Scale Economies and Technological Change in Federal Reserve ACH Payment Processing

by Paul W. Bauer and Diana Hancock

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Introduction

Technological advances — accompanied by corresponding cultural changes and behavior adjustments — have had a tremendous influence on the array of payment instruments offered in the United States, on the diverse systems for processing them, and on their relative costs. Starting with the development of Magnetic Ink Character Recognition (MICR) in the 1950s, which facilitated the automation of check processing, the use of computers has transformed virtually every aspect of banking and the payments system.[1] For example, many new products, such as automated teller machines, point-of-sale terminals, touch-tone bill paying, and customer-initiated cash management services, are now widely available. Advances in computer technology—speed, storage, communications, and encryption capabilities—have meant faster, more accurate, more secure, and less costly back-office processing.

Since 1973, the use of electronic funds transfers has been accelerated by development of the automated clearinghouse (ACH). The ACH system, a nationwide, value-dated electronic funds transfer system typically used for recurring consumer and commercial payments, accommodates many types of transfers. The most common uses are to make utility, payroll, Social Security, tax, insurance premium, school tuition, mortgage, monthly investment, and dividend payments, and to manage business' cash concentration and disbursement activities.[2]

In the early 1980s, many observers argued that it would eventually become less expensive to transfer funds and settle most accounts electronically than to use traditional paper-based methods.[3] Consistent with those expectations, the Federal Reserve's direct and support costs for processing ACH payments today (approximately 1.4 cents per transaction) are less than

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[1] Payment data encoded at the bottom of checks have allowed high-speed check-sorting machines to process 80,000 to 100,000 checks per hour.

[2] The National Automated Clearing House Association (1995) estimates that 42 percent of the private-sector workforce and 84 percent of government employees are paid using direct deposit. Also, more than 50 percent of Social Security recipients currently receive their benefits through direct deposit.

[3] See, for example, Humphrey (1982, 1984, 1985).

for paper checks (about 2.5 cents per check).[4] Based on Federal Reserve data, the real unit cost (in 1994 dollars) of processing an ACH payment *fell* from 9.1 cents in 1979 to 1.4 cents in 1994. In contrast, the real unit cost of processing paper checks *rose* from 2.0 cents to 2.5 cents over the same period.[5]

Several hypotheses could account for the dramatic decline in both the absolute and the relative real costs of ACH processing. First, as the volume of ACH payments grew at double-digit rates, per-item costs may have dropped because processing sites were able to achieve greater scale efficiency. By their basic nature, telecommunication systems, which consist of communication equipment and circuits, offer significant economies of scale over wide ranges of output.[6] Such systems are one of the major inputs used in ACH payment processing. Early studies by Humphrey (1982, 1984, 1985), which used cross-sectional data from Federal Reserve ACH operations over the 1977–1982 period, verified that average ACH production costs fell as volume expanded. During that time, for each 1 percent rise in ACH processing volume, total production costs increased only 0.6 to 0.7 percent.

Second, technological change may have made it cheaper to provide ACH services. With the same quantities of inputs, more funds transfers could be processed. Software improvements, for example, could have resulted in fewer computing resources being used to process the same number of electronic payments.

Third, some of the major inputs used for electronic payment processing, including computers, experienced large quality-adjusted price declines during the 1980s. For the same cost, newer machines could process payments faster than their predecessors and could perform sophisticated tasks that were not previously feasible. Falling input prices would help to explain the absolute decline in real processing costs. At the same time, employee wages, paper costs, and other expenses associated with processing paper checks were generally rising.[7] The change in relative input prices would help to explain the decline in the relative real unit costs of ACH processing.

This study estimates the contribution of each of these factors—scale economies, technological change, and falling input prices—to the absolute reduction in the real processing cost of an ACH transfer. We use Federal Reserve data over the 1979–1994 period and various specifications for ACH cost functions.[8] Not surprisingly, we find that all three factors played a significant role. The split between cost savings attributed to scale economies (through volume growth) versus technological change depends on the specification chosen for the cost function. While scale economies accounted for a decline in unit costs on the order of 20 to 40 percent, technological change explained more than 30 percent. Cost savings attributed to input price reductions generally accounted for less than 10 percent of the real per-unit decline in ACH payment processing costs.

Our findings suggest that consolidating the Federal Reserve ACH processing sites will improve scale efficiency, further reducing processing costs. If recent experience is any guide, technological change will also present opportunities for further unit-cost declines. In addition, the marginal cost estimates presented in this study suggest that replacing paper checks with ACH transfers could enhance economic efficiency.

■ [4] Direct and support costs cover all expenses specifically attributable to providing Federal Reserve priced services, including labor, building, data processing, and data communication costs. They do not include allocations of overhead expenses, such as legal, accounting, and personal services, nor the Private-Sector Adjustment Factor (PSAF), which takes into account the taxes that would have been paid and the return on capital that would have been provided had the services been performed by a private firm. Further, this definition of direct and support costs does not include the costs to payors and payees of processing payments. Thus, the Federal Reserve's costs are only a portion of the social costs of providing payment services.

■ [5] The real unit costs of processing ACH transfers and checks are calculated using the implicit GDP price deflator for 1979 and 1994.

■ [6] Scale economies were first studied in industries employing pipelines and boilers. There is a clear mathematical reason for this. Expanding the diameter of a pipe increases the amount of material required to manufacture it by only two-thirds as much as its capacity. (See, for example, Berndt [1991].) Similarly, in the context of communication systems, laying a fiber-optic line is not much costlier than laying a copper wire, but the former has many times the carrying capacity.

■ [7] Per-item wages have fallen over time because of capital improvements.

■ [8] The cost function is the minimum cost of producing any specified level of output given technological constraints and input prices.

