TECHNICAL CHANGE, REGULATION, AND ECONOMIES OF SCALE FOR LARGE COMMERCIAL BANKS: AN APPLICATION OF A MODIFIED VERSION OF SHEPHARD'S LEMMA

Douglas D. Evanoff, Philip R. Israilevich
and Randall C. Merris

Working Paper Series
Issues in Financial Regulation
Research Department
Federal Reserve Bank of Chicago
June, 1989 (WP-89-11)

DRAFT

Technical Change, Regulation, and Economies of Scale For Large Commercial Banks: An Application of a Modified Version of Shephard's Lemma

by
Douglas D. Evanoff *
Philip R. Israilevich
and
Randall C. Merris

*The authors are economists at the Federal Reserve Bank of Chicago. Individually they are also affiliated with DePaul University, the University of Illinois-Urbana, and the Asian Development Bank, respectively. Helpful comments and suggestions were provided by Herbert Baer, Jeffrey Brown, and Larry Mote. Betsy Dale provided helpful assistance in data collection. The views expressed are those of the authors and may not be shared by others, including the Federal Reserve Bank of Chicago or the Federal Reserve System.

Relative Price Efficiency, Technical Change, and Economies of Scale For Large Commercial Banks

Recent additions to the extensive literature on production in commercial banking have incorporated duality theory and flexible functional forms to evaluate economies of scale and scope, competitive viability, and the effect on bank costs of restrictions on geographic expansion. The empirical studies generally find that scale economies are exhausted at relatively low output levels. The resulting policy implications are that cost economies should be given little consideration in bank regulatory decisions concerning bank acquisitions and expansion.

Use of the existing literature as the basis for weighing cost economies in bank regulatory decisions may grant a more significant role to past studies than merited. Potential problems exists as a result of sample selection and the exclusion of relevant explanatory variables. However, perhaps the major problem with previous bank cost studies is methodological. More specifically, recent studies have utilized duality theory to generate a neoclassical cost function based on the maintained assumption of cost minimization with respect to market input prices in competitive markets. However, extensive evidence exists suggesting that this is not the behavior practiced by regulated firms. Banking firms are subject to extensive regulation in nearly all facets of operations, raising the possibility that behavior consistent with cost minimization subject to market input prices may not occur.

The purpose of this study is to generate cost estimates for large banks utilizing a generalized cost function that subsumes the standard neoclassical cost function as a special case. The generalized model allows for cost minimization with respect to *shadow* input prices which may deviate from market prices because of regulation-induced distortions in the production process. From a theoretical or economic viewpoint the generalized model is superior to the neoclassical model. We test to see if there is also a statistical difference. Behavior based on shadow input prices could result in significantly different measures of economies of scale, elasticities of substitution, factor shares, and other economic measures than those found when minimizing cost subject to market prices. The generally neglected role of technical change could also be altered. Each of these aspects of bank production is evaluated within the context of both the generalized model and the more restrictive neoclassical model.

The results suggest that the neoclassical cost framework is inappropriate for modeling the production behavior of the large banks analyzed. The constraints imposed by regulation, and the resulting cost minimization subject to shadow input prices, are shown to alter estimates of the various elements of bank costs. Thus, the results found in previous bank cost studies employing the traditional neoclassical framework may be biased.

The next section briefly reviews the literature on bank cost studies and introduces the motivation for the study. Section 2 introduces the generalized cost model, and the data to which we apply this are discussed in Section 3. The empirical results are detailed in Section 4. The final section draws conclusions and discusses the implications of the findings.

1. BACKGROUND AND MOTIVATION

Many of the early studies of bank costs utilized the Cobb-Douglas cost function and generally found scale economies over a rather substantial range of output (Bell and Murphy 1968, Benston 1965, 1972). With the development of flexible functional forms a number of recent studies have reevaluated bank costs taking into account directly the potential for U-shaped average cost curves, multi-product production, and economies of scope as well as scale effects. These studies generally have found that any benefits from scale economies are fully exhausted at relatively low levels of output (Benston, Hanweck, and Humphrey 1982, Berger, Hanweck, Humphrey 1987, Gilligan and Smirlock 1984, and Gilligan, Smirlock and Marshall 1984). In fact, significant diseconomies have been found for banks constrained to produce at single offices by unit banking laws (Berger, Hanweck, and Humphrey).

These studies analyzed relatively small banks and in most cases utilized data from the Federal Reserve System's Functional Cost Analysis (FCA) Program. While rich in cost allocation detail, FCA samples include a very limited number of banks which are not representative of the industry (Heggestad and Mingo, 1978), may be of insufficient size to generate results not deteriorated by multicollinearity resulting from the use of flexible function forms, and exclude the very banks (those over $1 billion in assets) which are most likely to be involved in acquisitions and market expansion.[1]

Analyses of costs for large commercial banks are not nearly as prevalent. Additionally, there has been a near total neglect of the role of technical change on bank production costs. In light of the significant advances in electronic technology which have been incorporated into bank operations in recent years the potential effect on bank costs could be substantial.[2] Studies by Shaffer (1984) and Hunter and Timme (1986; hereafter HT) consider large banks and find significant scale economies. HT also evaluated the effect of technical change on production and found it to be important in determining bank costs and to enhance scale effects.

Most of the bank cost studies in the 1980s have utilized developments in duality theory as developed and refined by Hoteling (1932) and Shephard (1953, 1970), and summarized in Diewert (1971, 1974) and Jorgenson (1986). While duality theory and the adoption of flexible functional forms have produced advances in modeling bank costs, there is evidence that the functional forms used may still be too restrictive. Duality implies that under certain conditions the cost function provides a description of the production process that is equivalent to that provided by the production function. Additionally, given that the conditions hold, the factor shares can be derived directly via differentiation from the cost function--Shephard's Lemma. The conditions required to generate the dual cost function are firm cost minimization in competitive markets constrained *only* by the predetermined output level, and certain regularity conditions to produce well behaved cost functions.[3]

It is seriously doubtful that these conditions hold in banking. Despite the trend toward deregulation, the banking industry still is heavily supervised and behavior is obviously restrained.[4] Restrictions include reserve requirements, capital requirements, geographic and product limitations, usuary laws, loan size limitations, allowable interest on certain deposit accounts, and market entry barriers. The regulatory constraints are likely to significantly alter the optimum choice of inputs from the firm's perspective because the marginal cost of utilizing an additional unit of an input may be significantly different from what it would be without the additional constraints.[5] For example, assume for illustrative purposes that a bank operates in a market where limited branching is allowed and prices on deposits are limited by regulation to below-market levels. The role of physical capital may now be significantly expanded. Office proliferation may occur as a means to compete for deposits and the perceived return on these expenditures, or conversely the effective price of the capital, will be affected. Thus, in determining *true* or *effective* input prices the bank manager will account for the additional constraints. Other restrictions will similarly lead to adjustments in marginal behavior. While the direction and magnitude of the distortions produced by banking restrictions are not obvious, there is little reason to believe they are offsetting.

