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Abstract

This paper uses a stochastic cost frontier to examine the scale economies, cost efficiencies, and technological change of three payment instruments--check, automated clearinghouse (ACH) transfers, and Fedwire processing--provided by the Federal Reserve over the period 1990-94. We find evidence of substantial scale economies and cost inefficiencies in the ACH and Fedwire services. Check processing also exhibits substantial cost inefficiency, but constant returns to scale. Technological progress is found to be sizable for ACH and Fedwire; check processing is found to have experienced technological "regress," probably because of a decrease in processing volume over the sample period.

Money is not, properly speaking, one of the subjects of commerce; but only the instrument which men have agreed upon to facilitate the exchange of one commodity for another. It is none of the wheels of trade: it is the oil which renders the motions of the wheels more smooth and easy.

--David Hume, *Essays Moral and Political*, 1741

I. Introduction

The payments system, the means of conducting transactions in an economy (Hume's "oil"), has undergone tremendous change over the centuries. Commodity money was replaced by fiat (usually paper) money, reducing transportation and storage costs. The invention of checks to supplement fiat money further reduced those costs, lessened the problem of theft, and provided a record of transactions. Most recently, the advent of electronic payment instructions has greatly reduced the time and handling costs associated with checks. Between the great evolutionary leaps forward that created new forms of payment instructions, smaller degrees of gradual evolution occurred within all the payment mechanisms, refining and improving them and reducing the costs associated with their use. The development of the payments system has indeed rendered the functioning of global commerce "more smooth and easy."

An advanced economy has many payment instruments, each possessing different characteristics that make it suitable for some transactions but not others. For example, cash (currency and coins) is very convenient for low-value consumer purchases; however, few large companies would consider paying their employees in cash. Thus, while cash comprises about 80 percent of the volume of transactions in the U.S., it accounts for less than 1 percent of their value. Checks, automated clearinghouse (ACH) transfers, and wire transfers combined account for about 99 percent of the value transferred by the payments system (see Humphrey and Berger [1990]). Credit cards, point-of-sale, and automated teller machine bill payments are all experiencing rapid growth in volume, but have yet to attract a large share of transaction value. It is unlikely that "e-cash"--digital cash that will permit cybermarkets to flourish--will account for a significant share for some time to come.[1]

In this paper we examine the Federal Reserve's costs of processing three of the most important payment

[1]See Humphrey, Pulley, and Vesala (1996) for information on recent use patterns for a variety of payment instruments for developed countries.

services: checks, ACH transfers, and wire transfers of funds (Fedwire).[2] We estimate three frontier cost systems that allow us to derive estimates of marginal cost, scale economies, cost efficiency, and technological change for each service. Each of these properties has important implications for the pricing, delivery, and market structure of these payment services.

II. Overview of Check Processing, Automated Clearinghouses, and Fedwire Funds Transfer Services

Before the Depository Institutions Deregulation and Monetary Control Act (MCA) of 1980 was passed, the Federal Reserve offered its payments services (check processing, ACH transactions, and Fedwire) at no charge to member banks. The MCA required the Federal Reserve to offer its payments services to all depository institutions, not just member banks, and directed it to begin charging for these services.[3] The Board of Governors has established guidelines for pricing payment services. Prices are set to recover all direct and indirect costs, including a markup over cost (the "Private Sector Adjustment Factor" [PSAF]) that reflects other costs (for example, taxes) incurred by private-sector providers of payments services. The prices of ACH and Fedwire funds transfer are determined nationally; however, because input prices, transportation requirements, and the mix of banks served vary from region to region, fees for check services vary substantially across Federal Reserve offices. While the passage of the MCA increased the number of banks eligible to use Federal Reserve payment services, a large decline in the volume of the Federal Reserve's check processing services occurred as the new pricing requirement made it easier for private providers of payment services to compete for member banks' business.[4]

The following is a brief description of each of the Federal Reserve's payments services. It is intended to provide insight into the costs associated with these important services, but it does not reveal all of the complexities faced by a typical Federal Reserve processing site. For example, within each of the three services, transactions processed can be differentiated by the locations of the transmitting and receiving banks involved, the time available

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[2] In this paper, Fedwire transactions refer to fund transfers, not to book-entry Treasury security transfers.

[3] In the remainder of the paper, the term bank will be used to refer to any depository institution.

[4] Though the Federal Reserve's check service volume declined, its ACH and Fedwire services have experienced steady rates of volume growth.

for processing, and the amount of processing required by specific customers. Costs can vary significantly as a result of this myriad of product characteristics. While our analysis attempts to control differences across sites, some possibly important factors are no doubt missing. We hope that future research efforts will address any deficiencies.

Check Processing

Conceptually, the processing of checks is a straightforward operation. A payor writes a check to a payee, who deposits it at his/her bank. In the case of "on-us" items (when the payor and payee are customers of the same bank), the bank debits the payor's account and credits the payee's account. This situation represents about 25 percent of all transactions involving checks. If the payor and the payee have accounts at different banks, then the payee's bank must somehow present the check to the payor's bank. This type of settlement accounts for the remaining 75 percent of check transactions. In this case, the payee's bank has the option of sending the check directly to the payor's bank for payment, or it can employ the services of a local clearinghouse, a correspondent bank, or a Federal Reserve office to process the "transit" check. In 1994, Federal Reserve Banks processed approximately 35 to 40 percent of the transit checks-- approximately 17 billion of them. If the account on which a check is drawn has insufficient funds to cover it, the check is returned to the bank of first deposit directly or through one or more returning banks. This return process is more labor intensive, and thus more costly, than the forward processing of checks.

Automated Clearinghouse Services

The ACH system is a value-dated electronic funds transfer system that can be used to make either credit transfers or debit transfers. The five principal participants in ACH transactions are the payor, the payee, the payor's bank, the payee's bank, and the provider of the ACH service. With credit transfers (for example, 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 or utility payments), the payee's bank initiates the transfer and receives funds from the payor's bank. The Federal Reserve handled about 94 percent of the roughly 2.5 billion commercial and government ACH transactions processed in 1994.