FIGURE 1

Unit Costs (1994 dollars)

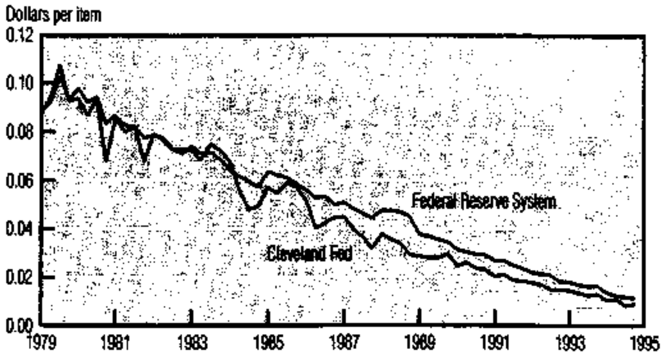


FIGURE 2

ACH Processing Volume

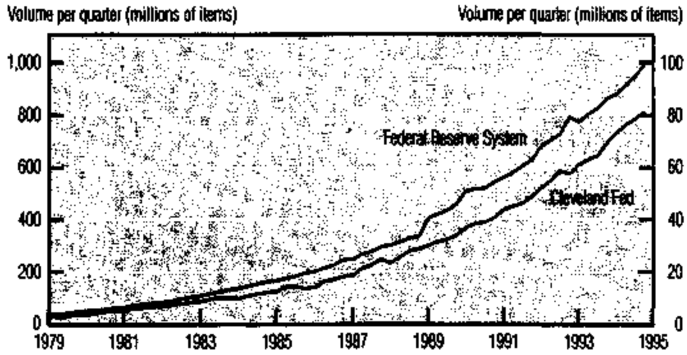
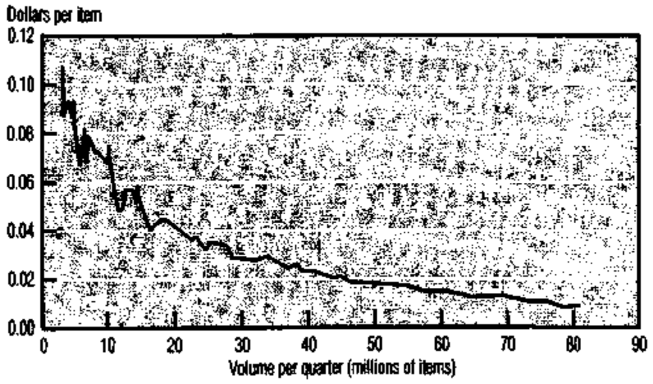


FIGURE 3

Real Unit Costs vs. ACH Processing Volume for the Cleveland Fed, 1979–1994 (1994 dollars)



SOURCE: Authors' calculations.

I. What Is an ACH Transfer?

The ACH system is a value-dated electronic funds transfer system. The principal participants in an ACH transaction are the payor, the payee, the payor's bank, the payee's bank, and the ACH operator.[9] Either credit transfers or debit transfers may be made using an ACH system. With credit transfers, such as direct payroll deposits, the payor's bank typically initiates the transfer, and funds flow from the payor's bank to the payee's bank. With debit transfers, such as mortgage payments, the payee's bank initiates the transfer and receives funds from the payor's bank.

ACH transactions offer several key advantages over paper instruments. First, in most cases, payors know exactly when the funds will be removed from their accounts, and payees know exactly when the funds will be deposited to their accounts. Second, particularly for consumer bill payments, ACH transactions may be convenient because the payor does not have to remember to write and deliver a paper check, and the payee does not have to cash or deposit it. Third, the total costs to all parties are much lower for ACH transactions than for paper checks.[10] Finally, accounting efficiencies may exist for business payors and payees who have implemented electronic data interchange to facilitate communications with trading partners.[11]

II. A Look at the Raw Data

Before presenting statistical measures of scale economies and technological change, it is instructive to look at the raw data to determine how Federal Reserve ACH processing costs have varied over time and with different volume levels. Figure 1 presents unit costs (in 1994 dollars) over the 1979–1994 period, using

[9] We use the term "bank" to refer to all depository institutions.

[10] The full social cost of processing an ACH item is only about a third to a half as much as for a check (see Humphrey and Berger [1990] and Wells [1994]).

[11] See Knudson, Walton, and Young (1994) for a discussion of the potential benefits of financial electronic data interchange (a combination of electronic remittance data and electronic funds transfers) for business payments.

processing volumes as the measure of output.[12] Despite improvements in the ACH service—including the introduction of encryption, increased use of backup facilities, more deliveries per day, a wider variety of formats, provisions allowing more information to be supplied with the payment, and conversion to an all-electronic ACH environment—Federal Reserve per-unit costs have fallen steadily. Similar declines are observed at each processing site. For example, the Cleveland District's unit-cost decline paralleled that of the System as a whole. This suggests that technological change could have been the dominant factor driving down ACH processing costs. However, output volume and input prices did not remain constant.

Between 1979 and 1994, total ACH processing volume at the Federal Reserve grew at an average annual rate of more than 22 percent (see figure 2), reaching 2.4 billion payments valued at $8.4 trillion by the end of 1994.[13] If scale economies exist, then volume growth of this magnitude could account for a large share of the decline in unit costs.

Figure 3 plots the unit cost per ACH transfer processed in the Cleveland Federal Reserve District against the number of quarterly transfers processed at that site over the 1979–1994 period. Note that unit costs fell fairly steadily as volume increased. The experience at other Federal Reserve ACH processing sites was similar. Figure 3 suggests that scale economies (resulting from increased volume) were the dominant factor pushing down ACH processing costs. In general, however, output, technology, and input prices were all fluctuating (in some cases dramatically) over this period, necessitating a multivariate approach to data analysis to investigate changes in ACH costs. Both the formulation of public policies for electronic payments and the appropriate pricing framework for such payments hinge on an accurate understanding of the different sources of real unit-cost reductions.

In general, the cost-function approach we employ in this paper is well suited to handling the contemporaneous effects of scale economies, as well as technological change and other factors. Unfortunately, the Federal Reserve's ACH data for each processing site show a strong correlation (greater than 99 percent) between the number of items processed (output) and a time trend (a technology index that is commonly used when a better measure is lacking). With such a high degree of correlation, it is difficult to disentangle the effects of technological change (the time trend) from those of scale economies (volume growth).

From a technical standpoint, econometric models that include two highly correlated variables have upwardly biased standard errors, making it difficult to obtain precise estimates of the model's parameters. Also, the cost-function coefficient estimates could be sensitive to small changes in the model's specification.

Since there is reason to believe that both scale economies and technological change are important factors in the real unit-cost decline for ACH processing, we choose to test for model robustness by trying alternative specifications for the cost function (for example, employing yearly indicators instead of a time trend to allow for technological change). We also use different sample periods within our pooled cross-section and time-series samples.