Atkinson and Halvorsen (1980; hereafter AH) found that regulation-induced distortions rendered use of the traditional neoclassical cost function inappropriate. Evaluating the costs of electric utility companies, the traditional cost model was shown to produce significantly biased estimates of cost parameters, scale effects, factor shares, and price elasticities.

HT directly evaluated the role of technical change on the cost structure of commercial banks. They analyzed the effect of this change on scale elasticities and the effect of organization structure on the role of technology. However, if cost minimization behavior in banking is altered by regulatory constraints in the manner found by AH, then HT's use of the restrictive neoclassical cost function may produce biased estimates of the role of technology. This may partially explain some of their results which we believe to be counter intuitive. What is needed is a more general bank cost model which allows for distortions induced by regulation and the resulting change in cost minimizing behavior.

In the next section we present a model which has been utilized in slightly different forms by AH (1980, 1984), Lau and Yotopoulos (1971), Lovell and Sickles (1983), and Toda (1976, 1977). It is more general than the neoclassical model because a modified version of Shephard's Lemma is used in which cost minimizing behavior is based on *shadow* input prices. These prices account for distortions created by regulation. The neoclassical cost function is shown to be a special case of the general model when regulation is not binding.

2. A GENERALIZED MODEL OF BANK COSTS--THE SHADOW-PRICE MODEL

The Theoretical Model

AH derived the shadow price (SP) model and applied it to production under regulatory constraint in the U.S. electric power industry. In modeling the production behavior of large banks, we directly apply their SP model, augmented to include variables pertinent to banking. Derivation of the SP model inclusive of our modifications is summarized in this section.[6]

In the neoclassical cost model firms are assumed to minimize costs in the Lagrangian-constrained cost function given by:

$$L = \mathbf{P}'\mathbf{X} - \mu[f(\mathbf{X},\mathbf{Z})-Q] \tag{1}$$

where $\mathbf{P}$ and $\mathbf{X}$ are m x 1 vectors of input prices and quantities, respectively; $f(\mathbf{X},\mathbf{Z})$ is a well-behaved neoclassical production function; $\mathbf{Z}$ is a vector of exogenous variables; Q is output; and μ is a Lagrangian multiplier.

From the first-order conditions for cost minimization, the marginal rate of technical substitution between inputs i and j is equal to the ratio of prices of the two inputs. That is,

$$\frac{f_i}{f_j} = \frac{P_i}{P_j} \qquad i \neq j = 1,\ldots m, \qquad (2)$$

where $f_i \equiv \partial f/\partial X_i$ is the marginal product of input i, and P_i is the price of input i. Given input prices, and the predetermined level of output as the only constraint, the optimal combination of inputs can be derived to minimize costs.

Assume now that additional constraints exist. The Lagrangian-constrained cost function to be minimized becomes:

$$L = \mathbf{P}'\mathbf{X} - \mu[f(\mathbf{X},\mathbf{Z})-Q] - \sum_{h=1}^{n}\lambda_h R_h(\mathbf{P},\mathbf{X}) \qquad (3)$$

where R_h (h=1,...,n) are constraints arising from regulation, and λ_h (h=1,...,n) are Lagrangian multipliers. From the first-order conditions for cost minimization, the marginal rate of technical substitution between inputs i and j is equal to the ratio of effective prices of the two inputs. That is,

$$\frac{f_i}{f_j} = \frac{P_i + \sum_{h=1}^{n}\lambda_h \partial R_i/\partial X_i}{P_j + \sum_{h=1}^{n}\lambda_h \partial R_j/\partial X_j} = \frac{P_i^*}{P_j^*} \qquad (4)$$

$$i \neq j = 1,\ldots m,$$

where P_i^* is the effective or *shadow price* of input i.

In the absence of binding regulatory constraints, equation (4) reduces to the neoclassical condition whereby the marginal rate of technical substitution equals the ratio of *market prices* of inputs;

$$\frac{f_i}{f_j} = \frac{P_i}{P_j} = \frac{P_i^*}{P_j^*} \qquad i \neq j = 1,\ldots m. \tag{5}$$

This special case is referred to as the Market-Price (MP) Model and is nested within the more general Shadow-Price (SP) Model.

The shadow prices of the inputs are not directly observable. Therefore, following Lau and Yotopolous (1971) and AH (1984), the shadow prices are approximated by

$$P_i^* = k_i P_i \qquad i = 1,\ldots,m, \tag{6}$$

where k_i is an input- and firm-specific factor of proportionality. As noted by AH, the shadow-price approximations can be interpreted as first-order Taylor's series expansions of arbitrary shadow-price functions. When regulation is nonbinding, all shadow prices equal the respective market prices, implying $k_i = 1$ for all i, and the shadow cost function reduces to the neoclassical cost function.

Differing from the neoclassical cost function only in the input-price variables, the shadow cost function is given by

$$C^S = C^S(\mathbf{kP}, Q, \mathbf{Z}), \tag{7}$$

where $\mathbf{kP}$ is a vector of shadow prices of inputs.
Applying Shephard's Lemma (1970), the set of derived input demand functions can be obtained:

$$X_i = \frac{\partial C^S}{\partial (k_i P_i)}. \tag{8}$$

Using equation (8), the firm's total *actual* cost is

$$C^A = \mathbf{P'X} = \sum_{i=1}^{m} P_i \frac{\partial C^S}{\partial (k_i P_i)}. \tag{9}$$

The shadow factor-cost shares are obtained by logarithmic differentiation of C^S:

$$M_i^S = \frac{\partial \ln C_i^S}{\partial \ln (k_i P_i)} = \frac{k_i P_i X_i}{C^S} \qquad i = 1, \ldots, m. \tag{10}$$

Rearranging equation (10),

$$X_i = \frac{M_i^S C^S}{k_i P_i} \qquad\qquad i = 1, \ldots, m, \tag{11}$$

and substituting equation (11) into equation (9) gives,

$$C^A = C^S \sum_{i=1}^{m} \frac{M_i^S}{k_i}. \tag{12}$$

Taking logarithms,

$$\ln C^A = \ln C^S + \ln \sum_{i=1}^{m} \frac{M_i^S}{k_i}. \tag{13}$$

Using equations (11) and (12), *actual* factor-cost shares can also be obtained,

$$M_i^A = \frac{P_i X_i}{C^A} = \frac{M_i^S k_i^{-1}}{\sum_{i=1}^{m} M_i^S k_i^{-1}} \qquad i = 1, \ldots, m. \tag{14}$$

Intuitive Comparison of the SP and MP Cost Models

In the MP model it is assumed that the observed and optimal combination of inputs are equal and are determined by the observed input prices. Accordingly, the observed and optimal costs are equivalent and determine the behavior of the firm. The SP model differentiates optimal and observed behavior by allowing for the effect of additional constraints which may cause the observed and effective input prices to differ. Thus, the input combination is adopted in response to the effective or shadow input prices. The resulting shadow cost function is a more comprehensive representation of costs to be minimized and is the appropriate dual to the production process. The SP model also allows one to calculate the optimal (unobserved) input combination given observed prices, **P**. This combination of inputs is relevant for measuring the cost differences resulting from production under competitive conditions and those under binding regulatory constraints. Correspondingly, differences in C^A computed with **P** and $\mathbf{P}^*$ measure the cost of the binding constraints. We employ this procedure in Section 4.