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, ACH transactions may be more convenient, particularly for recurring payments, because the payor need not remember to write and deliver a paper check, and the payee need not cash or deposit it. Third, the total costs to all parties are much lower for ACH transactions than for paper checks.[5] Finally, accounting efficiencies may exist for business payors and payees that have implemented financial electronic data interchange to facilitate communications with trading partners.[6]

Fedwire Service

The Fedwire funds transfer service is a real-time, gross settlement system in which the sender of funds initiates the transfer. Banks that maintain a reserve or clearing account with a Federal Reserve Bank may use Fedwire to send payments to or receive payments from other account holders directly. In contrast with ACH payments, which take two days to process, Fedwire is an immediate payment mechanism and is therefore used for time-critical payments. Fedwire transfers are used primarily for payments related to interbank overnight loans, interbank settlement transactions, payments between corporations, and settlement of securities transactions.

Unlike check and ACH debit transactions, which can be returned unpaid, Fedwire transactions have the advantage that the funds transfer is final when credited to the receiving bank's Federal Reserve account, or when the Federal Reserve Bank sends advice of the payment to the bank, whichever comes first. When funds are transferred via Fedwire, Uniform Commercial Code (UCC) 4A requires that they be made available to the recipient upon acceptance by the recipient's bank. UCC 4A also applies to corporate ACH credit transactions.

While large-value transactions systems, like the Federal Reserve's Fedwire and the private Clearing House Interbank Payments System (CHIPS), accounted for only about 120 million transactions in 1994, as compared with 60 billion check transactions and over 2.5 billion ACH transactions (Bank for International Settlements [1995]), they accounted for most of the value of noncash transactions. In 1994, Fedwire and CHIPS transactions were valued at over $500 trillion, whereas the values of checks processed by the Federal Reserve and total ACH

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

[6]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.

transactions were only $13 trillion and $10 trillion, respectively. The Fedwire service accounts for more than half of all large-value transactions, though it handles less than half of the dollar volume.

III. Estimation Technique

Frontier cost functions for each of the three payment services are estimated to measure their marginal costs, economies of scale, cost efficiencies, and rates of technological change. A variety of methodologies exist for calculating cost frontiers; each of them measures efficiency relative to a "best-practice" cost curve. In this paper cost frontiers are estimated using a stochastic, parametric model.[7,8] A stochastic form is chosen so that noise is less likely to be commingled with inefficiency; a parametric form so that estimates of the underlying technology's various properties, such as marginal costs and scale economies, can be derived.

The estimation of cost frontiers requires data on cost, output quantities, input prices, and any environmental factors that might influence the level of costs. Let C_{it} be the level of observed cost incurred by the I ($I = 1,\dots,N$) processor in period t ($t = 1,\dots,T$), y_{it} be the vector of output quantities produced by the I^{th} processor in period t, w_{it} be the vector of input prices facing processor I in period t, and E_{it} be a vector of characteristics describing the environment faced by the I^{th} processor in period t. A stochastic, parametric frontier (log) cost function can be written as:

$$\ln C_{it} = \ln C(y_{it}, w_{it}, E_{it}, t; \beta) + v_{it} + u_{it}. \qquad (1)$$

That is, the observed (log) cost, $\ln C_{it}$, is the sum of frontier (log) cost, $\ln C_{it}(y_{it}, w_{it}, E_{it}, t; \beta)$, random deviations from minimal cost, v_{it}, and deviations from minimal cost due to inefficiencies, u_{it}. The random disturbance may be positive, zero, or negative ($v_{it} \gtrless 0$), while the disturbance due to inefficiency is non-negative ($u_{it} \geq 0$), since inefficiency cannot cause cost to be less than the frontier level.

Before estimating the cost frontier given by equation (1), two further modeling decisions must be made. First, a functional form must be chosen to represent the parametric relationship between cost, output, input prices,

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[7]See Charnes et al. (1994) and Greene (1993), respectively, for overviews of the programming and econometric approaches to frontier estimation.

[8]For examples of frontiers applied to financial services, see Aly et al. (1990), Bauer, Berger, and Humphrey (1993), Bauer and Hancock (1993), Berger (1993), Berger, Hancock, and Humphrey (1993), Berger and Humphrey (1991), Elyasiani and Mehdian (1990), Ferrier and Lovell (1990), Ferrier et al. (1993), Fried, Lovell, and Vanden Eeckaut (1993), Mester (1993), and Rangan et al. (1988).

and environmental variables. Because of its flexibility, we have chosen a hybrid cost function that combines the terms of the standard translog model and the first-, second-, and third-order trigonometric terms of the Fourier functional form. This hybrid cost function offers a close, global approximation to any underlying functional form (Gallant [1981] and Berger, Leusner, and Mingo [1995]). Second, the inefficiency term must be modeled. The availability of repeated observations over time (that is, panel data) alleviates the need to make an assumption about the particular distribution followed by the inefficiency term. Instead, we use the distribution-free "within" frontier model of Schmidt and Sickles (1984), modified for use with a cost function. This model identifies site-specific, time-invariant measures of inefficiency (that is, $u_{it} = u_i$) based on observation-specific constants. The within model provides consistent estimates of the individual intercepts as $T \to \infty$, and allows the individual inefficiency effect to be consistently separated from the overall residual as $N \to \infty$. Furthermore, it allows for correlation between the inefficiency terms and the regressors. Unfortunately, any variables that do not change over time must be excluded from the estimation, and the effects of these variables are included in the efficiency estimate.