III. Estimation

To determine the effects of scale economies, technological change, and falling input prices on ACH processing costs, we estimate a cost function using quarterly cost data for Federal Reserve processing sites. This function maps the best (least-cost) method of processing each level of transfers when inputs, such as labor and computers, can be varied freely. In general, the least costly production method depends on the scale of operations. The cost function is a useful concept for our purposes, because many characteristics of technology can be derived from it, such as estimates of scale economies, marginal costs, and technological change (as will be explained more fully below).

We employ the translog cost function because it provides a good local approximation of any arbitrary twice-differentiable cost function. Thus, the translog function can model many

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[12] Throughout this paper, payments initiated and received at a processing site are counted once. Payments received and partially processed at one site and then transmitted and processed again at another are counted at both the sending and receiving sites. Therefore, processing volumes exceed the number of ACH payments made.

[13] A National Automated Clearing House Association press release dated March 27, 1995 ("ACH Statistics Fact Sheet") estimates that the total volume of payments handled by ACH processors (including the Federal Reserve) was 2.5 billion, valued at $10.1 trillion, in 1994. These statistics exclude estimated "on-us" items (wherein the payor and payee accounts are held at the same bank and consequently do not require external processing). Although the growth rate and volume of ACH payments may seem impressive, these payments accounted for fewer than 4 percent of all noncash transactions processed domestically and only about 1 percent of the dollars exchanged in 1994.

different possible relationships among the number of transfers processed (outputs), inputs, and environmental factors, depending on its parameter values. Our general translog cost function can be written as

$$(1)\quad \ln C_{it} = \beta_0 + \beta_y \ln y_{it} + 1/2\, \beta_{yy} (\ln y_{it})^2 + \sum_{k=1}^{K} \gamma_k \ln w_{kit} + 1/2 \sum_{k=1}^{K} \sum_{j=1}^{K} \delta_{kj} \ln w_{kit} \ln w_{jit} + \sum_{k=1}^{K} \delta_{yk} \ln y_{it} \ln w_{kit} + \sum_{m=1}^{M} \lambda_m Z_{mit} + \sum_{j=1980}^{1994} \Phi_j YR_j + \sum_{j=2}^{12} \xi_j D_j + v_{it}\,,$$

where y_{it} is the number of ACH items processed at site i in period t, w_{it} is a vector of K input prices for site i in period t, Z_{it} is a vector of M environmental variables for site i in period t, D_j (j=2,...,12) is a set of site indicator variables (one for every processing site),[14] YR_j (j=1980,...,1994) is a set of T–1 yearly indicator variables (one for every year except the first), and v represents the error term.[15] In some specifications, we use the time-trend term T = 1,...,N, and its squared term, T^2, instead of the yearly indicator variables, YR_j, to represent technological change.

Depending on the model specification and the sample period selected, we set some of the coefficients of the translog cost function equal to zero. Several specifications of the cost function are estimated using ordinary least squares (OLS), and we denote these models as OLS Models 1 and 2. These elementary cost functions include only an intercept, the log of the number of items processed at each site, yearly indicators or a time-trend variable, and, in the case of OLS Model 2, some environmental variables. OLS Model 2 is similar to the cost function estimated by Humphrey (1982, 1984, 1985) for the ACH service.

In our most sophisticated specification, we estimate the translog specification of the cost function jointly with the input share equations derived using Shephard's Lemma.[16] Estimation of both the cost function and the input share equations provides additional degrees of freedom and statistical precision. The system of cost and share equations is estimated using the iterative seemingly unrelated regression (ITSUR) technique.[17] We denote these models as ITSUR Models 1 and 2. ITSUR Model 1 does not include site indicator variables (D_j), in effect forcing the coefficients ξ_j (j = 2,...,13) to equal zero. For both ITSUR models, we estimate equation (1), along with the corresponding equations for input shares, imposing the usual mathematical restrictions of symmetry and linear homogeneity in input prices. These restrictions, derived from economic theory, reduce the number of cost-function parameters that need to be estimated and thereby increase the number of degrees of freedom available. Symmetry restrictions follow from assuming that the cost function is twice differentiable in input prices, or

$$(2)\qquad \frac{\partial^2 C}{\partial w_k \partial w_j} = \frac{\partial^2 C}{\partial w_j \partial w_k}\,.$$

This forces $\delta_{kj} = \delta_{jk}$ for every k and j. Linear homogeneity in input prices means that only relative input prices matter. That is, proportional changes in input prices affect only the level of cost, not the cost-minimizing set of inputs.[18] Linear homogeneity restrictions result from defining the cost function as yielding the minimum cost of producing a given output level when faced with a particular set of input prices. In order to impose linear homogeneity, the following parameters related to the $\ln w_{kit}$'s are restricted such that

$$(3)\qquad \sum_k \gamma_k = 1 \text{ and } \sum_k \theta_{yk} = \sum_k \delta_{kl} = 0.$$

IV. Decomposition of Cost Savings over Time

For a particular site, one could examine the ratio of unit costs in two periods. Although this ratio would show whether unit costs had risen or fallen, it would not indicate whether the shift

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[14] The first processing site is the base against which the others are measured. Consequently, it does not have a site indicator variable. The choice of the base site does not affect our final results.

[15] The number of yearly indicator variables, YR_j, depends on how many years of data are included in the sample.

[16] See Diewert (1982) for a discussion of Shephard's Lemma.

[17] See Bauer and Hancock (1993) for a look at the various econometric techniques that can be used to estimate a system of cost and share equations.

[18] Mathematically, linear homogeneity can be expressed as $\lambda C(y, w) = C(y, \lambda w)$, where λ is greater than zero ($\lambda = 2$ if input prices double).

stemmed from scale economies, input price differences, environmental differences, or technological change. To decompose the movements in unit costs attributable to various factors across time using cost-function (1), we can rewrite the ratio of a site's current unit costs (with the period denoted by subscript *S*) to that of the first period (with the period denoted by subscript *0*) as follows:[19]

$$(4)\qquad \ln\left[\frac{(C_{iS}/y_{iS})}{(C_{i0}/y_{i0})}\right]$$

$$= \ln\left[\frac{C(y_{iS}, w_{iS}, z_{iS})\exp(\epsilon_{iS})}{y_{iS}}\right]$$

$$- \ln\left[\frac{C(y_{i0}, w_{i0}, z_{i0})\exp(\epsilon_{i0})}{y_{i0}}\right].$$

