidation of the U.S. banking industry. Among these are rapid advances in computer and communications technology. These have led to the development of new bank services (from ATM machines to internet banking) and financial instruments (*e.g.,* various sorts of derivative securities), as well as increased competition for banks from non-bank financial firms and markets. Perhaps even more important have been changes in regulation, including the deregulation of deposit interest rates, revisions to capital requirements, and elimination of many state and, beginning in 1997, federal restrictions on branch banking.

The many technological and regulatory changes affecting banking in recent years have substantially altered the environment in which banks operate. Such changes may have

[1] Specifically, in 1982, average profit rates were lower for each successively larger asset-size category. The categories are less than $100 million, $100–$300 million, $300–$1,000 million, $1,000–$15,000 million, and greater than $15,000 million.

significantly altered the technology of bank production, with possible consequences for the long-run viability of the industry. Numerous studies, based largely on data from the 1980s and early 1990s, have found that commercial banks tend to suffer from substantial managerial inefficiency. That is, the average bank operates considerably less efficiently than the existing technology allows, as estimated by the operations of the most efficient banks (see Berger, Hunter and Timme, 1993, for a survey of this literature). By itself, efficiency can be a misleading measure of the well-being of either a bank or an industry, however, particularly for one undergoing a major environmental transformation. Rapid technical progress, for example, which makes feasible the production of given levels of outputs with fewer inputs (or, equivalently, the production of more outputs with given levels of inputs) than in the past, could result in lower average bank efficiency, even if banks became increasingly productive over time.[2]

Whereas most studies of efficiency in banking have failed to consider the effects of technical change, studies of technical change in banking have typically failed to isolate shifts in the efficient frontier from changes in average inefficiency. An important exception is Bauer, Berger and Humphrey (1993), who separate changes in average inefficiency from changes in scale economies for banks operating on the efficient frontier to come up with a measure of total factor productivity. For a panel of banks with assets of more than $100 million during 1977-88, Bauer *et al.* find little change in average inefficiency, but a noticeable decline in productivity over the period, which they attribute to deregulation and increases in competition, both among banks and from non-bank sources.

Bauer *et al.* (1993), however, do not examine differences in productivity among banks of

[2]Suppose, for example, that technical progress caused the efficient frontier to shift by 10 percent from one year to the next, *i.e.,* that on the new efficient frontier banks use 10 percent fewer inputs to produce a given level of outputs than on the old frontier. The average bank might have a productivity gain of, say, 6 percent, *i.e.,* be able to produce a given level of inputs with 6 percent fewer inputs than in the first year, but still experience increased inefficiency (measured as the distance to the efficient frontier) of 4 percent.

different sizes, and their sample excludes the very small banks whose numbers have declined the most in recent years and which may well have felt the largest effects of deregulation and technical change. As Berger *et al.* (1995) emphasize, the technological and regulatory changes occurring since 1980 probably had very different effects on different sized banks, which may explain the substantial shifts over time in the size distribution of banks. The elimination of branching laws, for example, increased competition, especially for small banks in small banking markets. Increased competition could force banks to operate more efficiently in order to survive. Consequently, we might expect to see efficiency gains among surviving banks, especially small surviving banks. Other changes, such as improvements in computer or communications technology, could have altered the technology of bank production in ways favoring either small or large banks.[3]

Among the few studies attempting to measure technical change among banks of different sizes, Humphrey (1993) finds that banks as a whole experienced positive technical change during the pre-deregulation period of 1977-80, substantial technical regress during 1980-82, and essentially no change during 1983-88. Small banks (those with assets between \$100 and \$200 million) suffered considerable technical regress relative to large banks, however, which he attributes to the relatively high dependence of small banks on the types of deposits that were deregulated in 1980, and subsequent sharp increases in their interest rates. Hunter and Timme (1991) also observe that larger banks enjoyed greater technological gains during 1980-86 than small banks, as do Elyasiani and Mehdian (1990), who conclude that large banks enjoyed a "high pace" of technological advancement between 1980 and 1985.

This paper advances the work in this area by extending the sample period through 1993, as well as by measuring average efficiency and technological changes for the universe of

[3]These changes will not, however, necessarily result in observable gains in efficiency or productivity if, for example, they improve the quality of bank output (*e.g.*, by increasing the number of ATM machines or providing bank customers with increased account options).

U.S. commercial banks, rather than for small samples. More importantly, like Bauer *et al.* (1993), we employ a methodology that permits isolation of technological changes from changes in average inefficiency. But, in contrast to Bauer *et al.,* who estimate translog cost equations, we use non-parametric methods to construct indices of productivity change, and then decompose changes in total factor productivity into changes in technology and changes in technical efficiency. This enables us to gauge the extent to which technical progress (or regress) and the catching-up (or falling behind) of the average bank relative to the efficient frontier account for changes in productivity, as well as to provide a comparison for estimates of total factor productivity based on econometric techniques.

We find that, on average, commercial banks experienced improved productivity between 1984 and 1993, but the failure of many banks to adapt quickly to technical change explains why average inefficiency remained high throughout the period. We find considerable variation between years, however. For example, banks generally became less productive during 1989-92, and only those with at least $1 billion of assets became more productive during 1992-93.