Given our assumptions, the cost function to be estimated can be written as:

$$\begin{aligned}
\ln C_{it} = \theta_1 &+ \sum_{l=1}^{L} \alpha_l \ln y_{lit} + \frac{1}{2} \sum_{l=1}^{L} \sum_{k=1}^{L} \alpha_{lk} \ln y_{lit} \ln y_{kit} \\
&+ \sum_{k=1}^{K} \beta_k \ln w_{kit} + \frac{1}{2} \sum_{l=1}^{K} \sum_{k=1}^{K} \beta_{lk} \ln w_{lit} \ln w_{kit} \\
&+ \sum_{l=1}^{L} \sum_{k=1}^{K} \delta_{lk} \ln y_{lit} \ln w_{kit} + \sum_{m=1}^{M} \gamma_m \ln E_{mit} \\
&+ \sum_{j=1}^{3} \phi_j QTR_j + \sum_{r=2}^{N} \theta_r PS_r + \lambda YEAR \\
&+ \sum_{l=1}^{L} \left[\psi_l \cos z_{lit} + \omega_l \sin z_{lit} \right] \\
&+ \sum_{l=1}^{L} \sum_{k=1}^{L} \left[\psi_{lk} \cos(z_{lit} + z_{kit}) + \omega_{lk} \sin(z_{lit} + z_{kit}) \right] \\
&+ \sum_{l=1}^{L} \sum_{k=1}^{L} \sum_{m=1}^{L} \left[\psi_{lkm} \cos(z_{lit} + z_{kit} + z_{mit}) + \omega_{lkm} \sin(z_{lit} + z_{kit} + z_{mit}) \right] \\
&+ v_{it},
\end{aligned} \tag{2}$$

where C, y, w, and E are as defined above, QTR is a set of dummy variables to indicate the quarter in which an observation operates (one for each quarter except the first), *PS* is a set of dummy variables indicating which processing site is being observed (one for each site except the first), *YEAR*, which indicates the year of observation, is included as a proxy for technological change, and z is logged output mapped into the interval $[0.1 \cdot 2\pi, 0.9 \cdot 2\pi]$ using a linear transformation (see Berger, Leusner, and Mingo [1995]). Note that the inefficiency portion of the "error" term (u) in equation (1) has been replaced by the site-specific dummy variables in equation (2). To improve the statistical efficiency of the estimates, equation (2) was estimated together with its corresponding input share equations (derived via Shephard's lemma). The usual linear homogeneity and symmetry restrictions were imposed prior to estimation.

Note also that the translog functional form, a second-order local approximation, is nested within equation (2). If all of the ψ and ω coefficients are restricted to zero in equation (2), then the hybrid translog-Fourier model reduces to the standard translog model. These restrictions were tested in the empirical analysis reported below.

Given that $u_i \geq 0$, the observation-specific constants can be normalized so that the processing site with the lowest intercept is deemed 100 percent efficient (that is, $u_i = 0$) and serves as the benchmark against which other sites' efficiencies are assessed. This can be accomplished as follows:

$$\begin{aligned} &Let\ \hat{\theta} = \min_i(\hat{\theta}_i), \\ &then\ \hat{u}_i = \hat{\theta}_i - \hat{\theta},\ i = 1,\ldots,N. \end{aligned} \tag{3}$$

Since the estimated cost functions are in log form, the measures of cost efficiency, which range from 0 to 1, are given by $\exp\{-\hat{u}_i\} = \exp\{-(\hat{\theta}_i - \hat{\theta})\}$.

IV. Data

We estimated three cost function/cost share systems of equations, one for the operations of each payment system considered: check, ACH, and Fedwire. Each of the data sets used in our analysis consists of 20 quarterly observations over the years 1990-94.[9] Data on total costs, output volumes, input prices, and environmental variables are included for the 47 Federal Reserve check processing sites, 12 ACH sites, and 12 Fedwire sites.[10] The total number of observations is 931 for check processing, 232 for the ACH service, and 240 for Fedwire.[11] Though we used data from the individual check processing sites, the check results are aggregated to the District level in the discussion of our findings. The primary data source used was the annual functional cost accounting reports collected by the Federal Reserve's Planning and Control System (PACS). Since the purpose of PACS is to monitor costs and to improve resource allocation within the System, the reported data should be fairly accurate; however, some data errors are likely to be present. The use of a stochastic frontier should mitigate the effects of measurement error. The PACS data were supplemented with data from various Federal Reserve surveys, Bureau of Economic Analysis and Bureau of Labor Statistics price indexes, and pricing data from industry sources.[12]

IV.a Total Cost and Input Prices

Total costs for all three payments services were proxied by their activity production costs, which include direct and support costs, but exclude imputed costs and certain overhead expenses, such as special District projects. The processing cost of each payment mechanism is composed of payments for four inputs--labor (*L*), materials (*M*), communications equipment and transit (*T*), and buildings (*B*). Table 1 reports the average share of total cost attributable to each input over the 20 quarters for each of the three payments services.

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[9]We chose this period for several reasons. First, the data series are all complete for this period. Second, the Monetary Control Act of 1980 required that full-cost pricing be introduced for each of the Federal Reserve's payments services. For ACH, full-cost pricing was only gradually introduced and was not completed until 1985. By 1990 markets should have adjusted fully to MCA's full-cost pricing requirement. Third, processing site consolidation could cloud the effects of scale economies; relative to the 1980s, little consolidation of Federal Reserve processing sites occurred during our sample period. Fourth, Expedited Funds Availability (Title 6 of the Competitive Banking Equality Act [CEBA] of 1987) may have changed the technology of check processing. By 1990, the Federal Reserve could take return items for which they hadn't handled the forward processing. Furthermore, all return items were to be in a new format that would allow increased automation of their processing. Finally, such dramatic technological changes have taken place that a single cost function may be unable to fit a longer sample period adequately. Consequently, we concentrate on the most recent data available.

[10]One processing site each for ACH and Fedwire services was excluded from the sample for reasons detailed below.

[11]Not all processing sites were in operation for the full 20-quarter sample period. One check-processing site ceased operations at the end of 1992 (eight quarters prior to the end of the sample period); another site operated for just one month of the fourth quarter of 1994 and was therefore dropped for that period. Thus, nine "site-quarters" are missing from the check service data. One of the ACH processing sites also ceased operations at the end of 1992, reducing the number of ACH service observations by eight site-quarters.

[12]Data construction parallels Bauer and Hancock (1992), who provide details.