Estimation of the SP model produces two sets of results. Although both are derived by using a modified version of Shephard's Lemma, the actual, C^A, and shadow cost, C^S, estimates are conceptually different. C^A results are based on observed data and are useful for forecasting observed behavior. C^S estimates represent optimizing behavior incorporating all relevant information and, although not directly observable, are the more meaningful of the two expressions if one is interested in evaluating or influencing bank behavior. This can be illustrated with an example. Bank regulators may be interested in evaluating the effect of regulation on factor shares and may observe that as regulation increases, the capital share increases. Regulation is therefore determined to be capital using in banking; a result similar to that found in other industries. However, viewing observed input prices, quantities, and shares may be misleading. Bankers may actually attempt to economize on capital as regulation increases, but this effect may be obscured in the observed data. It is the shadow input prices which are actually influencing behavior. Bankers may consider the true, effective cost of capital to be significantly lower than the market price as a direct result of regulation. Thus, the product of the quantity of capital used and the shadow price may decline, i.e., regulation may actually be capital saving.[7] Bank regulatory policies, or an evaluation of those policies, based on the observed data may be misguided.

3. EMPIRICAL SPECIFICATIONS AND DATA SOURCES

In applying the Shadow-Price Model to large U.S. banks, the following empirical specifications are adopted:

1. Z is specified to include the following variables:

   B = Number of bank offices,

   H = Holding company structure (H = 1 for banks in multi-bank holding companies; H = 0 for banks in one-bank holding companies),

   T = A time trend to account for technological change.

2. Banks produce a single output by utilizing the services of two inputs: labor (L) and capital (K).

3. The shadow cost function is specified in translog form, a convenient approximation to an arbitrary continuous twice-differentiable function. Total shadow cost is specified as linearly homogeneous in shadow prices.

4. The shadow price factors, k_i (i = L,K), are specifed as input specific but as identical across banking firms. Ideally, k_L and k_K would be input, firm, and time specific, but such generality is beyond the scope of our empirical estimation.[8] The shadow price factor for labor, k_L, is set equal to unity; the shadow price factor for capital, k_K, is a parameter to be

estimated. The absolute values of k_L and k_K cannot be estimated, given that the equations for total actual cost and factor cost shares are homogeneous of degree zero in k_L and k_K. Therefore, we cannot test for absolute price efficiency, but can test for relative price efficiency ($k_L = k_K$).

The total shadow cost function in translog form is

$$\begin{aligned}
\ln C^S = {} & \beta_0 + \beta_Q \ln Q + (1/2)\beta_{QQ}(\ln Q)^2 + \textstyle\sum_i \gamma_{iQ} \ln Q \ln(k_i P_i) + \sum_i \beta_i \ln(k_i P_i) \\
& + (1/2)\textstyle\sum_i \sum_j \gamma_{ij} \ln(k_i P_i)\ln(k_j P_j) + \phi_T \ln T + (1/2)\phi_{TT}(\ln T)^2 \\
& + \theta_{QT} \ln Q \ln T + \textstyle\sum_i \gamma_{iT} \ln(k_i P_i) \ln T + \beta_B \ln B + (1/2)\beta_{BB}(\ln B)^2 \\
& + \gamma_{QB} \ln Q \ln B + \gamma_{TB} \ln T \ln B + \textstyle\sum_i \gamma_{iB} \ln(k_i P_i) \ln B + \beta_H H \\
& + \gamma_{HQ} H \ln Q + \gamma_{HT} H \ln T + \gamma_{HB} H \ln B + \textstyle\sum_i \gamma_{iH} \ln(k_i P_i) H \qquad (15) \\
& \qquad i = L,K \qquad j = L,K
\end{aligned}$$

where $\gamma_{LK} = \gamma_{KL}$. Linear homogeneity in shadow prices implies the following adding-up restrictions on parameters:

$$\textstyle\sum_i \beta_i = 1, \ \sum_i \gamma_{iQ} = \sum_i \gamma_{iB} = \sum_i \gamma_{iT} = \sum_i \gamma_{iH} = 0$$

$$\textstyle\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = \sum_i \sum_j \gamma_{ij} = 0 \qquad i,j = L,K. \qquad (16)$$

Shadow cost shares for the translog specification are derived by logarithmic differentiation of C^S in equation (15):

$$\begin{aligned}
M_i^S & = \frac{\partial \ln C^S}{\partial \ln(k_i P_i)} \\
& = \beta_i + \textstyle\sum_j \gamma_{ij} \ln(k_j P_j) + \gamma_{iQ} \ln Q \\
& \quad + \gamma_{iT} \ln T + \gamma_{iB} \ln B + \gamma_{iH} H \qquad i,j = L,K. \qquad (17)
\end{aligned}$$

From equations (13), (15), and (17), total actual costs are

$$\ln C^A = \ln C^S + \ln\{ \textstyle\sum_i [\beta_i + \sum_j \gamma_{ij} \ln(k_j P_j) + \gamma_{iQ} \ln Q$$

$$+ \textstyle\sum \gamma_{iT} \ln T + \sum \gamma_{iB} \ln B + \sum \gamma_{iH} H] k_i^{-1} \} \qquad (18)$$

$$i,j = L,K,$$

where $\ln C^S$ is given in equation (15).

Using equations (11), (12), (14), and (17), actual cost shares are given by

$$M_i^A = [\beta_i + \textstyle\sum_j \gamma_{ij} \ln(k_j P_j) + \gamma_{iQ} \ln Q + \gamma_{iT} \ln T + \gamma_{iB} \ln B + \gamma_{iH} H] k_i^{-1} /$$

$$\textstyle\sum_i [\beta_i + \sum_j \gamma_{ij} \ln(k_j P_j) + \gamma_{iQ} \ln Q + \gamma_{iT} \ln T + \gamma_{iB} \ln B + \gamma_{iH} H] k_i^{-1}$$

$$i,j = L,K. \qquad (19)$$

Equation (18) and one of the share equations (19), appended with classical additive disturbance terms, constitute the set of equations to be jointly estimated. One share equation is dropped because of the singularity of the variance-covariance matrix of the error terms for the three-equation system resulting from the adding-up conditions on the share equations. We arbitrarily drop the capital-share equation and jointly estimate the total actual cost and actual labor-share equations. The empirical results are invariant to the choice of share equation deleted and to the normalization, $k_L = 1$, for the labor shadow-price factor.[9]

Data

To estimate the generalized cost function a panel data set for the years 1972-87 was collected that consisted of data for the largest banks in the U.S. which were members of a holding company over the entire period. The final data set, after eliminating some banks because of data problems in individual years, consisted of 164 banks for a total of 2,624 observations. This sample is similar to that used by HT, although there are more banks and five additional recent years of data included. Therefore, differences in results could be the consequences of different samples and estimation methods, as well as the different model specification.