We also find pronounced differences in productivity gains among banks of different sizes throughout the period. In general, we observe that banks with at least $300 million of assets (in 1985 dollars) became more productive on average, while those with less than $300 million of assets became less productive. Our findings thus support the conclusions of Berger *et al.* (1995), who argue that deregulation and technical change likely had differential effects on banks of different sizes. They also stand in contrast with Bauer *et al.* (1993) who find a decline in average productivity for banks in their sample, but support those studies of technical progress which find relative gains for larger sized banks.

The next section describes our methodology for measuring changes in productivity and the decomposition into changes in efficiency and technology. The data are described in Section 3, and Section 4 presents our results. Conclusions are discussed in the final section.

2. METHODOLOGY

Our analysis of commercial bank production uses nonparametric techniques based on the Shepard (1970) output distance function, which measures the technical inefficiency of a firm relative to a convex combination of the best-practice firms. The output distance function gives a measure of how much a bank's outputs can be proportionately increased given the observed levels of its inputs.[4] Linear programming techniques are used to estimate the distance functions, and resemble other linear programming-based measures of technical efficiency known as data envelopment analysis (DEA). We construct Malmquist indices from the distance function estimates to measure changes in commercial bank productivity over time, and decompose these changes into changes in technology and changes in efficiency.[5]

Because the impacts of technological advances and regulatory changes might vary across banks of different sizes, we allow for variable returns to scale in measuring productivity changes for banks in various size groups. This permits modeling of the entire range of the technology. Although some researchers might argue that the operations of "small"

[4]Alternatively, input distance functions measure the feasible proportionate contraction of inputs conditional on observed outputs. In both cases, efficiency is measured in terms of normalized Euclidian distances to the best-practice frontier, and the notion of efficiency is pure technical efficiency. Estimation of distance functions in either direction requires assumptions (which are the same for both directions) only on the underlying technology, and not on the behavior of bank managers. Thus the choice of orientation is largely arbitrary.

[5]Berg *et al.* (1992) use this methodology to study productivity changes in Norwegian banks. Other applications include Färe *et al.* (1994), who use linear programming (LP) methods to construct Malmquist indices to assess productivity changes across countries; their methods are closely related to the LP methods used by Chavas and Cox (1990). See Lovell (1993) for an extensive list of other DEA applications. The Malmquist index allows for inefficient operation and does not imply an underlying functional form for technology, and is thus more general than alternative indices such as the Törnqvist index advocated by Caves *et al.* (1982). Caves *et al.* (1982) prove that the Malmquist and Törnqvist indices are equivalent when the underlying technology is translog, second-order terms are constant over time, and firms are cost-minimizers and revenue-maximizers.

and "large" banks differ fundamentally, banks of all sizes presumably strive for technical efficiency. Systematic differences in the operations of different sized banks should be captured by the variable-returns technology we employ. Moreover, our technique ensures that each bank is compared to the best-practice frontier defined by banks of similar size. This approach also ensures a large sample, thereby avoiding biases associated with applying DEA to small samples, and of comparing results from different sample sizes (as would be necessary if large and small banks are examined separately).[6]

To begin, consider N banks which employ n inputs to produce m outputs over T time periods. For the ith bank, $i = 1, \ldots, N$, let $\boldsymbol{x}_i^t \in \mathbb{R}_+^n$ and $\boldsymbol{y}_i^t \in \mathbb{R}_+^m$ denote input and output vectors, respectively, used at time t, $t = 1, \ldots, T$. Then the technology faced by banks at time t is the set

$$\Psi^t = \{(\boldsymbol{x}^t, \boldsymbol{y}^t) | \boldsymbol{x}^t \text{ can produce } \boldsymbol{y}^t\}. \tag{1}$$

Ψ^t is the usual production set, and is assumed closed, convex for all $(\boldsymbol{x}^t, \boldsymbol{y}^t)$. In addition, we assume that all production requires use of some inputs, *i.e.*, $(\boldsymbol{x}^t, \boldsymbol{y}^t) \notin \Psi^t$ if $\boldsymbol{y}^t \geq 0$, $\boldsymbol{x}^t = 0$; and both inputs and outputs are strongly disposable, *i.e.*, if $(\boldsymbol{x}^t, \boldsymbol{y}^t) \in \Psi^t$ then $\tilde{\boldsymbol{x}}^t \geq \boldsymbol{x}^t \Rightarrow (\tilde{\boldsymbol{x}}^t, \boldsymbol{y}^t) \in \Psi^t$ and $\tilde{\boldsymbol{y}}^t \leq \boldsymbol{y}^t \Rightarrow (\boldsymbol{x}^t, \tilde{\boldsymbol{y}}^t) \in \Psi^t$.

The Shephard (1970) output distance function corresponding to bank i is defined as

$$D_i^{t|t} \equiv \inf\{\theta | (\boldsymbol{x}_i^t, \boldsymbol{y}_i^t/\theta) \in \Psi^t\}, \tag{2}$$

and measures the output technical efficiency of bank i at time t relative to the technology existing at time t. Clearly, $D_i^{t|t} \leq 1$, with $D_i^{t|t} = 1$ indicating that the ith bank is on the boundary of the production set and hence is technically efficient.