The price of labor (P_L) was constructed as the sum of expenditures on labor (including salaries, retirement, and other benefits) divided by the number of employee processing hours. Based on cost shares, check processing is the most labor-intensive payments service, due largely to the paper-based nature of the service and, to a lesser extent, return items. ACH is much less labor-intensive than check processing, though some return items continue to be initiated manually. Because most banks initiate transfers electronically, Fedwire is the least labor-intensive of the payments services.

Due to the massive amounts of clearing data to track, all three payments services make heavy use of materials, which consist of computers and data processing, office equipment and supplies, printing and duplicating, and, in the case of check processing, check reader-sorters. The price of materials (P_M) is given by a Tornquist approximation to a Divisia price index. It was constructed from the service prices of supplies, machines, and check reader-sorters. The service price of supplies (office equipment and supplies, and printing and duplicating) was represented by the implicit price deflator for gross domestic product (GDP). The service price of machines (computers and data processing) was constructed from cost-accounting expenditure data supplemented with the implicit price deflator for office, computing, and accounting machinery. To construct a price for data system support services (primarily used for in-house, product-specific software development), we utilized expenditures for labor and hours worked in that area of each Reserve Bank. Unlike prices for other computer hardware, those of check reader-sorters did not decline over the sample period. Therefore, a separate price index for check reader-sorters was constructed using historical data from industry sources. For computer hardware and check reader-sorters, an estimate of the service value, or price, of machines was constructed using a perpetual inventory model derived by Hall and Jorgenson (1967).[13]

Communications and transit expenditures consist of the costs associated with data and other communications, shipping, and travel. Communications costs form the bulk of this cost category for ACH and Fedwire. Better than half of Fedwire's costs are associated with this input category, due to the communications equipment that is needed because most transfers are sent and received electronically. Check processing is the least

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[13]The Tornquist index was constructed using the rates of growth in the prices for each input category. These rates of growth were weighted by the average proportionate shares of materials expenses attributable to each category over adjoining periods.

communications- and transit-intensive service. Most of its expenditures in this category are due to the costs of flying paper checks around the country. The implicit price deflator for communications equipment purchases by nonresidential producers was used for data and other communications expenses. The fixed-weight aircraft price index for private purchases of producers' durable equipment was employed for shipping and travel expenditures. The Tornquist approximation of a Divisia price index was calculated for transit (P_T), based on the expenditure shares of communications and shipping and their individual price indexes.

Buildings have the smallest cost share among the four inputs, because the Federal Reserve does not finance buildings; thus, interest expenses associated with the acquisition of fixed assets are not present in the PACS's cost-accounting framework. Instead, interest costs are included in the PSAF used to set prices for Federal Reserve payments services. The share of buildings is greatest for check processing, owing to the bulkiness of check-sorting machines. The price of buildings (P_B), measured as square-foot replacement costs adjusted by site-specific depreciation rates, was constructed using cost accounting information from the PACS data and annual replacement-cost indexes available from Means (1995).

IV.b Outputs and Environmental Variables

Check Processing

Check processing is a multiproduct operation consisting of forward items and return items.[14] Forward items (y_{FOR}) are much more numerous than are return items (y_{RET}),[15] but have a much lower per-item processing cost. A collection of other factors that may affect the cost of processing checks were included as elements of the environmental vector, E. The number of endpoints (EP), locations to which checks are delivered, was included in the cost equation together with its squared value. The item-pass ratio (IPR), the average number of times a check must pass through a reader-sorter, is a proxy of the check-sort pattern. IPR is a function of the number of "pockets" on a reader-sorter, the number of banks for which a site processes checks, and the distribution of checks

[14] Fine-sort items (i.e., checks that are fully presorted by banks) were not included in the check processing output, nor were their production costs included in the cost measure.

[15] The ratio of forward items to return items handled by the Federal Reserve was approximately 70:1 over the sample period.

across endpoints, as well as other factors. A dummy variable indicating whether IBM (*IBM* = 1) or Unisys (*IBM* = 0) machines were used at a site during each quarter was included to control for potential differences in maintenance expenses, failure rates, and down times. Some sites process forward and return items separately; other sites process them simultaneously. The latter method is likely more costly. A dummy variable was used to indicate whether a site intermingled the two items (*NTRMNGLE* = 1) or processed them separately (*NTRMNGLE* = 0). Checks are processed at three different types of offices--District Banks, branches of District Banks, and regional check processing centers (RCPCs). Since costs are likely to vary across these settings, two dummy variables were included to control for office type. District Banks served as the reference group; RCPCs were indicated by *RCPC* = 1 (0 otherwise); branches of District Banks were indicated by *BRANCH* = 1 (0 otherwise). RCPCs have three potential cost advantages over District Banks: They were set up specifically to process checks, they are typically located outside of the central business district, and, because they do not handle securities or currency, their physical security costs are relatively low. Branches of District Banks are also likely to have cost advantages relative to the District Banks: Branches do not offer ACH or Fedwire services nor do they house monetary policy functions. Government checks are processed at just one site per district; a dummy variable, *GOVCK*, was included to indicate those sites that process government checks.

ACH

Site-specific figures that focus on transactions processed, rather than the number of payments, served as our measure of output for the ACH service (y_{ACH}).[16] The number of ACH processing sites fell over the sample period; by 1993, only the 12 District Banks processed ACH items. During the period under study, the largest volumes were handled by the 12 District Banks and the Los Angeles branch of the San Francisco Federal Reserve Bank. Thus, with the exception of the Los Angeles ACH site, we aggregate ACH data to the District level. Los Angeles is treated as a separate site because of its large volume of transactions. One of the 12 Districts was omitted from our empirical analysis because the bulk of its transactions were processed by a private provider of ACH services.

[16]ACH payments initiated and received at the same processing site are counted as only one transaction. Payments partially processed at one site, then transmitted to a second site, are counted as transactions at both the transmitting and receiving sites. Thus, the processing volume of ACH sites exceeds the actual number of ACH payments made by the system as a whole. Note that with a single processing site, volume processed would equal the actual number of payments transacted.