The Federal Reserve Call Report was the major data source. Costs, C, were defined as the sum of expenditures on labor and physical capital. Bank output, Q, was defined as the dollar value of loans and investment securities. Alternative balance sheet output measures were considered and produced similar results, some of which are summarized in the appendix.[10] The number of banking offices, B, was also taken from the Call Report as was the type of bank holding company organization, H. Technical progress was accounted for with a time trend, T = 1,2,...,16. The input price for labor, P_L, was obtained from the Bureau of Labor Statistics. State level wage trends were collected for each year and assigned to each bank according to the location of its home office. The price of physical capital, P_K, was approximated from Call Report data as the ratio of physical capital expenditures measured as additions to plant and equipment, furniture, and physical premises, to the reported book value of net bank premises, furniture and physical equipment.

4. EMPIRICAL RESULTS

In this section, various hypotheses nested within the shadow-price model are tested, and estimated elasticities of scale, technical change, and input demand and substitution are presented. Results are reported for all banks in the sample and for the subsamples of banks in MBHCs and OBHCs, respectively.

Basic Results and Hypothesis Tests

Table 1 contains the coefficient estimates for both the shadow-price (SP) and market-price (MP) models estimated by the iterated seemingly unrelated regression method with the parameter restrictions in equation (16) imposed. While not globally stable, the stability conditions are met for all data points in our sample.[11] The parameter estimates and generalized R^2 results for the SP and MP models appear quite similar. However, closer scrutiny reveals that the two models are not equivalent. Results from the more general SP model suggest that the additional production constraints are binding. The estimated value for k_K, .562, which is significantly different from one in a statistical sense, suggests that bank managers perceive the price of physical capital to be less than the observed market price. Additionally, the likelihood-ratio test of relative price efficiency ($k_L=k_K=1$) indicates strong rejection of the MP model relative to the more general SP model, as shown by the test results in Table 2. Therefore, except for direct comparison of the two models to get an indication of the extent of the potential bias produced by the commonly used MP model, our discussion will concentrate on the results from the SP model.

Scale Economies

To test for returns to scale in the SP model, the elasticity of total actual cost with respect to output--i.e., the actual scale elasticity--was derived by differentiation of equation (18).

$$SE^A = \frac{\partial \ln C^A}{\partial \ln Q} = \beta_Q + \beta_{QQ}\ln Q + \sum_i \gamma_{iQ}\ln(k_i P_i)$$

$$+ \theta_{TQ}\ln T + \theta_{BQ}\ln B + \theta_{HQ}H + \frac{\sum_i k_i^{-1}\gamma_{iQ}}{\sum_i k_i^{-1}M_i^S} \qquad i=L,K. \qquad (20)$$

The shadow cost measure is given by the right-side expression in equation (20) with the last term deleted,

$$SE^S = \frac{\partial \ln C^S}{\partial \ln Q} \qquad (21)$$

If the production process everywhere exhibits constant returns to scale, then $\beta_Q = 1$ and all other coefficients in equation (20) equal zero. Likelihood-ratio test results based on the SP model, estimated with and without these restrictions, are shown in Table 2. The hypothesis of constant returns to scale is strongly rejected. Table 2 also shows the relevant parameter restrictions and likelihood-ratio test statistics for the testing and rejection of homogeneity and homotheticity of the production function.

Estimated scale elasticities were also calculated at specific data points. Estimates were derived for (1) each observation in the sample, (2) at the grand means of data for the entire sample, and (3) at the means of the data for the MBHC and OBHC subsamples. For the SP model, results for both shadow and actual scale elasticities, SE^S and SE^A, are reported in Table 3.

As shown in Panel (a) of Table 3, the estimated averages for SE^S and SE^A are less than unity in all cases, indicating increasing returns to scale for both MBHCs and OBHCs. Panel (b) of Table 3 shows that actual scale elasticities were less than unity for all observations on OBHCs and for 97 percent of the observations on MBHCs. Closer viewing of the three percent of the institutions displaying decreasing returns to scale revealed that the majority of them were located in unit banking states. This finding is consistent with earlier studies that found greater diseconomies in states limiting bank branching.

For comparative purposes, scale elasticities were calculated using the coefficient estimates from the MP model. As shown in Panel (c) of Table 3, the actual scale elasticities (SE) at the means of the data for all observations, for MBHCs, and for OBHCs were quite close to the corresponding estimates from the SP model. However, a test of the equality of the resulting mean estimates of the two models (SE vs. SE^A or SE^S) suggested that the estimates were statistically different. All of these estimates, however, indicate considerably smaller economies of scale than were reported by HT. The mean value of SE reported by HT was 0.71 for MBHCs and 0.69 for OBHCs.

In Panel (c) of Table 3, we have included estimates for the MP model of mean values of a measure of augmented scale economies (ASE) originated by Benston, Hanweck, and Humphrey (1982) and also employed by HT. The ASE measure is designed to capture both the direct effect of an increase in output on cost and the indirect effect arising from the effect of higher output on the number of bank offices utilized in production. ASE is defined as

$$ASE = SE^A + \frac{\partial \ln C}{\partial \ln B}\frac{\partial \ln B}{\partial \ln Q}. \tag{22}$$

Our estimates indicate relatively minor augmented economies of scale for MBHCs and insignificant augmented economies for OBHCs.[12]

Impact of Technical Change

The impact of technical change on bank costs is explored by examining the elasticity of cost with respect to the time trend, T.

$$\begin{aligned} TCH^A &= \frac{\partial \ln C}{\partial \ln T} \\ &= \phi_T + \phi_{TT}\ln T + \textstyle\sum_i \gamma_{iT}\ln(k_i P_i) \\ &\quad + \theta_{QT}\ln Q + \theta_{TB}\ln B + \theta_{TH}H + \frac{\sum_i k_i^{-1}\gamma_{iT}}{\sum_i k_i^{-1}M_i^S} \qquad i=L,K. \end{aligned} \tag{23}$$

The technical-change elasticity of shadow cost TCH^S is given by the right-side expression for the elasticity of actual cost TCH^A

in equation (23) with the last term excluded. Technical advancement is gauged by the extent to which these measures are less than zero. Based on calculations at the means of the data, our estimates suggest significant technical progress. As shown in Panel (a) of Table 3, our results suggest greater technical progress on average for MBHCs than for OBHCs. This is in line with our priors and suggests that economies of technology dissemination within the MBHC organization form exists. However, the finding is in direct conflict with the conclusion from HT. Evaluation of technical progress at each data point showed that 91.6 percent of the observations produced negative values for TCH^S. Once again, MBHCs were found to realize larger benefits from technology.

The results presented in Table 3 can be used to compare the role of technology in the MP and SP models to get an indication of the extent of the bias produced by utilizing the more restrictive model. Relative to the SP model the MP model is shown to understate the effect of technical change (TCH^S=-0.338 and TCH=-0.306) and the difference is statistically significant. Thus, previous estimates of the role of technical change may be misleading.