[6]See Korostelev *et al.* (1995) for a discussion of this problem.

We can also measure the efficiency of bank i at time t_1 relative to the technology at time t_2 by defining the distance function

$$D_i^{t_1|t_2} \equiv \inf\{\theta | (\boldsymbol{x}_i^{t_1}, \boldsymbol{y}_i^{t_1}/\theta) \in \Psi^{t_2}\}. \tag{3}$$

Similarly, we can also measure the efficiency of bank i at time t_2 relative to the technology at time t_1 by defining

$$D_i^{t_2|t_1} \equiv \inf\{\theta | (\boldsymbol{x}_i^{t_2}, \boldsymbol{y}_i^{t_2}/\theta) \in \Psi^{t_1}\}. \tag{4}$$

Then, Malmquist-type indices to measure productivity change from time t_1 to time t_2 (relative to the technology at time t_1) may be defined as

$$\Delta\text{Prod}^{t_1} \equiv \frac{D^{t_2|t_1}}{D^{t_1|t_1}} \tag{5}$$

and (relative to the technology at time t_2) as

$$\Delta\text{Prod}^{t_2} \equiv \frac{D^{t_2|t_2}}{D^{t_1|t_2}}. \tag{6}$$

The indices in (5)–(6) are called *Malmquist-type indices* after Malmquist (1953), who suggested comparing the input of a firm at two different points in time in terms of the minimum input required to produce the output of one period under the technology of the other period. Caves *et al.* (1982) extended this idea to define Malmquist productivity indices similar to those in (5)–(6), though they define the indices so that two firms could be compared at a point in time t, whereas here we compare one firm over two periods. In addition, Caves *et al.* assume $D^{t_1|t_1} = D^{t_2|t_2} = 1$; *i.e.*, they assume no technical inefficiency, which we allow for in our study.

Färe *et al.* (1991, 1992) combine the indices in (5)–(6) into a single Malmquist-type index by computing the geometric mean

$$\Delta\text{Prod}^{t_1,t_2} = \left(\frac{D^{t_2|t_1}}{D^{t_1|t_1}} \times \frac{D^{t_2|t_2}}{D^{t_1|t_2}}\right)^{1/2}. \tag{7}$$

Färe *et al.* then decompose the index of productivity change into changes in efficiency and technology by rewriting (7) as

$$\Delta \text{Prod}^{t_1,t_2} = \frac{D^{t_2|t_2}}{D^{t_1|t_1}} \times \left(\frac{D^{t_2|t_1}}{D^{t_2|t_2}} \times \frac{D^{t_1|t_1}}{D^{t_1|t_2}} \right)^{1/2}. \tag{8}$$

The ratio $D^{t_2|t_2}/D^{t_1|t_1}$ in (8) measures the change in output technical efficiency between periods t_1 and t_2, and hence we can define

$$\Delta \text{Eff}^{t_1,t_2} \equiv \frac{D^{t_2|t_2}}{D^{t_1|t_1}}. \tag{9}$$

Values of $\Delta \text{Eff}^{t_1,t_2}$ greater than 1.0 indicate increases in efficiency, while values less than 1.0 indicate decreases in efficiency.

The first ratio inside the parentheses in (8) measures the position of the kth firm in input-output space at time t_2 relative to technologies at times t_1 and t_2. Thus, this ratio gives a measure of the shift in technology relative to the position of the kth firm at time t_2. Similarly, the second ratio inside the parentheses in (8) measures the position of the kth firm in input-output space at time t_1 relative to technologies at times t_1 and t_2.[7] Thus, this ratio gives a measure of the shift in technology relative to the position of the kth bank at time t_1. Hence, we can define

$$\Delta \text{Tech}^{t_1,t_2} \equiv \left(\frac{D^{t_2|t_1}}{D^{t_2|t_2}} \times \frac{D^{t_1|t_1}}{D^{t_1|t_2}} \right)^{1/2}. \tag{10}$$

$\Delta \text{Tech}^{t_1,t_2}$ is the geometric mean of two measures of the shift in technology from t_1 to t_2, and is itself a measure of technical change. Values of $\Delta \text{Tech}^{t_1,t_2}$ greater than 1.0 indicate improvements in technology, while values less than 1.0 indicate technical regress.

The measurement of technical change is illustrated in Figure 1 where two output quantities y_1, y_2 are produced from a single input. Suppose the production frontier shifts outward as shown between time t_1 and t_2; point A gives a firm's location

[7] The second ratio inside the parentheses in (8) is analgous to the measure of technical change used by Elyasiani and Mehdian (1990).

at time t_1, and point B gives the same firm's location at time t_2. For this firm, $D^{t_1|t_1} = OA/OA'$, $D^{t_1|t_2} = OA/OA''$, $D^{t_2|t_2} = OB/OB''$, and $D^{t_2|t_1} = OB/OB'$, and $\Delta\text{Tech} = \left(\frac{OB/OB'}{OB/OB''} \times \frac{OA/OA'}{OA/OA''}\right)^{1/2}$. Thus ΔTech measures technical change relative to the firm's position at time t_1 and at time t_2.