The empirical analysis included three control variables to account for differences in ACH sites' processing environments. These sites have some discretion over processing schedules for government items, which may therefore be less costly to process than items processed for commercial customers. However, because government items are concentrated within certain relatively short periods each month, they may cause peak-load problems that would make them more costly than commercial items. In view of these considerations, the proportion of government items (*PGI*) processed was included. As was the case for check processing, the number of endpoints (*EP*) and endpoints squared (EP^2) were included. In this case, the number of endpoints refers to the number of banks or processors receiving ACH payments information. Finally, the proportion of banks receiving electronic payment information (*PEER*) was included, since nonelectronic delivery of information via computer tapes, diskettes, paper, and so on, increases transportation costs.[17] By contrast, increased use of electronic networks for information delivery might give rise to greater scale efficiencies.

Fedwire

Output (y_{FED}) was measured as the total number of Fedwire funds transfers processed at each site. PACS contains information on the number of transfers that originated within each district, the number of interdistrict originations, and the sum of total originations and interdistrict receipts. The number of intradistrict receipts could be derived from these three numbers. Total transfers processed for each site were defined as the sum of originations (inter- and intradistrict) and receipts (inter- and intradistrict), which reflects the number of reserve account entries associated with Fedwire funds tranfers. This measure of output is consistent with the current pricing strategy employed for the Fedwire service, under which both sending and receiving banks are charged a fee for Fedwire transfers.

One processing site employed a slightly different technology than the others (for example, it had a mainframe computer dedicated to Fedwire). Furthermore, the site's output was more than twice as large as any other processing site's. Because it was the only site operating in the upper range of output, disentangling the effects of scale economies and cost efficiency was problematic. Therefore, the cost function for Fedwire was

[17] Over time, ACH transactions have migrated to various electronic forms (tapes, diskettes, and on-line connections). As of July 1, 1993, all commercial (non-federal government) ACH transactions were delivered electronically; as of July 1, 1994, all federal government ACH transactions were also delivered electronically.

estimated both with and without this site in the data set to determine its impact on our findings.

Three environmental variables for each Fedwire site were included to control for differences across sites that might affect costs. Extension time (*EXT*), the number of extra minutes a site had to remain open to clear all of its daily transactions, may affect costs.[18,19] The number of Fedwire customers is also likely to affect costs. Unfortunately, quarterly data on the number of Fedwire customers were not available for the full period of study. Instead, the number of accounts at each processing site was used as a proxy for the number of customers (*CUST*).[20] Note that this variable is similar to the number of endpoints used in the analyses of check and ACH processing. The number of financial-institution accounts should be a good proxy for the number of Fedwire customers, since there was a 0.98 correlation between the two variables during periods for which data on both were available. Finally, the percentage of Fedwire transfers processed on-line (*ONLINE*) was included, since these transactions were probably less costly than those processed off-line. (Note the similarity with the control variable *PEER* used in the analysis of ACH transactions.)

IV.c Other Variables

Three final sets of variables used in the cost analysis were dummy variables to control for quarterly effects (QTR_i, $i = 2,3,4$), dummy variables for all but the first processing site (PS_r, $r = 2,\ldots,N$), and a time trend ($YEAR = 1,\ldots,5$). The site-specific dummy variables were included to allow for the measurement of cost efficiency using the within frontier cost model. The time trend was included to capture the effects of technological change that may have occurred over time. Given the relatively short time period, a more elaborate model of technological change was not practical.

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[18] Unlike the other environmental variable, the actual value of *EXT* was used rather than its natural log. This was due to the fact that some sites used no extension time.

[19] Extension time is likely to be needed to clear transactions on peak activity days. However, extension time also may be an endogenous measure of processing-site efficiency: A less efficient site may need extension time to settle the same number of transactions that an efficient site could settle during its normal hours of operation.

[20] While the number of customers served by each processing site will probably affect costs, the composition of each site's customer base is likely to be more illuminating. For example, the number of customers by connection type (dial-up, leased-line, multi-drop, etc.), the proportion of low volume customers, or the geographic dispersion of customers are all factors that future research might consider.

V. Results

The parameter estimates and their t-statistics for the hybrid translog-Fourier frontier cost functions for the check and ACH services appear in tables 2 and 3, respectively. Though the nested translog forms of the hybrid translog-Fourier cost frontiers were rejected for all three payments services,[21] our Fedwire results (tables 4a and 4b) are based on the nested translog frontier cost function. For the check and ACH services, the hybrid translog-Fourier models fit the data well, most signs being as expected, and most parameter estimates being statistically significant. However, the hybrid translog-Fourier results for Fedwire violated monotonicity: Predicted costs fell as output increased in some ranges. In effect, the hybrid model was too flexible a functional form, as it allowed a violation of a fundamental property of the cost function given by economic theory. Since we choose economic theory over statistical considerations, the (nested) translog is our preferred model for Fedwire. Furthermore, due to the strong influence of one particular processing site (*PS*2) on the Fedwire models, two sets of results are reported. The first set (table 4a) includes all 12 processing sites; the second set (table 4b) excludes site *PS*2.

V.a Unit Cost, Marginal Cost, and Scale Economies

We are interested in the unit cost (based on activity production costs), marginal cost, and scale economies associated with each of the three payment services offered by the Federal Reserve. The scale economies are represented by the cost elasticity, which is defined as the percentage increase in cost for a 1 percent increase in (one of the) output(s):

$$\eta_i = \frac{\partial \ln C(w, y, E, t; \beta)}{\partial \ln y_i} . \tag{4}$$

and, in the case of check processing, the ray cost elasticity, which is given by the following expression:

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[21]For all three payments services, the null hypothesis that all of the sine and cosine coefficients were equal to zero was firmly rejected. For check processing, F(3662,18) = 14.57 (Prob > F: 0.0001); for ACH transactions, F(899,6) = 4.24 (Prob > F: 0.0003); for Fedwire (with *PS*2), F(884,6) = 8.69 (Prob > F: 0.0001). Full translog results are available from the authors upon request.

$$\eta = \sum_{i=1}^{2} \eta_i . \tag{5}$$

The unit costs, marginal costs, and cost elasticities and their 95 percent confidence intervals for check, ACH, and Fedwire services are given in tables 5, 6, and 7, respectively; table 5 also shows the ray cost elasticity for check processing. For comparison purposes, tables 5 and 6 contain the results for both the hybrid translog-Fourier cost systems and the nested translog models for the check and ACH services. Table 7 contains the translog results for Fedwire, both with and without *PS*2.