Using the cost function defined in equation (1) and recalling that the log of a ratio is equal to the difference of the log of the numerator minus the log of the denominator, the percentage change in unit costs between periods, *S* and *0*, or equation (4), can be rearranged into the following expression:

$$(5)\qquad \ln\left[\frac{(C_{iS}/y_{iS})}{(C_{i0}/y_{i0})}\right] = \left[\Phi_S - \Phi_0\right]$$

$$\Big[\beta_y(\ln y_{iS} - \ln y_{i0})$$

$$+ 1/2\,\beta_{yy}(\ln y_{iS}^2 - \ln y_{i0}^2)$$

$$- (\ln y_{iS} - \ln y_{i0})\Big]$$

$$+ \Big[\sum_{k=1}^{K}\gamma_k(\ln w_{kS} - \ln w_{k0})$$

$$+ 1/2\sum_{k=1}^{K}\sum_{j=1}^{K}\delta_{kj}(\ln w_{kiS}\ln w_{kjS}$$

$$- \ln w_{ki0}\ln w_{kj0})\Big]$$

$$+ \left[\sum_{k=1}^{K}\theta_k(\ln y_{iS}\ln w_{kiS} - \ln y_{i0}\ln w_{ki0})\right]$$

$$+ \left[\sum_{m=1}^{M}\lambda_m(\ln Z_{miS} - \ln Z_{mi0})\right]$$

$$+ \left[\epsilon_{iS} - \epsilon_{i0}\right],$$

where the bracketed terms are defined as the technological change effects, scale effects (different processing volumes), input price effects (different input prices), interaction effects between processing volumes and input prices, environmental effects, and a random effect.[20, 21] Although these terms are in logarithmic differences, they can be roughly interpreted as the percentage difference in costs stemming from the various effects.[22] Equation (5) provides a convenient framework for quantifying the source of cost savings over time.

V. Data Construction

We collected quarterly data from 1979 to 1994 on total costs, ACH processing volumes, input prices, and environmental variables for Federal Reserve ACH processing sites. During the 1979–1989 period, the number of these sites fell from 38 to 21. By an overwhelming margin, the largest volumes were handled by the 12 Reserve Banks and the Los Angeles branch of the San Francisco Fed. By 1993, only the 12 main Reserve Bank offices were still processing ACH items. Consequently, we aggregated the data at the District level, with the exception of the Los Angeles facility, which we treated as a separate site. The New York Fed was omitted from the estimations because most of the commercial ACH volume in its region was processed by the New York Automated Clearing House.

Our primary data source is quarterly cost accounting reports prepared by the Federal Reserve in its Planning and Control System (PACS). This information is supplemented by other cost and revenue data, results from occasional Federal Reserve surveys, and price index figures from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics.

Production costs for processed ACH transactions are included in our calculations, but

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[19] Any two periods could be chosen to compare unit costs, but comparing the first to the last is likely to be the most informative.

[20] This decomposition uses the same methodology employed in Bauer (1993) to study differences in unit costs across Federal Reserve check-processing sites.

[21] The interaction effect is a collection of terms that cannot be classified cleanly into any of the other categories. Fortunately, the magnitude of this effect tends to be small.

[22] For the exact percentage difference, the antilog of each expression minus one should be used. We report the exact percentage differences of our results in table 5.

TABLE 1

Average Input Cost Shares, 1989–1994 (percent)

Input Classification	Cost Shares
Labor	21.3
Materials	40.6
Communications	35.6
Building	2.5

SOURCE: Authors' calculations.

imputed costs and certain overhead expenses, such as accounting costs and special District projects, are not. For the output measure, we use site-specific figures that focus on transactions processed at a site, rather than the number of payments (see footnote 12).

Labor, material, communication, and building costs are inputs for ACH processing. The shares of direct and support costs for each of these factors over the 1989–1994 period are reported in table 1.[23] Labor expenditures include salaries, retirement, and other benefits. The price of labor is total labor expenditures divided by the number of employee hours spent processing ACH transactions.

While buildings' share of costs is small, the interest expenses associated with the acquisition of fixed assets are not represented in the cost-accounting framework (these are included in the inputed costs [PSAF] rather than in direct and support costs). Cost accounting information is supplemented by annual replacement-cost indexes for each site, available from the R.S. Means Company.[24] Square-foot replacement costs, adjusted by the depreciation rate, are used to calculate maintenance and building prices for each site.

Expenditures for materials are composed of outlays for office equipment and supplies, printing and duplicating, and data processing. The service price for materials is constructed by supplementing cost-accounting expenditure data with indexes for information and processing equipment.[25] For computer hardware, an estimate of the service value, or price, of machines is constructed using formulas that employ a perpetual inventory model.[26] For data system support services, which are primarily used for in-house, product-specific software development, we construct a price by utilizing expenditures for labor and hours worked in that area of each Reserve Bank. For the service price of supplies (printing and duplicating, office supplies, and office equipment), we use the GDP implicit price deflator. We apply index number theory to construct a price index for materials that uses expenditures and prices for the components of materials—data processing, data systems support, and office supplies and equipment.

Communications expenditures comprise the expenses associated with data and other communications, shipping, and travel. The implicit price deflator for communications equipment purchases by nonresidential producers is used for data and other communications. The fixed-weight aircraft price index for private purchases of producers' durable equipment is employed for shipping and travel expenditures. Using index number theory, we calculate an overall price index for communications using the expenditure shares of two categories of communications (communications and shipping) and their individual price indexes.

Environmental variables that may affect ACH processing costs are the proportion of federal government items in the processing stream, the number of banks served by a processing site, and the proportion of banks receiving electronic payment information. On one hand, government items may be less expensive to process because the Federal Reserve has more discretion over file-processing times for these items than for commercial items. On the other hand, government items could be more expensive to process than commercial items because they are concentrated over short periods during the month and thus may drive processing capacity needs. The number of endpoints is the number of banks or processors to which ACH payments

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[23] We focus on this period for several reasons. First, all of the data series are complete. Second, in the early period, full-cost pricing (required by the Monetary Control Act of 1980) was gradually introduced. Third, consolidation of processing sites could cloud the effects of scale economies in the early period. Consolidation effects are likely to be of minor significance, however, because of the low processing volumes and costs incurred at the additional sites. Finally, such dramatic technological changes occurred that a single cost function may be unable to fit the entire sample period adequately. Consequently, by concentrating on the most recent data, we should get the best estimates of the current cost function for ACH processing.

[24] Data on replacement costs for buildings are taken from Means (1994).