From the definitions in (8)–(10), we can write $\Delta\text{Prod}^{t_1,t_2} = \Delta\text{Eff}^{t_1,t_2} \times \Delta\text{Tech}^{t_1,t_2}$. Changes in productivity, as measured by the Malmquist-type index in (8), are thus composed of both changes in efficiency and changes in technology, with $\Delta\text{Prod}^{t_1,t_2}$ less than (greater than) unity representing a loss (gain) of productivity. The advantage of Malmquist-type indices is that productivity changes can be decomposed into these separate components.

In order to estimate the indices $\Delta\text{Prod}^{t_1,t_2}$, $\Delta\text{Eff}^{t_1,t_2}$, and $\Delta\text{Tech}^{t_1,t_2}$, we must first estimate the technology implied by (1). Following Färe *et al.* (1985) and others, we estimate the production set by the convex hull of the observations, so that

$$\widehat{\Psi}^t = \{(\boldsymbol{x}^t, \boldsymbol{y}^t) | \boldsymbol{y}^t \le \boldsymbol{Y}^t \boldsymbol{q},\ \boldsymbol{x}^t \ge \boldsymbol{X}^t \boldsymbol{q},\ \overrightarrow{\mathbf{1}}\,\boldsymbol{q} = 1,\ \boldsymbol{q} \in \mathbb{R}_+^N\}, \tag{11}$$

where K gives the number of firms, $\boldsymbol{Y}^t = [\,\boldsymbol{y}_1^t \ \ \ldots \ \ \boldsymbol{y}_K^t\,]$, $\boldsymbol{X}^t = [\,\boldsymbol{x}_1^t \ \ \ldots \ \ \boldsymbol{x}_K^t\,]$, $\overrightarrow{\mathbf{1}}$ is a $(1 \times N)$ vector of ones, and $\boldsymbol{q}$ is a $(N \times 1)$ vector of intensity variables which serve to form the variable-returns technology. Other returns to scale may be imposed by modifying the constraint $\overrightarrow{\mathbf{1}}\,\boldsymbol{q} = 1$ (*e.g.*, see Grosskopf, 1986). With variable returns, the technology may exhibit either increasing, constant, or decreasing returns to scale at different points along the technology.

Given an estimate of the technology as in (11), the output distance function $D_i^{t|t}$ for bank i can be estimated by replacing Ψ^t in (2) with $\widehat{\Psi}^t$ from (11), then solving the resulting LP problem

$$\left(\widehat{D}_i^{t|t}\right)^{-1} = \max\{\theta_i | \boldsymbol{X}^t q_i \le \boldsymbol{x}_i^t,\ \boldsymbol{Y}^t q_i \ge \theta \boldsymbol{y}_i^t,\ \overrightarrow{\mathbf{1}}\,\boldsymbol{q}_i = 1,\ \boldsymbol{q}_i \in \mathbb{R}_+^n\}. \tag{12}$$

Here, $\widehat{D}_i^{t|t}$ provides an estimate of the technical efficiency of bank i at time t relative to the contemporaneous technology. Similarly, the distance function in (3) measuring efficiency of firm i at time t_1 relative to the technology at time t_2 can be estimated by solving the LP problem

$$\left(\widehat{D}_i^{t_1|t_2}\right)^{-1} = \max\{\theta_i | \boldsymbol{X}^{t_2} \boldsymbol{q}_i \leq \boldsymbol{x}_i^{t_1},\ \boldsymbol{Y}^{t_2} q_i \geq \theta \boldsymbol{y}_i^{t_1},\ \overrightarrow{\mathbf{1}} \boldsymbol{q}_i = 1,\ \boldsymbol{q}_i \in \mathbb{R}_+^n\}. \tag{13}$$

The distance function in (4) can be estimated by solving a similar LP problem obtained by reversing the t_1 and t_2 superscripts in (13). Clearly, $\widehat{D}_i^{t_1|t_2}$ and $\widehat{D}_i^{t_2|t_1}$ may exceed unity, since the set $\widehat{\Psi}^{t_1}$ does not necessarily contain $(\boldsymbol{x}_i^{t_2}, \boldsymbol{y}_i^{t_2})$, and $\widehat{\Psi}^{t_2}$ does not necessarily contain $(\boldsymbol{x}_i^{t_1}, \boldsymbol{y}_i^{t_1})$.

The indices $\Delta\text{Prod}^{t_1,t_2}$, $\Delta\text{Eff}^{t_1,t_2}$ and $\Delta\text{Tech}^{t_1,t_2}$ are estimated by replacing the distance function values in (8)–(10) with their corresponding estimates. Conceivably, for some observations the LP problems from which the distance functions $D_i^{t_1|t_2}$ and $D_i^{t_2|t_1}$ are to be estimated will involve infeasible sets of constraints. In such cases the distance function cannot be computed for these observations since no solution to the LP problem exists. Consequently, $\Delta\text{Tech}^{t_1,t_2}$ and $\Delta\text{Prod}^{t_1,t_2}$ may be undefined for some observations.