The influence of technical change on scale economies is examined by differentiating the scale elasticity with respect to lnT. We focus on the effect of lnT on unaugmented scale elasticities. Differentiating SE^A in equation (20) with respect to lnT, and using equation (17) gives,

$$TCHSE^A = \frac{\partial SE^A}{\partial \ln T} = \frac{\partial^2 \ln C^A}{\partial \ln C \partial \ln T}$$

$$= \theta_{QT} - \sum_i k_i^{-1} \gamma_{iT} \frac{\sum_i k_i^{-1} \gamma_{iQ}}{(\sum_i k_i^{-1} M_i^S)^2} \qquad i=L,K. \qquad (24)$$

Differentiating SE^S as defined in equation (21) gives,

$$TCHSE^S = \frac{\partial SE^S}{\partial \ln T} = \theta_{QT}, \qquad (25)$$

the first term of $TCHSE^A$ in equation (24).

Using the grand mean data for all banks and the parameter estimates from the SP model, our estimates of $TCHSE^A$ and $TCHSE^S$ in Table 3 imply that technical change has led to modest decreases on average in economies of scale. Thus, the average cost curve has flattened over time. This coincides with findings from other industries in which technology makes it easier to produce output and is used as a means to break down scale barriers and make size less important. This appears reasonable given the declining price and increased efficiency of technical advances, particularly computer technology (Bresnahan 1986), over the period analyzed. These results contrast with the HT findings that technical change had actually enhanced economies of scale. That is, their results suggests it essentially serves as a barrier as it makes size more advantageous.

Finally, the effect of technology on factors shares can also be derived. For the shadow cost function, differentiation of equation (19) gives,

$$\frac{\partial M_i^S}{\partial \ln T} = \gamma_{iT} \tag{26}$$

From Table 1, $\gamma_{LT} = -0.012$ suggesting that technology is labor saving and, equivalently, capital using relative to labor. Again, this is in agreement with expectations and coincides with what has been found in other industries.

Elasticities of Demand and Substitution

The own-price elasticity of demand for the input i, holding Q constant, is given by

$$\eta_{ii} \equiv \frac{\partial X_i}{\partial P_i}\frac{P_i}{X_i} = \frac{M_i^S(M_i^S-1)+\gamma_{ii}}{M_i^S} \tag{27}$$

using X_i as defined in equation (11)

The cross-price elasticity of demand for a constant output is

$$\eta_{ij} \equiv \frac{\partial X_i}{\partial P_j}\frac{P_j}{X_i} = \frac{M_i^S M_j^S+\gamma_{ij}}{M_i^S} \tag{28}$$

Table 4 displays the results for these elasticities calculated at the grand means of the data for all banks in the sample and for the MBHC and OBHC subsamples. Because of the coefficient restriction in our two-input model, the own- and cross-price elasticities are equal in absolute value and opposite in sign. Concentrating on the SP model, the own-price elasticity estimates were the same to two decimal places for MBHCs and OBHCs. The own-price elasticity for each input is negative but less than unity in absolute value, with the estimated own-price elasticity of the demand for capital being relatively greater than the own-price elasticity of labor demand. As required for the two-input case, the cross-price elasticities are positive, indicating that the inputs are gross substitutes. Results from the MP model are also presented in Table 4. Once again the results from this rejected model differ significantly from those using the more general model.

Estimates for the Allen (1966) partial elasticities of substitution, also shown in Table 4, are given by

$$\sigma_{ij} = \frac{1}{M_j^S} \eta_{ij} = 1 + \frac{\gamma_{ij}}{M_i^S M_j^S}. \tag{29}$$

The estimated σ_{LK} (= σ_{KL}) are greater than zero, as required for inputs that are substitutes, and are very nearly the same for MBHCs and OBHCs based on the coefficient estimates from either the SP or MP model.

Regulatory Costs and Factor Shares

The effects of regulation on actual production costs and factor utilization are investigated by comparing results for the SP model under the alternative assumptions of relative price efficiency and inefficiency. Estimated actual production costs and factor shares under relative price efficiency are calculated by using the estimated parameters of the SP model, except with $k_K = k_L = 1$ imposed. Results under relative price inefficiency are obtained by using the estimated coefficients of the SP model, inclusive of $k_K = 0.562$. The estimates of total production costs and factor shares, shown in Table 5, are based on calculations at the grand means of the data sets for all banks, MBHCs, and OBHCs.

For all banks, the estimated regulatory costs arising from relative price inefficiency amount to 1.8 percent greater total (and average) production costs than would have prevailed under relative price efficiency. This would translate into a significantly greater effect on bank returns on equity or assets. The regulation-induced effects are about the same for MBHCs and OBHCs.

As stated earlier, analyzing C^A could result in significantly misleading information to parties interested in evaluating cost elements which influence behavior. A revealing example of this is seen when evaluating the effect of regulation on factor shares. Viewing the results in Table 5 for C^A the share of capital increases significantly with regulation--from 17 to 25 percent. However the share of capital actually *decreases* with regulation when the more meaningful shadow cost shares are considered.[13] Thus, while the observed capital share increases, bank managers actually economize on physical capital based on their perceived price of capital, including the costs of regulatory constraints.

Potential Explanations for Price Inefficiency in Banking

The estimated value of k_K=.562 suggests that, relative to labor, bankers perceive the *true* price of physical capital to be significantly less than the market price. We have discussed how this alters cost elements and the behavior of bank management. An obvious question exists: Why do bankers perceive the effective price of capital as being relatively inexpensive? Although alternative explanations may exist, three tentative explanations are offered here. First, to convince current and potential customers that the institution is a credible and viable alternative and will be in the market over the long-haul, bank management may spend large sums to generate an imposing physical structure. The behavior is part of a long run strategic plan. This "commitment theory" coincides with the observed ornate architecture and plush surroundings found at many large commercial banks. Second, if financial capital requirements are binding then more equity capital would be raised than would be generated without the requirement. The resulting suboptimal debt-equity ratio may result in expenditures for physical capital which would not have occurred without the regulated capital requirement. Finally, as a direct result of regulation, bankers frequently compete on a non-price basis (Evanoff 1989, Kolari and Zardkoohi). One means of doing this is to increase service through additional capital expenditures on offices and teller machines.

5. SUMMARY AND CONCLUSIONS

Researchers making recent contributions to the bank cost literature have distinguished their efforts by utilizing alternative data sources, output measures, measures of economies of scale and scope, and alternative means to account for differences in the the cost structures of unit and branch banks. Our contribution is more basic. It is a fundamental critique of the methodology used in these studies. Each employs a neoclassical cost framework based on the assumption of cost minimization in competitive markets characterized by relative price efficiency. Given the extent of regulation in the banking industry, there is significant reason to doubt the validity of this assumption.

We estimate bank production costs and factor shares, taking into account the influences of technical progress. The empirical results are based on a model which incorporates a modified version of Shephard's Lemma. The model is based on minimization of costs which reflect "shadow" input prices which may deviate from market prices because of the influence of regulatory constraints. The model based on this shadow price behavior subsumes the neoclassical model as a special case. Our empirical results suggest that use of the neoclassical specification is inappropriate for our sample of banks, i.e., relative price efficiency is rejected.