[25] The BEA's implicit price deflator for information processing and related equipment is used for data processing and computer hardware.

[26] These formulas were derived by Hall and Jorgenson (1967).

TABLE 2

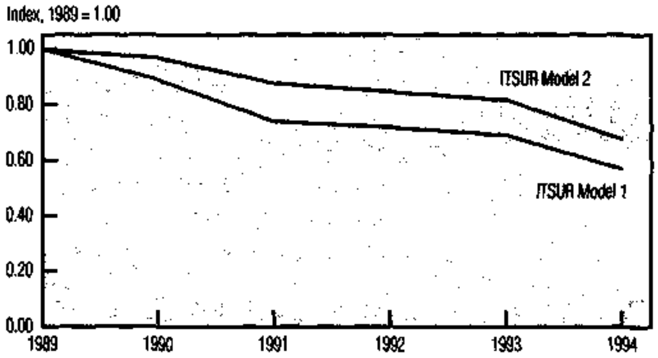
Technological Change Indexes (1989 = 1.000)

Year	ITSUR Model 1	ITSUR Model 2
1989	1.000	1.000
1990	0.889	0.973
1991	0.739	0.876
1992	0.716	0.847
1993	0.691	0.818
1994	0.568	0.676

SOURCE: Authors' calculations.

FIGURE 4

Technological Change Indexes



SOURCE: Authors' calculations.

information is delivered. Nonelectronic deliveries by computer tapes, diskettes, and paper methods increase transportation costs.[27] In contrast, using electronic networks for deliveries may create greater scale efficiencies.

VI. Empirical Results

We estimated cost functions with and without the data for the early (1979–1988) period both to provide a historical perspective and to ease comparison with previous studies. The empirical results for the OLS cost-function models are reported in the appendix. Estimates from these models demonstrate that our qualitative findings are robust to changes in the assumptions employed in the estimation and in the sample period selected. In the body of the paper, we focus on the two ITSUR models estimated using data from 1989 to 1994. It is only during this period that data on the number of endpoints with electronic connections are available. Another reason we concentrate on the more recent period is that the methods used for ACH processing have changed dramatically over time. In the earlier period, ACH transaction data were delivered to the Federal Reserve Banks on computer tapes, and the Fed delivered data to receiving institutions on both computer tapes and paper listings. In the more recent period, however, ACH processing has essentially become a computer network-based system. We are interested in whether different technologies for transmitting ACH transfers yield strikingly different estimates for scale economies and for technological change. Therefore, we estimate the cost function for the latest period possible —subject to the constraint of having sufficient degrees of freedom to estimate the model with statistical precision.

ITSUR Models 1 and 2 estimate the cost function jointly with three of the four input share equations using the ITSUR technique. These models are preferred because they allow for a fuller complement of regressors and because including the cost-share equations increases statistical precision. ITSUR Model 2 differs from ITSUR Model 1 in that it includes processing-site indicator variables that allow for site-specific conditions not otherwise controlled for.

Technological Change

Table 2 presents estimates of technological change obtained from the two models above. The technological change index is set equal to one in 1989, with numbers below that indicating technological advance over the base year. For example, ITSUR Model 1's 1994 index indicates that unit costs are only 56.8 percent of costs in 1989, other things held constant. ITSUR Model 2 finds somewhat less technological change, with 1994 costs only 67.6 percent of those incurred in 1989. For ITSUR Model 1, this works out to a technological change estimate of more than 10 percent per year from 1989 to 1994. Inclusion of processing-site-specific intercepts (ITSUR Model 2) lowers the estimate to just over 7.5 percent per year—still a rather hefty reduction. While the estimates of technological change differ, both models find the same pattern of unit-cost declines (see figure 4).

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[27] All ACH transactions were delivered electronically as of July 1, 1993 for the commercial (non-federal government) sector and as of July 1, 1994 for the federal government sector.

TABLE 3

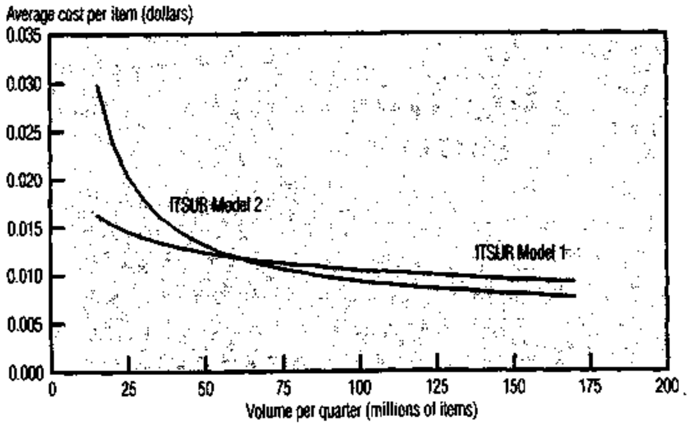
Cost Elasticity Estimates

Federal Reserve ACH Processing Site	ITSUR Model 1		ITSUR Model 2	
	1989	1994	1989	1994
1	0.756	0.764	0.413	0.587
2	0.766	0.776	0.280	0.444
3	0.754	0.761	0.449	0.661
4	0.760	0.771	0.328	0.550
5	0.760	0.766	0.301	0.486
6	0.756	0.763	0.390	0.566
7	0.758	0.760	0.256	0.487
8	0.761	0.768	0.192	0.442
9	0.758	0.765	0.381	0.583
10	0.761	0.761	0.349	0.624
11	0.763	0.772	0.212	0.419

SOURCE: Authors' calculations.

FIGURE 5

Estimated Average Cost Functions



SOURCE: Authors' calculations.

Scale Economies

Cost elasticities measure the effect of a one-percentage-point increase in output on total cost. For example, a cost elasticity of 0.75 means that if output increases 1 percent, costs would rise only 0.75 percent. A cost elasticity of less than one indicates the existence of scale economies (that is, average cost falls as output increases). Alternatively, a cost elasticity greater than one indicates the existence of scale diseconomies (average cost rises as output increases).