3. THE DATA

In order to measure productivity change, we must first specify a model of bank production. The literature treats banks as going concerns that combine labor, capital, and various financial inputs to produce financial outputs. One approach, termed the *production* approach, measures output by the number of deposit and loan accounts serviced by the bank. The more common *intermediation* approach views banks as financial intermediaries, with outputs measured in dollar amounts and with labor, capital, and various funding sources treated as inputs.[8]

[8]For further discussion of the two approaches, see Berger *et al.* (1987). Mester (1987) observes that

The intermediation approach has several variants. Berger and Humphrey (1991, 1992) classify activities for which banks create high value-added, such as loans, demand deposits, and time and savings deposits as "important" outputs, with labor, capital, and purchased funds classified as inputs. Alternatively, Aly *et al.* (1990), Hancock (1991) and Fixler and Zieschang (1992) adopt a "user-cost" framework where a bank asset is classified as an output if the financial return on the asset exceeds the opportunity cost of the investment, and a liability is classified as an output if the financial cost of the liability is less than its opportunity cost.[9] While their details differ, empirically the value-added and user-cost approaches tend to suggest similar classifications of bank inputs and outputs, with the principal exception being the classification of demand deposits as an output in most user-cost studies and as both an input and an output when the value-added approach is taken. We adopt the intermediation approach, and because our measurement of technical efficiency depends on a mutually exclusive distinction between inputs and outputs, we follow Aly *et al.* (1990) and other studies that classify inputs and outputs on the basis of user-cost.

We define three inputs: labor (X_1), physical capital (X_2), and purchased funds (X_3). Labor is measured by the number of full-time equivalent employees on the payroll at the end of each period. Capital is measured by the book value of premises and fixed assets (including capitalized leases). Purchased funds include time and savings deposits, net federal funds purchased and securities sold under agreements to repurchase, and other borrowed money. We define five outputs: real estate loans (Y_1), commercial and industrial loans (Y_2), consumer loans (Y_3), all other loans (Y_4), and total demand deposits (Y_5). Specification of these inputs and outputs is consistent with earlier studies by Aly *et al.* and

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the choice between the production and intermediation approaches often depends upon available data; the majority of studies on banking efficiency have adopted the intermediation approach.

[9]See Hancock (1991, pp. 27–33) or Berger and Humphrey (1992, pp. 248–250).

others.

All data were obtained from the FDIC Reports of Condition and Income (Call Reports) for the first quarter of each year 1984–1993. We omitted banks with missing values for any of the inputs or outputs. In addition, we omitted banks making no loans, or that had total loans in excess of purchased funds plus demand deposits.[10] Our resulting sample has from 11,387 observations in 1993 to a high of 14,108 observations in 1985. The Call Report data include a unique identifier that allows us to track individual banks over the 10 years represented in our data.

The distance function in (2) is independent of units of measurement in the inputs and outputs. However, since we use (2)–(4) to construct Malmquist indices, we convert all dollar values to 1985 prices using the quarterly implicit GNP deflator. Descriptive statistics for the input and output variables for each year are shown in the Appendix.

Table 1 shows the size distribution of banks in each year, with size measured in terms of total assets measured in 1985 dollars (*ASSETS*). The four size categories, $ASSETS >$ \$1 billion, \$1 billion $\geq ASSETS >$ \$300 million, \$300 million $\geq ASSETS \geq$ \$100 million, and $ASSETS <$ \$100 million are similar to the categories used by the FDIC and Federal Reserve System in reporting bank data. The disproportionate number of failures among small banks and the consolidation of banks through mergers and acquisitions throughout the period explain why the number of banks fell, while the distribution of banks by size shifted toward larger banks, even after controlling for inflation.

4. ESTIMATION RESULTS

[10]The Call Reports include data on specialty institutions such as credit card subsidiaries of holding companies, which do not conform to the traditional view of banks. While some such institutions may remain in our sample, our deletion criteria should minimize their impact on efficiency scores measured for other banks. In addition, because we focus on averages of efficiency scores and productivity indices, the presence of nontraditional banks in our sample should have minimal impact on the results. Other studies have avoided this issue by using small, selective samples.

In order to estimate technical efficiency, the LP problem in (12) must be solved for each bank at each time period. For each period, we computed $\widehat{D}_i^{t|t}$ using the reference technology defined by all banks in the sample. Since the distance function approach is deterministic in that no explicit noise term exists in the model, values of the computed distance functions may incorporate statistical noise as well as information on inefficiency. Thus, we focus on averages across banks rather than on distance function values for individual banks. Arithmetic mean values of the computed distance function values are shown in Table 2 by year and by bank size.

The average values of the distance functions reported in Table 2 indicate that in each year the largest banks are, on average, more technically efficient than banks in the smaller size categories. This finding is consistent with results from estimation of a parametric profit function by Berger, Hancock, and Humphrey (1993), who also find that large banks are substantially more efficient than small banks. Comparing efficiency across years is problematic, however, because changes in average distance function values from one year to the next could be due either to movement of banks within the input/output space, or to technological change, *i.e.*, to movement of the boundary of the production set over time. The example shown in Figure 1 makes this apparent. If the firm had remained at point A and the technology shifted as shown (from t_1 to t_2), the output distance function values $D^{t_1|t_2}$ and $D^{t_2|t_1}$ would indicate a decrease in efficiency. In terms of converting inputs into outputs, however, by remaining at point A, the firm is no more or less productive at time t_2 than at time t_1. Studies that focus solely on efficiency, therefore, can give an incomplete view of the performance of banks over time.