The weighted average cost of processing a check across the 47 sites is just under 2 cents per check.[22] The marginal cost of forward items, about 1.4 cents on average, is substantially less than that of return items, 38.6 cents on average, corroborating the view that return items are much more costly to process than forward items.[23] The returns to scale for the joint provision of forward and return items (ray cost elasticity) averages .97 for the 47 processing sites, implying that a one percent increase in both outputs would increase costs by just .97 percent. The confidence intervals for the cost elasticity suggest that 12 processing sites have insufficient volume to achieve scale efficiency and that three operate with scale diseconomies; the remaining 32 sites are characterized by constant returns to scale, indicating that they operated very near the scale efficient rate of output. Figure 1 plots the average cost curves based on the unit costs at the sample means of the check processing sites for both the hybrid translog-Fourier and translog models. Note that the two plots are quite similar. The figure reveals that unit cost drops dramatically as output initially rises, but quickly flattens out.[24]

Our findings on scale economies for Federal Reserve check processing services differ from those of

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[22]Recall that check processing is a multiproduct activity--both forward and return items are processed. However, the share of forward items is more than 98 percent; therefore, unit cost is calculated on the basis of forward items only. This simplification should have a negligible effect on the measure of unit cost.

[23]The hybrid translog-Fourier cost function results exhibit a few "local" violations of monotonicity; that is, some point estimates of marginal cost are negative. However, these violations only occur for very small processing sites. Overall, the hybrid translog-Fourier results are very similar to those of the nested translog model. These problems are not as severe as for Fedwire, where there were "nonlocal" (occurring over a broad range of output) violations.

[24]Note the inherent wave forms embedded in the hybrid translog-Fourier functional form as a result of the sine and cosine terms. This is the source of the local violations of monotonicity for the smallest processing sites.

Humphrey (1980, 1981a, 1984, 1985), which were based on a single-output model for earlier time periods, and from those of Bauer and Hancock (1993), who estimated a multiproduct cost function over the period 1979-90. It appears that constant returns to scale, rather than increasing returns, characterize the operation of all but the smallest, and perhaps the very largest, processing sites. The difference between our results and those of previous studies may be partly due to our choice of functional form. First, because the hybrid translog-Fourier model allows for a "flatter" function, the range of constant returns to scale may be broader than for the functional forms used in earlier studies. Second, the standard-error terms for some of the hybrid translog-Fourier's coefficient are large, so statistically the range of constant returns to scale is broader. The hybrid translog-Fourier and the (nested) translog point estimates of cost elasticity were roughly similar. However, the standard errors of the Fourier estimates were much larger than those of the translog estimates, making it less likely that a null hypothesis of constant returns to scale would be rejected.

The weighted average of the unit cost of an ACH is 1.7 cents for the 12 Federal Reserve processing sites in our sample; marginal cost averages less than a penny (0.9 cents) per transaction. The mean level of the cost elasticity for ACH is .48, indicating that the Federal Reserve's ACH service is characterized by increasing returns to scale. Plots of the hybrid translog-Fourier and translog average cost curves for ACH appear in figure 2, which also reveals that increasing returns exist for most of the observed output levels for ACH services provided by the Federal Reserve. While the average cost curve for the hybrid translog-Fourier model appears to rise at the highest level of output, this finding is based on just one processing site whose output is significantly higher than that of any other site.

Interestingly, Humphrey (1981b, 1982, 1984, 1985) found roughly the same magnitude of economies of scale for Federal Reserve ACH services as we did, even though the volume of output in our sample period is much greater than in his. The ACH results are also broadly consistent with those of Bauer and Hancock (1995a).

The weighted average unit cost of a Fedwire transaction is 24.2 cents for the 12 processing sites in the data set. As mentioned above, site *PS2* exerts a strong influence over the estimation results. The average marginal cost is 26.5 cents when *PS2* is included, but just 20.4 cents when it is excluded. For the full sample, the cost elasticity averages 1.14; the two smallest Fedwire sites are found to experience scale economies, the largest site

(*PS*2) experienced scale diseconomies (with a cost elasticity of 1.70); all other sites appear to operate under constant returns to scale. With *PS*2 excluded from the analysis, the cost elasticity averages just 0.79. This cost elasticity indicates that the 11 remaining sites experienced scale economies, though none of the cost elasticities are statistically significantly different from 1 (constant returns to scale). The biggest differences in the cost elasticities across the two sets of estimates are for the smallest and largest sites; for the medium-sized sites, all the results are roughly similar. The average cost curves associated with the two translog models estimated for Fedwire, one with and one without *PS*2, appear in figure 3, which also contains a scatter plot of the raw data. The figure conveys the influence of *PS*2, which is represented by the cluster of data points at the highest output levels. The right half of the average cost curve is based solely on *PS*2, making it unlikely that scale economies and cost efficiency have been correctly disentangled for *PS*2. If *PS*2 is cost efficient, then diseconomies of scale exist for the highest output levels; however, if *PS*2 is cost inefficient, then it is likely that constant returns to scale--or possibly even scale economies--exist throughout the observed range of output levels. Intuitively, the latter possibility is more appealing. Like ACH, Fedwire would seem to be the type of service that would offer scale economies, since both are highly dependent on communications and computers, resources for which unit costs are likely to decline as volume increases.

Our Fedwire results are similar to those of Humphrey (1982, 1984), which seemed to suggest relatively slight scale economies in the Fedwire services. Humphrey (1982, 1984) found that 98 percent of all Fedwire transfers took place in offices with constant returns to scale. However, he employed only cross-sectional data and included the largest processing site in his model. Given the large jump in volume between the largest and next-largest site, his model, like ours, would have had trouble differentiating scale economies and cost efficiency. Without *PS*2, we find about the same level of scale economies for Fedwire as did Bauer and Hancock (1995b), who employed data from 1988 to 1992.