Although still finding significant scale economies during the 1989–1994 period, ITSUR Models 1 and 2 provide estimates of cost elasticities of widely different magnitudes. Table 3 presents cost elasticity estimates for each of the processing sites that remained in operation for the entire sample period, using their mean processing volume levels for 1989 and 1994. ITSUR Model 2 provides greater estimates of scale economies for all sites than does ITSUR Model 1. To understand why, consider figure 5, which plots the estimated average cost curves using both models. To the naked eye, these curves appear to be reasonably similar. In ITSUR Model 1, however, the coefficient of the squared term for the number of items processed is close to zero and is statistically insignificant. Based on this model, the cost elasticity is essentially constant at around 0.75 throughout the full range of observed output, implying that scale economies are never exhausted. In contrast, for ITSUR Model 2, the squared term for the number of items processed is positive and statistically significant. This means that the cost elasticity varies along with the number of items processed. Consequently, ITSUR Model 2 suggests that scale economies will eventually be exhausted (that is, the average cost curve will eventually begin to rise).

The volume level at which scale economies are exhausted is important, because it helps to determine whether consolidating the Federal Reserve processing sites could lower unit costs. Scale economies are exhausted when the cost elasticity equals one. By setting the cost elasticity equal to one, we can solve for the implied number of items processed by a site operating at an efficient scale. Using this procedure and ITSUR Model 2, an estimate of about 800 million items processed per quarter for a scale-efficient site is implied. This is more than five times the quarterly processing volume of the largest Federal Reserve site observed in our sample (144 million items per quarter).

For both ITSUR models, estimates of the volume level at which scale economies are exhausted need to be viewed with a fair degree of skepticism. Recall that the translog cost function is a good local approximation of the cost function and is therefore quite reliable in studying output ranges actually observed in the data. While both models find significant scale economies in the current range of output, going beyond this range is highly speculative.

TABLE 4

Marginal Cost Estimates (dollars per item)

Federal Reserve ACH Processing Site	ITSUR Model 1		ITSUR Model 2	
	1989	1994	1989	1994
1	0.0204	0.0095	0.0112	0.0073
2	0.0215	0.0095	0.0079	0.0054
3	0.0233	0.0087	0.0139	0.0076
4	0.0182	0.0068	0.0078	0.0049
5	0.0269	0.0135	0.0107	0.0086
6	0.0204	0.0056	0.0105	0.0042
7	0.0321	0.0085	0.0109	0.0054
8	0.0215	0.0069	0.0054	0.0040
9	0.0205	0.0064	0.0103	0.0048
10	0.0262	0.0076	0.0120	0.0062
11	0.0361	0.0110	0.0101	0.0060
Volume-weighted System average	0.0234	0.0083	0.0106	0.0060

SOURCE: Authors' calculations.

The presence of scale economies implies that scale efficiency could be improved by consolidating the Federal Reserve ACH processing sites. Indeed, the Fed is currently consolidating its ACH operations at one computing site with backup facilities at another. Our empirical results suggest that these efforts will reduce average processing costs significantly. Comparing the average ACH processing cost at the current largest site with a forecasted average cost for a consolidated site handling all currently processed ACH items, the predicted average decline is 30 percent and 25 percent for ITSUR Models 1 and 2, respectively.[28] Neither model predicts that scale economies would be exhausted with one processing site, but ITSUR Model 2 predicts that further scale efficiencies from additional volume growth could be quite small.

Pricing

The Monetary Control Act of 1980 directs the Federal Reserve to establish fees on the basis of all direct and indirect costs incurred in providing payment services, including "interest on items credited prior to actual collection, overhead, and an allocation of imputed costs which takes into account the taxes that would have been paid and the return on capital that would have been provided had the services been provided by a private business firm." Thus, the total revenues raised from providing payment services must match the total costs incurred in production.

Generally, allocations of goods and services are most efficient when prices (the amount a consumer must pay to receive one unit of the good) are set equal to marginal costs (the additional cost of producing one more unit of output).[29] With scale economies of the magnitude we have found for ACH transactions, marginal cost pricing alone would not generate sufficient revenue to cover costs. The reason is that the presence of scale economies means unit costs fall as additional units are produced, and this can occur only if marginal costs are lower than average costs. The current Federal Reserve fee structure for the ACH service solves this problem by employing a multipart structure with both fixed and variable components.[30] Ideally, to encourage greater use of electronic payments, the variable fee should be set equal to marginal costs and the fixed fees set to make up the shortfall.

Our estimates of marginal costs, calculated using the two ITSUR models, are presented in table 4. Consistent with its finding of larger scale economies, ITSUR Model 2 generates lower marginal cost estimates than does ITSUR Model 1. Marginal costs for ITSUR Model 1 range from \$0.0056 to \$0.0135 per item in 1994, with a volume-weighted System average of \$0.0083. ITSUR Model 2's marginal costs are all estimated to be under \$0.01 per item in 1994, with a volume-weighted System average of \$0.006.

Sources of Cost Savings

In table 5, we use equation (5) to decompose unit-cost declines over the 1989–1994 period into technological change effects, scale economy effects, input price effects, environmental

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[28] Note that with full consolidation, the number of items processed will equal the number of payments processed, approximately 600 million items per quarter.

[29] Mathematically, marginal cost (*MC*), the change in costs resulting from a unit increase in output, is defined as $MC = \partial C / \partial y$.

[30] See Baumol and Bradford (1970), Oi (1971), Roberts (1979), Humphrey (1984), Sheshinski (1986), Brown and Sibley (1986), Hirshleifer and Glazer (1992), and Tirole (1994) for discussions about efficient pricing methods when there are positive scale economies for an industry's output level.

TABLE 5

Sources of Cost Savings

ITSUR Model 1

Federal Reserve ACH Processing Site	Unit Cost[a] 1989	Unit Cost[a] 1994	Overall Percentage Change	Technological Change Effects	Scale Economy Effects	Input Price Effects	Environmental Effects	Interaction Effects
1	0.027	0.012	–53.9	–43.2	–16.9	–5.8	0.1	0.5
2	0.028	0.012	–56.5	–43.2	–16.2	–8.3	–22.0	–0.3
3	0.031	0.011	–63.0	–43.2	–20.2	–6.0	–5.3	1.0
4	0.024	0.009	–62.9	–43.2	–21.2	–14.1	–5.7	0.3
5	0.035	0.018	–50.1	–43.2	–18.4	–9.8	–5.8	–0.4
6	0.027	0.007	–72.7	–43.2	–17.2	–9.2	8.1	0.2
7	0.042	0.011	–73.7	–43.2	–23.0	–6.5	2.5	–1.0
8	0.028	0.009	–68.1	–43.2	–24.6	–8.1	–28.3	–1.4
9	0.027	0.008	–69.3	–43.2	–19.6	–8.8	–0.8	0.5
10	0.034	0.010	–71.0	–43.2	–26.5	–4.0	1.3	0.5
11	0.047	0.014	–69.8	–43.2	–20.4	–5.3	–0.5	–1.1