Tables 3–5 show the average changes in efficiency, technology, and productivity estimated by computing ΔEff, ΔTech, and ΔProd from (8)–(10). As noted earlier, for each of these indices, values greater than unity represent an increase in efficiency, technology, or productivity, while values less than unity indicate a decrease. In order to preserve the multiplicative property of the Malmquist index decomposition in (8), the values reported in Tables 3–5 are geometric means. Single asterisks (*) are used to indicate means significantly different from unity at 90 percent confidence, and double asterisks (**) are used to indicate means significantly different from unity at 95 percent confidence.[11]

Table 3 displays geometric means for ΔEff for each time period, by size category. The smallest banks, *i.e.*, those with $ASSETS \leq \$100$ million, experienced an average improvement in technical efficiency over the intervals 1989–90 and 1992–93, but suffered declines in average efficiency in all other intervals except 1985–86, when the change was insignificant. Banks with \$100 million $< ASSETS \leq$ \$300 million experienced average declines in technical efficiency in every interval except 1992–93, when there was a large increase in efficiency. Banks with \$300 million $< ASSETS \leq$ \$1 billion show increases in efficiency in 1987–88 and 1992–93, insignificant change in 1988–89, and decreases in the other six periods. The largest banks show decreases in efficiency in 1986–87 and 1991–92 at the 95 percent level and in 1984–85 at the 90 percent level, an increase in 1992–93 at the 95 percent level and in 1985–86 at the 90 percent level, and insignificant changes in the remaining periods.

Changes in efficiency over the entire period of the study, 1984–93, are shown in the last line of Table 3, and are statistically significant at greater than 95 percent. These results indicate that over the period 1984–93, efficiency declined by about 14 percent for

[11]To determine whether a geometric mean $G \equiv \left(\prod_{i=1}^{N} Z_i\right)^{1/N}$ is significantly different from unity, where Z_i might represent either ΔEff, ΔTech, or ΔProd, we define $g = \log G$ and $z_i = \log Z_i$. Then $g = N^{-1} \sum_{i=1}^{N} z_i$. If the z_i are identically and independently distributed, then by the central limit theorem, g is approximately normally distributed with variance $\sigma^2(z)/N$. Hence confidence intervals for g may be constructed in the usual way; applying an exponential transformation then gives confidence intervals for G.

the largest banks to as much as 32 percent on average for the small banks.

Table 4 shows the geometric means for the index of technical change, ΔTech. These results indicate that changes in technology for banks in each period, with the exception of the largest banks in 1992–93, were significantly different from unity. With the exception of the smallest banks in 1985–86, all four size categories experienced technical progress in each of the first five periods of our study. In the last four periods, some categories began to experience technical regress, with all but the largest category experiencing significant technical regress in 1992–93. Thus, while efficiency was generally declining over the study period, technology was improving. For example, in 1986–87, efficiency declined for all four size groups as indicated by the results in Table 3, while technology advanced for all four size groups as indicated by the results in Table 4. This would result if banks typically moved very little in the input-output space during 1986–87, but the production frontier shifted outward. Apparently, a small proportion of banks in each category pushed the technology outward, but most banks failed to keep up with the technical progress.

As before, changes in technology over the entire period of the study are shown in the last line of Table 4. The changes in technology over the entire study period are significant, with technology advancing from about 27 percent on average for the smallest banks to about 42 percent on average for the largest banks. Our results are thus consistent with previous studies finding significant technical progress in banking during the 1980s, especially for larger-sized banks.

Finally, average productivity changes are given in Table 5. Decreasing efficiency and increasing technology tend to offset each other in determining changes in productivity. Nonetheless, productivity generally increased over the first five periods of the study, and decreased over the last four periods. On average, banks in the two largest size categories experienced significant increases in productivity over the entire period 1984–93, while banks in the two smallest size categories show a significant decline in productivity from 1984 to 1993, as indicated by the last line of Table 5.

5. SUMMARY AND CONCLUSIONS

During 1984–93, banks of all sizes experienced declines in technical efficiency. Yet, there was technological progess over the period for banks in all size categories. This suggests that a minority of banks in each size category were pushing the technology forward, while the majority of banks failed to keep up with the technological change. Among banks with $ASSETS >$ \$300 million, productivity increased on average, even though banks in this group on average did not keep up with the technological change. Among banks with $ASSETS \leq$ \$300 million, productivity declined on average, suggesting that not only did the average bank in this group fail to keep up with the changing technology, but it also experienced a decrease in its efficiency.