Using the new methodology, scale economies are found for the sample of banks considered. Technical progress was found to be substantial, but, in contrast to past findings, the results indicated that technical progress tended to decrease scale economies and was most beneficial to multibank holding companies. Results from the alternative model estimations under relative price efficiency (the MP model) and under relative price inefficiency (the SP model) revealed small differences in own- and cross-price elasticities of demand for input and Allen elasticities of substitution. Nevertheless, the results indicate that the influence of regulatory constraints should be incorporated into the modeling and estimation of large-bank production costs, given that the MP model was strongly rejected under the likelihood ratio test.

The results suggest that the cost of regulation for the sample banks on average is about 2 percent of actual costs. Future bank studies should account for the inefficiencies induced by regulation, attempt to measure the extent of the inefficiency and the implications, and provide input to policymakers concerned with reducing regulatory costs without altering the safety of the industry.

FOOTNOTES

[1]Shortcomings of the FCA data are discussed in Heggestad and Mingo (1978), McNulty (1983) and Gilligan and Smirlock (1984).

[2]See Lawrence and Shay (1986), and Solomon (1987), for discussions of the impact of telecommunications advances on the financial industry. Bell and Murphy (1968) attempted to indirectly account for the effect of technology on scale effects in banking.

[3]The standard regularity conditions include (1) positivity, (2) homogeneity, (3) monotonicity, and (4) concavity. See Jorgenson (1986) for a discussion of the conditions.

[4]Empirical studies of bank costs have ignored the potential problems resulting from violation of the competitive markets requirement embedded in the neoclassical model. Studies in other industries explicitly recognized the potential problem and discussed the resulting biases, but ignored the problem in estimation, e.g., McMullen and Stanley (1988) and Christensen and Green (1976). While studies of regulated utilities have attempted to account for regulation-induced distortions in the use of inputs--Joskow (1974), Nelson and Wohar (1983), and Israilevich and Kowalewski (1988)--only recently has this been incorporated into a generalized cost model--Atkinson and Halvorsen (1980, 1984).

[5]The idea that regulation distorts the optimal combination of inputs has most commonly been associated with the rate of return regulation of public utilities. However, its usefulness is obviously not limited to this form of regulatory restriction. For example, AH mention the potential role of electric utility company fuel adjustment clauses and environmental regulations in leading to the invalidity of Shephard's Lemma with respect to market input prices. Greenbaum and Haywood (1971) discuss the potential cost of regulation to the financial industry. Consistent with previous studies, we attribute the divergence of market and shadow prices entirely to regulatory effects. It is possible that other factors which occur as a result of noncompetitive behavior such as satisficing, or consistent data measurement errors could account for some of the difference. It should also be emphasized that we are discussing private market efficiency. *If* regulation is effectively dealing with externalities which are not taken into account by bank managers, the resulting private market inefficiency is the unavoidable private cost of minimizing the total social cost of bank operations.

[6]Also see AH (1984, pp. 648-54). The AH model builds upon the Lau and Yotopolous (1971) model of relative price efficiency.

[7] The events discussed in this example are precisely what we find when the more generalized model is estimated.

[8]To the extent that the firms evaluated are homogeneous with respect to their technology and the burden of regulation, the restriction of identical k_i values is appropriate.

[9]To check the estimation specifications we reestimated the SP and MP models with the cost and capital-share equations--i.e., with the labor-share equation deleted. The results were invariant. Invariance in the two-input case follows from the fact that all relevant parameter restrictions can be imposed on the two-equation subsystem, including the symmetry restriction across share equations. Obviously, zero row and column sums for the substitution matrix (i.e., matrix of input-price coefficients) of the share equations imply symmetry of the substitution matrix in the two-input case. This property of the two-input case accounts for the invariance of results that HT could not fully explain for their model. See HT, footnote 9, p. 159.

[10]The authors are fully aware of the controversy concerning appropriate measures of bank output. A number of recent studies have utilized a "production approach" and measured output as the *number* of loans, deposit accounts, or credit card accounts--e.g., Benston, Hanweck and Humphrey (1982), Berger, Hanweck and Humphrey (1987), Pavel and Binkley (1987) and Benston (1965). Others have utilized an "intermediary approach" measuring output as the *dollar value* of loans, deposits, securities, assets, or some combination of these balance sheet items--e.g., Sealey and Lindley (1977), Shaffer (1981, 1984, 1985), HT (1986),

and Kolari and Zardkoohi (1987). Additionally, recent studies have taken a multiproduct approach and have tested for jointness in production using various physical unit and dollar value measures of output. The lack of a consensus on the theory of banking renders the appropriate output measure an unsettled issue. Sealey and Lindley make what many consider to be a compelling case for using earning assets as outputs. Like HT we follow this approach. As discussed in HT, even if one wanted to use the "production approach", data limitations preclude it for large banks. Also like HT, we assume that the production process of raising funds is separable. The choice of an appropriate output measure is actually even more complex than deciding between physical unit or dollar value measures. The problem is further exacerbated by the presence of intangibles in bank output such as differing levels of service (e.g., see Evanoff 1988). We are interested in the cost structure of large banks with special emphasis on regulatory distortions and technical progress. For comparison purposes we use an output measure similar to that used by others evaluating these aspects of bank costs.

[11]The first two regularity conditions (footnote 3) are satisfied by the restrictions imposed in (16). Monotonicity requires that all the factor shares be positive. The second order condition requires that the cost function be concave in the input prices. In the two input case this condition is met if the Allen price elasticity is nonnegative, i.e.,

$$\sigma_{ij} = 1 + \frac{\gamma_{ij}}{M_i(1-M_i)} \geq 0$$

The maximum value for $M_i(1-M_i) = 0.25$, therefore, global satisfaction of the second order condition requires $\gamma_{ij} \geq -0.25$. From our results, and the restrictions in (16), $\gamma_{LK} = -\gamma_{LL} = -.033$. Thus the second order condition is met so long as M_i is less than $\approx .97$. This occurs for each data point in our sample and, realistically, it is difficult to imagine a large commercial bank with a labor or capital share greater than 97 percent. It is interesting to note that the SP model is less likely to have observations which violate this requirement than is the MP model.

[12]It should be emphasized that this alternative measure of scale economy is appropriate only to the extent that bank service demand is geographically dispersed; otherwise the bank could simply set up independent operations at one site. Following Benston, *et al.* (1982), HT obtained an estimate of $d \ln B / d \ln Q$ from the estimated coefficients of an auxiliary regression given by $\ln B = \alpha_0 + \alpha_1 \ln Q + \alpha_2 (1/2)(\ln Q)^2$. Using grand-mean data for lnQ, HT obtained an estimate of 0.725 for the elasticity of branches with respect to output. We estimated the effect of output on branches from the coefficient on lnQ in the auxiliary regression $\ln B = a_0 + a_1 \ln Q + a_2 \ln T$. This alternative specification was motivated by concerns over serial correlation of the error term in the auxilary regression. Our

estimated elasticity of B with respect to Q was 0.70. As in HT, the elasticity was assumed to be constant.