ITSUR Model 2

Federal Reserve ACH Processing Site	Unit Cost[a] 1989	Unit Cost[a] 1994	Overall Percentage Change	Technological Change Effects	Scale Economy Effects	Input Price Effects	Environmental Effects	Interaction Effects
1	0.027	0.012	–53.9	–32.4	–37.5	–5.9	0.8	0.6
2	0.028	0.012	–56.5	–32.4	–28.3	–8.3	13.7	–0.4
3	0.031	0.011	–63.0	–32.4	–46.8	–6.0	0.8	1.1
4	0.024	0.009	–62.9	–32.4	–41.4	–14.1	4.2	0.3
5	0.035	0.018	–50.1	–32.4	–34.2	–9.8	1.8	–0.4
6	0.027	0.007	–72.7	–32.4	–36.9	–9.2	–1.1	0.3
7	0.042	0.011	–73.7	–32.4	–40.5	–6.4	1.8	–1.0
8	0.028	0.009	–68.1	–32.4	–38.5	–8.0	18.9	–1.5
9	0.027	0.008	–69.3	–32.4	–41.3	–8.9	2.3	0.6
10	0.034	0.010	–71.0	–32.4	–53.3	–4.0	0.1	0.5
11	0.047	0.014	–69.8	–32.4	–32.2	–5.2	2.5	–1.1

a. In dollars.

SOURCE: Authors' calculations.

effects, and interaction effects. For each of the processing sites, unit costs fell precipitously. ITSUR Model 1 attributes the bulk of the decline, 43.2 percent, to technological change, versus only 32.4 percent for ITSUR Model 2. In contrast, ITSUR Model 2 finds larger cost savings due to scale economies than does ITSUR Model 1.

Falling input prices—mainly for data communications and data processing—generally account for less than 10 percent of the savings. As described in section V, we rely on the BEA's price indexes to help construct our measure of materials, which includes information-processing and related equipment. The quality of such equipment changed rapidly during the 1980s and 1990s. Thus, to the extent that the price series for materials do not adequately control for the qualitative changes in these inputs, our decomposition of cost savings resulting from technological change may be overstated, while cost savings resulting from input price reductions may be understated. To some degree, the distinction is arbitrary. The decline in ACH costs may stem from technological change within ACH payments processing itself or from technological change in the computer industry that has lowered input prices. In either case, reduced costs from technological change are not misattributed to scale economies.

Environmental and interaction-term effects tend to be relatively small, except for two sites, and these sites have by far the fewest number of endpoints. ITSUR Model 1 attributes their lower costs (other things held constant) only to this factor. ITSUR Model 2, however, also allows for a different intercept term for these sites and finds smaller District indicator variable coefficients, suggesting that some other site-related factor is at work.

VII. Conclusion

We employ a cost-function model of ACH processing to derive estimates of both scale economies and technological change from 1979 to 1994. Substantial and statistically significant scale economies are found to exist at all Federal Reserve processing sites. For example, using cost system models, we estimate that for each 10 percent increase in ACH processing volume, total production costs rose by less than 8 percent, indicating that average costs fall as volume rises. Therefore, consolidating the System's processing sites should reduce ACH processing costs substantially in the long run. In addition, given the potential scale economies for electronic payments processing and the low marginal costs, more attention is warranted for demand-side issues that would encourage payors to shift from paper checks to ACH transactions.

More than 30 percent of the decline in real unit costs between 1989 and 1994 can be attributed to technological change, with an annual rate of change of at least 7.5 percent. Scale economies led to a further 20 to 40 percent reduction. Another significant contributing factor to the decline in unit costs was lower input prices (primarily for communications and computing technology), which translated into a cost savings of about 8 percent between 1989 and 1994.

In the 1980s, some observers believed that scale economies would eventually push the interbank unit costs of processing ACH transactions below those of processing paper checks.[31] Our findings suggest that their expectations were correct. In addition, technological change and lower prices for communications and computing technology have also played a major role.

Clearly, more empirical research is needed on how new technologies affect the efficiency of the payments system. For example, scope economies between ACH payment processing and other payment processing, such as Fedwire and paper-based checks, could also be important in determining the scale efficiency and optimal product mix for payment service providers. Such scope economies could enable many more suppliers to operate efficiently and to reduce the real resource costs associated with processing payments. Finally, in order to construct a pricing mechanism that encourages efficiency in the payments system and yet still recovers costs, the demand side of payment service markets—including cross-elasticities between payments instruments—needs to be more fully understood.

Appendix: Sensitivity Analysis

The strong correlation between the number of ACH items processed and the time-trend variable makes it difficult to separate the effects of scale economies and technological change. Thus, we estimate equation (1) in several different ways in order to determine the robustness of our qualitative findings of significant scale economies and technological change. First, we measure technological change either with a smooth time trend or with discrete yearly indicator variables. Second, we estimate the model using data from the entire sample period, from each year separately, and from the 1989–1994 period only.

OLS Model 1 is the most basic cost-function specification. Costs are regressed against the output measure (number of items processed) and against quarterly indicator variables. Models indicated by an *a* use yearly indicator variables to measure technological change, while models indicated by a *b* use a time trend and its squared term. OLS Model 2 is similar to OLS Model 1, except that control variables for the price of labor, the number of endpoints, and the percentage of government items are also included. Model 2 is also similar to those estimated by Humphrey (1982, 1984, 1985). A squared term for output is not included because the high correlation between the time-trend variable and output implies that the square of the latter could not be adequately handled in a single-equation setting. Below, we briefly summarize the findings of these OLS estimations and compare them to the two ITSUR models presented in the body of the paper.

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[31] For example, see Humphrey (1982, 1984, 1985) and Zimmerman (1981).