The pattern of productivity change we find seems consistent with what one might expect of an industry undergoing rapid change. In response to new tools or market opportunities, a few pioneering firms might adapt quickly, while others respond cautiously and fall behind. Competitive or regulatory changes might also have different effects on different-sized firms. Relaxation of barriers to branching or increased reporting requirements would seem to favor larger banks, and the relatively large productivity gains of larger-sized banks since 1984 suggest that on average they have adapted better to the changed environment than small banks. Our results indicate, however, that many banks of all sizes have lagged behind the leaders, leaving room for significant productivity gains in the future. Ongoing technological improvement is a hopeful signal, though, of continued long-term viability of the banking industry.

APPENDIX

TABLE A1
Descriptive Statistics for Labor (X_1)

Year	N	Mean	Minimum	Maximum
1984	13238	55.7	1.0	3362.0
1985	14108	57.4	1.0	3799.0
1986	13659	56.4	1.0	3743.0
1987	13372	58.1	1.0	4527.0
1988	12881	59.7	1.0	4851.0
1989	12739	64.4	2.0	4698.0
1990	12341	65.7	1.0	4906.0
1991	12064	66.5	1.0	6706.0
1992	11721	67.6	2.0	6551.0
1993	11387	70.1	2.0	6712.0

TABLE A2
Descriptive Statistics for Capital (X_2)
(thousands of dollars)

Year	N	Mean	Minimum	Maximum
1984	13238	1519.62	1.11	110887.40
1985	14108	1548.78	1.07	111609.86
1986	13659	1522.18	1.04	109031.25
1987	13372	1572.32	1.01	164817.81
1988	12881	1615.76	0.97	171032.32
1989	12739	1746.86	0.94	168742.75
1990	12341	1785.69	0.90	165827.80
1991	12064	1815.56	0.85	196942.44
1992	11721	1837.68	0.83	198476.67
1993	11387	1906.20	0.81	252592.86

TABLE A3
Descriptive Statistics for Purchased Funds (X_3)
(thousands of dollars)

Year	N	Mean	Minimum	Maximum
1984	13238	47930.13	7.80	2207505.02
1985	14108	63009.22	37.51	13375858.52
1986	13659	57430.23	57.29	3461541.67
1987	13372	61540.29	52.63	4393038.46
1988	12881	65797.77	25.47	4008490.70
1989	12739	81640.04	36.48	11503385.41
1990	12341	84060.96	36.77	8814298.65
1991	12064	86177.73	52.41	7859292.10
1992	11721	87439.64	109.17	8484592.50
1993	11387	90032.39	149.23	11268227.90

TABLE A4
Descriptive Statistics for Real Estate Loans (Y_1)
(thousands of dollars)

Year	N	Mean	Minimum	Maximum
1984	13238	15179.33	0.00	1077304.35
1985	14108	21032.58	0.00	5841625.94
1986	13659	17871.12	0.00	1250671.88
1987	13372	20782.47	0.00	1689306.68
1988	12881	24105.64	0.00	1902429.97
1989	12739	35154.74	0.00	5063735.27
1990	12341	37165.07	0.00	4445226.01
1991	12064	38363.43	0.00	4546704.47
1992	11721	39471.06	0.00	4360882.50
1993	11387	40874.09	0.00	4259942.42

TABLE A5

Descriptive Statistics for Commercial and Industrial Loans (Y_2)
(thousands of dollars)

Year	N	Mean	Minimum	Maximum
1984	13238	12386.03	0.00	897154.96
1985	14108	13085.46	0.00	1284751.34
1986	13659	13262.68	0.00	1618807.29
1987	13372	13271.88	0.00	1313869.43
1988	12881	13551.67	0.00	1406033.30
1989	12739	14471.45	0.00	2145280.64
1990	12341	14100.19	0.00	1416320.18
1991	12064	13236.21	0.00	1290947.59
1992	11721	11691.79	0.00	1078298.33
1993	11387	11580.22	0.00	1561952.15

TABLE A6

Descriptive Statistics for Loans to Individuals (Y_3)
(thousands of dollars)

Year	N	Mean	Minimum	Maximum
1984	13238	9955.21	0.00	545123.75
1985	14108	11203.42	0.00	1444079.31
1986	13659	11312.55	0.00	943888.54
1987	13372	11642.47	0.00	2002553.64
1988	12881	12214.84	0.00	3423321.25
1989	12739	13213.26	0.00	3773180.54
1990	12341	13396.25	0.00	4869052.91
1991	12064	12967.63	0.00	5965125.43
1992	11721	12097.66	0.00	2769501.67
1993	11387	12187.67	0.00	2255184.10

TABLE A7

Descriptive Statistics for Other Loans (Y_4)
(thousands of dollars)

Year	N	Mean	Minimum	Maximum
1984	13238	5385.10	0.00	504086.96
1985	14108	5500.18	0.00	433965.70
1986	13659	5547.32	0.00	1142860.42
1987	13372	5274.00	0.00	1073440.28
1988	12881	5110.14	0.00	1095905.97
1989	12739	4817.08	0.00	686405.05
1990	12341	4655.20	0.00	880671.75
1991	12064	4872.17	0.00	3342339.35
1992	11721	4694.24	0.00	1691864.17
1993	11387	4508.58	0.00	2301368.21

TABLE A8

Descriptive Statistics for Demand Deposits (Y_5)
(thousands of dollars)