V.b Environmental Variables

Each of the estimated frontier cost systems contains a number of environmental variables to control for differences in the operating characteristics across processing sites. All of the environmental variables have statistically significant effects on the cost of check processing. The number of endpoints (*EP* and EP^2) is found to have a quadratic relationship with cost. Following an inverted-U shape, cost initially rises as the number of endpoints increases, but eventually falls as the number of endpoints increases. Predictably, cost increases with the number of times a check must pass through a reader-sorter (given by the item-pass ratio [*IPR*]). The processing sites that use IBM equipment (*IBM* = 1) had higher costs than those using Unisys equipment. However, this finding may result from differences in geography rather than differences in machinery. Most of the population of the U.S. is located in Districts that use Unisys equipment; most of the area of the U.S. is located in Districts that use IBM equipment. Thus, *IBM* may be serving as an indirect proxy for transportation costs. The type of site where checks are processed also has a statistically significant effect on cost; as a group, both RCPCs (*RCPC* = 1) and branches of District Banks (*BRANCH* = 1) have lower costs than did the District Banks. The intermingling of forward and return items is found to be more costly than the separate processing of the two. Finally, sites that processed government checks appear to have higher costs than those that did not. This finding warrants further study. It may suggest that there are diseconomies of scope between the processing of government checks and private checks; however, it could also result from an accounting anomaly.

For ACH transactions, the coefficient on the proportion of government items (*PGI*) processed is positive, but is not statistically significant. This suggests that either the benefit of having some discretion regarding when to process these items balances with any peak-load problems that they may create, or else that neither of these considerations has any noticeable effect on cost. The number of endpoints (*EP* and EP^2) has a negative relationship with cost--the larger the number of endpoints, the lower the cost of carrying out ACH transactions. The final environmental variable, the proportion of banks receiving their payment information electronically (*PEER*), does not have a statistically significant effect on cost, possibly because all banks were required to receive data electronically by the end of the sample period, leaving relatively little variation in this variable.

For Fedwire services, there is no statistical evidence that any of the three environmental variables (*CUST*, *EXT*, *ONLINE*) affects processing costs. The lack of significance for *ONLINE* probably results from lack of variability in the proportion of transfers processed on line; during the sample period, nearly all transfers were processed on line.

V.c Cost Efficiency

Site-specific and summary statistics for the three payments services' cost efficiency scores are reported in table 8 for all models. The average levels of cost efficiency for the check and ACH services are 68.1 percent and 59.4 percent, respectively, for the hybrid translog-Fourier frontier. As discussed above, the largest Fedwire site has a strong influence on the estimated scale economies and cost efficiencies associated with this service. The average cost efficiencies of the Fedwire service are 58.9 percent when *PS2* is included, and 66.0 percent when it is excluded from the analysis. The measures of cost efficiency indicate the proportion of observed cost that would have been expended had all the sites operated on the best-practice cost frontier defined by the site with an efficiency score of 1. At constant input prices, and given the linear homogeneity of the cost function, the efficiency measures also may be interpreted as the proportion of observed input quantities needed to produce the observed level of output relative to the best-practice performance. Comparing the consequences of unrealized scale economies and the presence of cost inefficiencies, our findings for check processing and Fedwire are similar to that of Ferrier and Lovell (1990) and Berger and Humphrey (1991) with regard to banks: The effects of cost inefficiencies dominate those of scale economies. This is especially true for check processing where scale economies have been exhausted. Fedwire, on the other hand, is characterized by substantial scale economies as well as substantial cost inefficiency. For ACH, we find that the effect of scale economies is slightly greater than that of cost inefficiencies, though both are substantial.

The relatively low levels of average efficiency indicate a great deal of dispersion in the ability of processing sites to convert their inputs into services. The inefficiency may result from principal-agent problems. Since there is no market for corporate control to "discipline" managers at Federal Reserve processing sites, monitoring costs will be higher at the Federal Reserve than at publicly traded corporations. Furthermore, the Federal Reserve lacks two important monitoring devices available to publicly traded firms (Putterman [1993]). First, for publicly traded firms, the value of tradeable shares serves as an indicator of incumbent managers' performance. Second, interest rates that private firms pay to finance expenditures indicate a project's performance or prospects. Since the Federal Reserve does not borrow funds to finance the purchase of buildings, this signal is not available to assess managerial performance. Alternatively, the high degree of market concentration (less for check processing than for the ACH and Fedwire services) and attendant market power within the markets for these payment services may reduce the competitive pressure on processing sites to perform as efficiently as possible. Instead of realizing higher "profits," the processing sites may indulge in the "quiet life" that market power affords (Hicks [1935]). Berger and Hannan (1994) found evidence of the "quiet life" in commercial banking, concluding that the efficiency cost of market concentration was several times greater than the social cost as measured by the welfare triangle. However, mergers and changes in technology give the Reserve Banks increasing competition from private providers of payment services. Finally, despite the inclusion of several environmental variables, heterogeneity across processing sites may not have been adequately modeled. The measured "inefficiency" in this case would reflect operating/environmental differences across sites, not true inefficiency. As Stigler (1976) noted, measured inefficiency may result from not incorporating the right variables or the right constraints in the analysis, or from failing to consider the correct economic objective of the organization under analysis.

Table 9 reports the rank correlation coefficients for the efficiency scores of the check, ACH, and Fedwire operations. The efficiency rankings based on the two different models estimated for each of the three payments services are all highly correlated. However, the efficiency rankings across the three payments services are all negatively correlated, though not with statistical significance. Thus, while the operating performances of processing sites are widely scattered, there is no evidence that the efficient operation of one payment service is related to the efficiency with which the other services are provided.

Interestingly, the use of IBM, as opposed to Unisys, check processing equipment is associated with higher costs based on the estimated parameters of the hybrid translog-Fourier frontier cost system. Indeed the mean level of cost efficiency is 9.2 percent higher for IBM-based processing sites. This suggests that the cost disadvantage of using IBM equipment is partially offset by other factors.