TABLE A–1

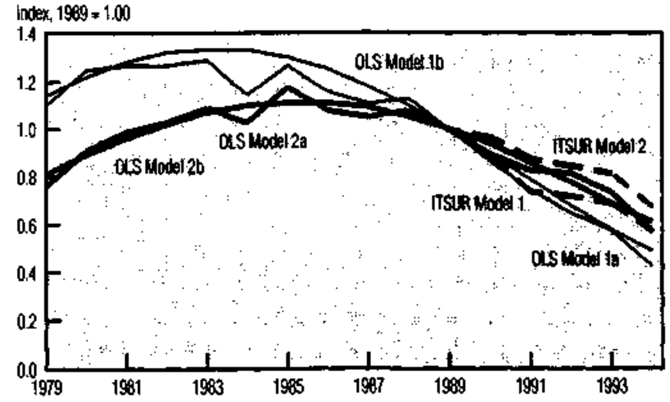
Technological Change Indexes (1989 = 1.000)

Year	OLS Model 1a	OLS Model 1b	OLS Model 2a	OLS Model 2b	OLS Model 1a	OLS Model 1b	OLS Model 2a	OLS Model 2b	ITSUR Model 1	ITSUR Model 2
1979	1.097	1.139	0.764	0.809						
1980	1.248	1.217	0.914	0.888						
1981	1.266	1.277	0.991	0.960						
1982	1.272	1.317	1.034	1.020						
1983	1.287	1.335	1.090	1.067						
1984	1.154	1.329	1.027	1.099						
1985	1.271	1.300	1.179	1.114						
1986	1.156	1.250	1.079	1.110						
1987	1.105	1.181	1.045	1.090						
1988	1.127	1.096	1.083	1.052						
1989	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1990	0.869	0.896	0.905	0.935	0.875	0.900	0.890	0.919	0.889	0.973
1991	0.753	0.789	0.829	0.861	0.763	0.791	0.777	0.822	0.739	0.876
1992	0.645	0.683	0.815	0.780	0.658	0.679	0.732	0.717	0.716	0.847
1993	0.581	0.581	0.744	0.695	0.596	0.569	0.638	0.609	0.691	0.818
1994	0.428	0.485	0.579	0.610	0.441	0.465	0.482	0.503	0.568	0.676

SOURCE: Authors' calculations.

FIGURE A–1

Technological Change Indexes



SOURCE: Authors' calculations.

Technological Change

Estimates of technological change for all models are reported in table A–1 and plotted in figure A–1. To ease comparison, all of the technological change indexes are normalized to equal one in 1989. Whether yearly indicator variables or a time trend and its squared term are used to measure technological change, the technological indexes are similar in magnitude (see figure A–1 and compare Models a and b). This finding holds up only when data from the more recent period, 1989 to 1994, are employed. Basically, the time-trend approach reports a smoothed version of the yearly indicator approach.

The rise in the technological change indexes during the early 1980s could suggest technological regress, defined as an upward shift in the cost function due to technological change. The technological change estimates from the early period (essentially, the start-up phase for ACH payments) are difficult to interpret, however, because it is plausible that the ACH cost function may have shifted substantially across time not only because of technological change, but also because of learning-by-doing economies.[32]

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[32] Learning-by-doing economies may have resulted from several factors. Workers performing repetitive tasks may have learned from cumulative experience to perform these jobs more quickly and efficiently. Operations management at a processing site may have been able to call on its experience to modify job assignments, rearrange the layout of facilities, or devise ways to reduce paper or other material wastes. In addition, software engineering may have improved computers' efficiency in processing batches of payments, so that the same amount of computer technology could process more ACH payments faster, or with greater security enhancement, and at lower cost.

TABLE A-2

Estimated Cost Elasticities (at sample means)

Sample Period	Cost-Function Model OLS Model 1 Model a	 Model b	 OLS Model 2 Model a	 Model b	 ITSUR Model 1	 ITSUR Model 2
1979–1994	0.885[a]	0.881[a]	0.638[a]	0.640[a]	—	—
1989	0.762[a]		0.424[a]		—	—
1990	0.852[a]		0.523[a]		—	—
1991	0.897		0.671[a]		—	—
1992	0.968		0.678[a]		—	—
1993	0.810[a]		0.648[a]		—	—
1994	0.828[a]		0.748		—	—
1989–1994	0.849[a]	0.851[a]	0.634[a]	0.648[a]	0.761[a]	0.448[a]

a. Cost elasticity estimate is statistically different from one.

SOURCE: Authors' calculations.

These cost-function shifts are difficult to model separately, particularly when a high correlation exists between output and a time trend. In addition, we use year-specific indicator variables or a time trend and its squared term to derive estimates of technological change. Thus, it need not be the case that technological regress occurred: Other time-specific factors could also have increased ACH processing costs in the early years. Plausible candidates include the one-time transition costs to newer technologies, shifts to higher-quality (higher-cost) services with more bells and whistles, and various changes in cost-accounting procedures. Unfortunately, adequate control variables for such factors are unavailable, so we could not further decompose these time-specific effects.

Estimates of technological change derived using models with more control variables tend to be larger, possibly because the models incorporate a greater number of environmental variables that control for site-specific characteristics.

Scale Economies

Estimates of cost elasticities at the sample means for the OLS models are reported in table A-2 for several different periods. Inclusion of additional site-specific regressors affects the estimates of scale economies, with OLS Model 2 yielding larger estimates (smaller cost elasticities) than OLS Model 1. All of these cost elasticities are statistically different from one at the 95 percent confidence level, confirming the presence of scale economies. Essentially, OLS Model 1 assigns more of the cost savings to technological change (and consequently, less to scale economies) than does OLS Model 2. Our estimates of cost elasticities are fairly close to the 0.70 to 0.75 figures reported in Humphrey (1982, 1984, 1985). Given the high degree of multicollinearity present in the data (particularly between output and a time trend), which overstates standard errors and implies a bias toward rejecting the hypothesis of scale economies, a finding of statistically significant scale economies shows strong support for this hypothesis.

As a further test of robustness, we also estimate the two OLS models using quarterly cross-sectional data for each year. Again, the scale economy estimates are larger when site-specific characteristics are included. Generally, the yearly cost elasticity estimates are statistically different from one at the 95 percent confidence level. Using OLS Model 1 in 1991 and 1992, however, we do not find statistically significant scale economies. These estimates are bound to be less precise than those generated by our other models because they are based on very few observations.

In summary, we subjected our cost-function model to a number of tests for robustness, primarily by varying the sample period and the regressors. While the magnitude of some of the results varies significantly, our qualitative findings across models are consistent. The sharp declines in unit cost appear to stem primarily from technological change and scale economies. Our finding of significant scale economies is robust to the model specification and selection of sample period.

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