[13]Alternatively, the effect of regulation on factor shares can be seen by differentiation of equations (17) and (19) with respect to k_i--recognizing k_K decreases with regulation. For the shadow cost (SP^S) function, differentiation of (17) generates

$$\frac{\partial M_i^S}{\partial k_i} = \sum_i \frac{\gamma_{ij}}{k_j}$$

which, since $\gamma_{KL} = -\gamma_{LL}$, declines with regulation as k_K decreases from one.

Table 1. Estimation Results for the MP and SP Models

Coefficient	MP Model (k_K=1)	SP Model
β_0	-0.930 (0.97)	-1.104 (1.16)
β_L	0.544 (45.4)**	0.679 (23.4)**
β_K	0.456 (38.1)**	0.321 (11.1)**
β_Q	0.577 (4.06)**	0.573 (4.04)**
β_{QQ}	0.020 (1.88)	0.020 (1.87)
γ_{LL}	0.048 (30.6)**	0.033 (10.2)**
γ_{LQ}	0.0075 (8.31)**	0.0051 (6.56)**
γ_{LB}	-0.0003 (0.52)	-0.00005 (0.11)
γ_{LH}	-0.0034 (1.88)	-0.0020 (1.53)
γ_{LT}	-0.018 (14.0)**	-0.012 (8.56)**
β_B	0.151 (2.49)*	0.106 (1.75)
β_{BB}	0.033 (4.30)**	0.025 (3.28)**
β_H	0.070 (0.39)	0.072 (0.40)
ϕ_T	-0.078 (0.59)	-0.132 (1.01)
ϕ_{TT}	-0.237 (10.7)**	-0.253 (11.4)**
θ_{QB}	-0.0090 (1.75)	-0.0044 (0.86)
θ_{QH}	0.023 (1.63)	0.021 (1.44)
θ_{BH}	-0.062 (6.27)**	-0.056 (5.57)**
θ_{QT}	0.024 (10.7)**	0.027 (2.62)**
θ_{TB}	0.0018 (0.29)	-0.0012 (0.19)
θ_{TH}	-0.084 (4.50)**	-0.085 (4.55)**
k_K	1.00	0.562 (7.77)**
Generalized R^2	.947	.948

Note: Parenthetical entries are absolute values of asymptotic t-ratios--* (**) indicating significance at the 5% (1%) level.

Table 2. Results of Hypothesis Tests

Null Hypothesis	Number of Restrictions (J)	Restrictions	LR	$\chi^2(J)$
Market-Price Model	1	$k_K = 1$	27.30	6.63
Shadow-Price Model with:				
(a) Constant Returns to Scale	6	$\beta_Q = 1$ $\gamma_{LQ} = \beta_{QQ} = \theta_{QT}$ $= \theta_{QB} = \theta_{QH} = 0$	27.30	16.81
(b) Homogeneity	5	$\gamma_{LQ} = \beta_{QQ} = \theta_{QT}$ $= \theta_{QB} = \theta_{QH} = 0$	138.69	15.09
(c) Homotheticity	4	$\gamma_{LQ} = \theta_{QT} = \theta_{QB}$ $= \theta_{QH} = 0$	127.65	13.28

Note: LR denotes the likelihood-ratio test statistic (-2 times the log-likelihood ratio); $\chi^2(J)$ denotes the chi-square value for J degrees of freedom, at the one-percent significance level.

Table 3. Scale Elasticities and Measures of Technical Change

Panel a. Shadow-Price Model

Banks	Number of Obs.	SE^S	SE^A	TCH^S	TCH^A
All banks	2624	0.924	0.921	-0.338	-0.329
		(7.47)**		(23.87)**	
MBHCs	1685	0.935	0.931	-0.392	-0.384
		(5.87)**		(23.71)**	
OBHCs	939	0.906	0.902	-0.241	-0.232
		(6.81)**		(14.20)**	

Panel b. Shadow-Price Model

	Obs. such that $SE^S < 1$		Obs. such that $TCH^S < 0$	
Banks	Number	Percent	Number	Percent
All banks	2580	98.3%	2404	91.6%
MBHCs	1651	98.0%	1596	94.7%
OBHCs	939	100.0%	808	86.0%

Panel c. Market-Price Model

Banks	Number of Obs.	SE	ASE	TCH
All banks	2624	0.916	0.978	-0.306
		(8.37)**	(2.34)*	(22.67)**
MBHCs	1685	0.928	0.972	-0.359
		(6.52)**	(2.66)**	(22.53)**
OBHCs	939	0.895	0.991	-0.210
		(7.67)**	(0.74)	(12.73)**

Note: Estimates are derived using the grand-mean values of the observations (Obs.) for all banks, multi-bank holding companies (MBHCs), and one-bank holding companies (OBHCs). Parenthetical entries are absolute values of asymptotic t-ratios. Tests of the equality of the estimated scale elasticity measure (SE vs SE^S) and effect of technical change (TCH vs TCH^S) in the two models were rejected; the calculated t-ratios were 8.5 and 6.1, respectively.

Table 4. Estimated Elasticities of Demand and Substitution

Price Elasticity		Relative Price Efficiency Not Imposed in Estimation (Shadow-Price Model)	Relative Price Efficiency Imposed in Estimation (Market-Price Model)
All banks			
η_{LL}		-0.1123	-0.1774
η_{KK}		-0.6284	-0.5601
η_{LK}		0.1123	0.1774
η_{KL}		0.6284	0.5601
MBHCs			
η_{LL}		-0.1114	-0.1763
η_{KK}		-0.6280	-0.5603
OBHCs			
η_{LL}		-0.1139	-0.1794
η_{KK}		-0.6292	-0.5597
Elasticity of Substitution			
All banks	σ_{LK}	0.7407	0.7375
		(8.65)**	(42.71)**
MBHCs	σ_{LK}	0.7393	0.7366
		(8.48)**	(41.93)**
OBHCs	σ_{LK}	0.7431	0.7391
		(8.95)**	(44.05)**

Note: Estimates are derived using grand-mean values of the data for all banks and the MBHC and OBHC subsamples.

Table 5. Estimated Costs and Factor Shares

	Fitted value with relative-price inefficiency $k_K = .562$	Fitted value with relative-price efficiency $k = 1$
All banks		
Total cost C^A	\$77,844.35	\$76,452.69
Labor share M_L^A	75.91%	82.92%
M_L^S	84.84%	82.92%
Capital share M_K^A	24.09%	17.08%
M_K^S	15.16%	17.08%
MBHCs		
Total cost C^A	\$71,233.44	\$69,948.11
Labor share M_L^A	76.05%	83.01%
M_L^S	84.93%	
Capital share M_K^A	23.95%	16.99%
M_K^S	15.07%	
OBHCs		
Total cost C^A	\$89,707.36	\$88,124.91
Labor share M_L^A	75.66%	82.74%
M_L^S	84.67%	
Capital share M_K^A	24.34%	17.26%
M_K^S	15.33%	

Note: Estimates are derived from the grand-mean values of the data for all banks and the MBHC and OBHC subsamples.