Year	N	Mean	Minimum	Maximum
1984	13238	13240.45	0.00	760143.81
1985	14108	12380.79	0.00	743834.94
1986	13659	13209.82	0.00	996858.33
1987	13372	13885.62	0.00	2047257.09
1988	12881	13670.87	0.00	1380175.32
1989	12739	13449.95	0.00	1519742.75
1990	12341	13155.58	0.00	1321627.80
1991	12064	12381.84	0.00	1225768.04
1992	11721	13761.14	0.00	1475101.67
1993	11387	14811.92	0.00	2127806.97

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TABLE 1

Frequency Distribution of Banks by Year, Size

Year	*ASSETS* >1BIL	300M–1BIL	100–300M	< 100M	All Banks
1984	87	451	1731	10969	13238
1985	141	519	1898	11550	14108
1986	121	482	1803	11253	13659
1987	143	474	1829	10926	13372
1988	159	477	1728	10517	12881
1989	214	546	1829	10150	12739
1990	206	564	1856	9715	12341
1991	206	560	1818	9480	12064
1992	203	545	1846	9127	11721
1993	205	532	1813	8837	11387

NOTE: *ASSETS* measured in 1985 dollars.

TABLE 2
Mean Technical Efficiency, by Size

	ASSETS			
Year	>1BIL	300M–1BIL	100–300M	< 100M
1984	0.8908	0.7421	0.6600	0.5980
1985	0.8474	0.7116	0.6254	0.5387
1986	0.8496	0.6969	0.6089	0.5372
1987	0.7992	0.6414	0.5319	0.4728
1988	0.7895	0.6418	0.5132	0.4220
1989	0.8111	0.6597	0.4948	0.4205
1990	0.8014	0.6441	0.4825	0.4328
1991	0.7917	0.5974	0.4420	0.4130
1992	0.7152	0.5234	0.4153	0.4071
1993	0.7276	0.5441	0.4518	0.4149

NOTE: *ASSETS* measured in 1985 dollars.

TABLE 3
Changes in Efficiency (ΔEff)

Period	*ASSETS*			
	>1BIL	300M–1BIL	100–300M	< 100M
1984–85	0.9736*	0.9505**	0.9333**	0.8910**
1985–86	1.0179*	0.9880**	0.9905**	1.0034
1986–87	0.9292**	0.9192**	0.8717**	0.8768**
1987–88	0.9839*	1.0170**	0.9764**	0.8945**
1988–89	0.9977	0.9999	0.9494**	0.9935**
1989–90	0.9853	0.9889**	0.9818**	1.0311**
1990–91	0.9985	0.9272**	0.9129**	0.9491**
1991–92	0.9031**	0.8787**	0.9388**	0.9796**
1992–93	1.0483**	1.0395**	1.1083**	1.0316**
1984–93	0.8654**	0.7916**	0.7053**	0.6725**

NOTE: *ASSETS* measured in 1985 dollars. Single asterisk (*) indicates mean is significantly different from unity at 90 percent; double asterisk (**) indicates mean is significantly different from unity at 95 percent.

TABLE 4
Changes in Technology (ΔTech)

	ASSETS			
Period	>1BIL	300M–1BIL	100–300M	< 100M
1984–85	1.0648**	1.0511**	1.0395**	1.0542**
1985–86	1.0491**	1.0478**	1.0299**	0.9927**
1986–87	1.1408**	1.1107**	1.1531**	1.1057**
1987–88	1.0705**	1.0124**	1.0513**	1.1224**
1988–89	1.0343**	1.0172**	1.0675**	1.0182**
1989–90	0.9713**	1.0083**	1.0157**	0.9743**
1990–91	0.9719**	1.0554**	1.0757**	1.0491**
1991–92	1.0844**	1.0963**	1.0168**	0.9918**
1992–93	0.9891	0.9478**	0.8937**	0.9617**
1984–93	1.4239**	1.3564**	1.3725**	1.2771**

NOTE: *ASSETS* measured in 1985 dollars. Single asterisk (*) indicates mean is significantly different from unity at 90 percent; double asterisk (**) indicates mean is significantly different from unity at 95 percent.

TABLE 5
Changes in Productivity (M)

Period	*ASSETS* >1BIL	300M–1BIL	100–300M	< 100M
1984–85	1.0367**	0.9991	0.9702**	0.9393**
1985–86	1.0678**	1.0352	1.0201**	0.9960**
1986–87	1.0599**	1.0210**	1.0052*	0.9691**
1987–88	1.0533**	1.0296**	1.0264**	1.0040**
1988–89	1.0319**	1.0171**	1.0135**	1.0118**
1989–90	0.9570**	0.9972	0.9967	1.0043**
1990–91	0.9704**	0.9786**	0.9820**	0.9952**
1991–92	0.9793**	0.9634**	0.9547**	0.9714**
1992–93	1.0369**	0.9852**	0.9905**	0.9921**
1984–93	1.2322**	1.0738**	0.9680**	0.8581**

NOTE: *ASSETS* measured in 1985 dollars. Single asterisk (*) indicates mean is significantly different from unity at 90 percent; double asterisk (**) indicates mean is significantly different from unity at 95 percent.

FIGURE 1
Measuring Technological Change