LITERATURE CITED

Atkinson, Scott E., and Robert Halvorsen. "Parametric Efficiency Tests, Economies of Scale, and Input Demand in U.S. Electric Power Generation." *International Economic Review* 25 (October 1984), 647-62.

_________________. "A Test of Relative and Absolute Price Efficiency in Regulated Utilities". *The Review of Economics and Statistics* 62 (February 1980), 185-96

Bell, Fredrick W., and Neil B. Murphy. *Costs in Commercial Banking: A Quantitative Analysis of Bank Behavior and Its Relation to Bank Regulation.* Research Report No. 41, Boston: Federal Reserve Bank of Boston, 1968.

Benston, George J. "Economies of Scale and Marginal Costs in Banking Operations" .*The National Banking Review* 2 (June 1965), 507-49.

_________________. "Economies of Scale of Financial Institutions." *Journal of Money, Credit, and Banking* 4 (May 1972), 312-41.

Benston, George J., Gerald A. Hanweck and David B. Humphrey. "Scale Economics in Banking: A Restructuring and Reassessment." *Journal of Money, Credit, and Banking* 14 (November 1982, Part 1), 435-56.

Berger, Allen N., Gerald A. Hanweck, and David B. Humphrey. "Competitive Viability in Banking: Scale, Scope, and Product Mix Economies." *Journal of Monetary Economics* 20 (December 1987), 501-520.

Bresnahan, Timothy. "Measuring the Spillovers From Technical Advances: Mainframe Computers in Financial Services." *American Economic Review* 76 (September 1986), 742-55.

Christensen, Laurits R., and William H. Greene. "Economies of Scale in U.S. Electric Power Generation." *Journal of* Political *Economy* 84 (August 1976, Part 1), 655-76.

Diewert, W. E. "Applications of Duality Theory" in M. Intriligator and D. Kendricks, editors. *Frontiers in Quantitative Economics*, volume 2. Amsterdam: North Holland, 1974.

Evanoff, Douglas D. "Bank Deposit Rate Deregulation and Customer Service Levels." *Journal of Consumer Affairs* 23 (Forthcoming 1989).

_________________. "Branch Banking and Service Accessibility" *Journal of Money, Credit, and Banking* 20 (May 1988), 191-202.

Gilligan, Thomas, and Michael Smirlock. "An Empirical Study of Joint Production and Scale Economies in Commercial Banking." *Journal of Banking and Finance* 8 (March 1984), 67-76.

Gilligan, Thomas, Michael Smirlock, and William Marshall. "Scale and Scope Economies in the Multiproduct Banking Firm." *Journal of Monetary Economics* 13 (May 1984), 393-405.

Greenbaum, Stuart I., and Charles F. Haywood. "Secular Change in the Financial Services Industry." *Journal of Money, Credit, and Banking* 3 (May 1971), 571-89.

Heggestad, Arnold A., and John J. Mingo. "On the Usefulness of Functional Cost Analysis Data." *Journal of Bank Research* 8 (Winter 1978), 251-56.

Hotelling, H. "Edgeworth's Taxation Paradox and the Nature of Demand and Supply Functions." *Journal of Political Economy* 40 (October 1932), 577-616.

Hunter, William C., and Stephen G. Timme. "Technical Change, Organization Form, and the Structure of Bank Production." *Journal of Money, Credit, and Banking* 18 (May 1986), 152-66.

Israilevich, Philip, and K. J. Kowalewski. "The Effect of Regulation on Ohio Electric Utilities." *Economic Review*, Federal Reserve Bank of Cleveland (Quarter 1, 1987), 10-19.

Jorgenson, Dale W. "Econometric Methods for Modeling Producer Behavior." in Z. Griliches and M. D. Intriligator (eds.), *Handbook of Econometrics*, Volume III. Elsevier Science Publishers, 1986.

Joskow, Paul L. "Inflation and Environmental Concern: Structural Change in the Process of Public Utility Price Regulation." *Journal of Law and Economics* 17 (October 1974), 291-327.

Kolari, James, and Asghar Zardkoohi. *Bank Costs, Structure, and Performance*. Lexington Mass.: D.C. Heath, 1987.

Lau, Lawrence J., and Pan A. Yotopoulos. "A Test For Relative Efficiency and Application to Indian Agriculture." *American Economic Review* 61 (March 1971), 94-109.

Lawrence, Colin, and Robert Shay, editors. *Technological Innovation, Regulation, and the Monetary Economy*. Cambridge, Mass.: Ballinger, 1986.

Lovell, C. A. Knox, and Robin Sickles. "Testing Efficiency Hypotheses in Joint Production: A Parametric Apprach." *Review of Economics and Statistics* 65 (February 1983), 51-58.

McNulty, James E. "Economies of Scale: Discussion." *Proceedings of a Conference on Bank Structure and Competition*. Federal Reserve Bank of Chicago (May 1983) 456-61.

Nelson, Randy A., and Mark E. Wohar. "Regulation, Scale Economies, and Productivity in Steam-Electric Generation." *International Economic Review* 24 (February 1983), 57-79.

Pavel, Christine, and Paula Binkley. "Costs and Competition in Bank Credit Cards." *Economic Perspectives*. Federal Reserve Bank of Chicago (March 1987), 3-13.

Sealey C. W. Jr., and James T. Lindley. "Inputs, Outputs, and a Theory of Production and Cost at Depository Financial Institutions. *Journal of Finance* 32 (September 1977), 1251-66.

Shaffer, Sherrill. "Competition, Economies of Scale, and Diversity of Firm Sizes." *Applied Economics* 17 (June 1985), 467-76.

____________. "Scale Economies in Multiproduct Firms." *Bulletin of Economic Research* 36 (1984), 51-58.

____________ and Edmond David. "Economies of Superscale and Interstate Expansion." Unpublished manuscript, Federal Reserve Bank of New York, (October 1986).

Shephard, R. W. *Theory of Cost and Production Functions*. Princeton: Princeton University Press, 1970.

Solomon, Elinor H. *Electronic Funds Transfers and Payments: The Public Policy Issues*. Boston: Kluwer-Nijhoff, 1987.

Toda Yasushi. "Substitutability and Price Distortion in the Demand for Factors of Production: An Empirical Estimation." *Applied Economics* 9 (September 1977), 203-17.

____________. "Estimation of a Cost Function When the Cost is Not Minimum: The Case of Soviet Manufacturing Industries, 1958-1971." *The Review of Economics and Statistics* 58 (August 1976), 259-268.

Appendix 1. Testing the Appropriateness of the Restricted Model Using Alternative Output Measures

Output Measure	$\hat{k}$	t	λ_{LR}	α
Total Assets	.554	6.93	36.08	.02(10)-7
Total Loans	.520	7.02	35.98	.02(10)-7
Total Loans and Deposits	.569	6.46	31.36	.02(10)-6
Total Loans, Deposits, and Investment Securities	.581	6.05	27.59	.02(10)-5

Note: t denotes the asymptotic t-ratio for testing the null hypothesis of $\hat{k}$ equal to unity; λ_{LR} is the likelihood ratio test statistic; and α is the significance level of λ_{LR} in the Chi-square test. Parenthetical entries are asymptotic standard errors.