V.d Technological Change

The rate of technological change (more properly, the rate of cost diminution) is modeled by including a time trend in the frontier cost functions estimated for each payment service. Thus, disembodied technological change, which manifests itself by shifting the cost function, is implicitly assumed. The technological change coefficients for all three payments services are shown in table 10. Note that the results across the two models estimated for each payment service are very similar. The cost of ACH transactions diminished at an average rate of about 11 percent per year over the 1990-94 period. Fedwire also enjoyed technological gains during this time, as its cost diminished at an annual rate of about 6 percent. Check processing, however, appears to have suffered the fate of technological "regress," as costs rose about 1.7 percent per year over the period. A number of factors offer likely explanations. First, and probably most important, processing volume declined at many sites over the sample period; cost reductions will almost certainly lag volume declines, since sites require time to shed their fixed costs. Second, the "quality" of checks processed declined over the period, because a high proportion of "high quality" check items (such as payroll checks and Social Security items) migrated to ACH. The remaining, "lower-quality" items are likely to involve greater processing costs. Third, the quality of service provided by Federal Reserve processing sites increased over the sample period. For example, magnetic ink character recognition (MICR) information services were added. Because the output measures are not adjusted for quality, the observed regress may reflect costs associated with capital-intensive quality improvements. Fourth, Federal Reserve Districts were changing to the new Funds 5.0 application during 1994 and 1995.[25] About half of the Districts made the conversion in 1994, the last year of our study. Costs were probably increased by conversion efforts and experimentation with the new technology to determine how to use the available advances most effectively (in other words, sites had not moved very far along the learning curve).[26] The lack of a measured change in output to accompany the cost increase associated with the new technology would result in the *appearance* of regress.

V.e Decomposition

The unit cost for each payment service varies substantially across processing sites (see the second column of tables

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[25]In addition, the Minneapolis Federal Reserve implemented imaging software in 1994.

[26]An alternative model that employed dummy variables to indicate the year of operation rather than the variable *YEAR* = 1,2,3,4,5, produced the following results: 1990, 0; 1991, -4.5; 1992, 0; 1993, 2.9; 1994, 6.1. Thus, technological "advance" is observed in 1991, but "decline" is observed in 1993 and 1994. These results lend support to our explanations for the technological "regress" found for the full sample period.

11, 12, 13a, and 13b). Unit cost is a useful summary measure of operating performance and is thus interesting in its own right. However, the *sources* of variation in unit cost may be of even greater interest. An advantage of the functional forms used is that differences in unit cost can be traced back to their "source" by examining logarithmic differences between a site's unit cost and the unit cost at the mean of the sample data (see Bauer [1993]).[27] There are six potential sources for cost differences in our analysis. First, differences in cost efficiency occur across sites. Some sites operate on the best-practice cost frontier, while others do not. Ceteris paribus, sites that lie above the cost frontier will have higher unit costs. Second, scale economies may account for cost differences. Other things being equal, a processing site that is too small to fully exploit scale economies will suffer a cost disadvantage. Third, sites may face disparate input prices. Those with higher input prices will have higher unit costs, other factors held constant. Fourth, a site's environment may be more or less advantageous compared to another site's. Holding other influences constant, sites with a more hospitable processing environment will experience lower unit costs. Fifth, there is a residual category that comprises all of the interactive terms of the hybrid translog-Fourier cost function. Fortunately, these "interaction effects" account for less than 1 percent of any of the unit cost differentials. Finally, there are random effects.

To discern the sources of unit cost variation, we form the (log) ratio of a site's mean cost over the sample period to the cost at the mean of the sample data:

$$\ln\left[\frac{(\bar{C}_i/\bar{y}_i)}{(\bar{C}/\bar{y})}\right] = \ln\left[\frac{C(\bar{y}_i,\bar{w}_i,\bar{E}_i)\cdot\exp(\bar{\epsilon}_i)}{\bar{y}_i}\right] - \ln\left[\frac{C(\bar{y},\bar{w},\bar{E})\cdot\exp(\bar{\epsilon})}{\bar{y}}\right], \qquad (6)$$

where the terms with the subscript i represent site-specific means and the other terms represent overall sample means. Using the cost function defined in equation (2), the percentage difference between the mean unit cost of a processing site and the unit cost at the mean of the data can be written as:[28]

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[27] Logarithms have the property that, close to zero, they can be interpreted roughly as percentages. For example, a logarithmic difference of 0.1 converts to roughly a 10 percent difference. For the exact percentage, you would need to calculate (1 - exp(0.1)).

[28] To simplify notation, the trigonometric Fourier terms do not appear in (7). They were, however, included in the empirical decompositions reported below.

$$
\begin{aligned}
\ln\left[\frac{(\bar{C}_i/\bar{y}_i)}{(\bar{C}/\bar{y})}\right] &= \left[\bar{\theta}_i - \bar{\theta}\right] \\
&+ \left[\alpha_y(\ln\bar{y}_i - \ln\bar{y}) + \frac{1}{2}\alpha_{yy}\{(\ln\bar{y}_i^2 - \ln\bar{y}^2) - (\ln\bar{y}_i - \ln\bar{y})\}\right] \\
&+ \left[\sum_{k=1}^{K}\beta_k(\ln\bar{w}_{ki} - \ln\bar{w}_k) + \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{K}\beta_{kj}(\ln\bar{w}_{ki}\ln\bar{w}_{ji} - \ln\bar{w}_k\ln\bar{w}_j)\right] \qquad (7) \\
&+ \left[\sum_{k=1}^{K}\delta_k(\ln\bar{y}_i\ln\bar{w}_{ki} - \ln\bar{y}\ln\bar{w}_k)\right] \\
&+ \left[\sum_{m=1}^{M}\gamma_m(\ln\bar{E}_{mi} - \ln\bar{E}_m)\right] \\
&+ \left[\bar{\epsilon}_i - \bar{\epsilon}\right]
\end{aligned}
$$

where the bracketed terms on the right-hand side of equation (7) are the efficiency effects, scale effects, input price effects, interaction effects (between processing volumes and input prices), environmental effects, and random effects, respectively. The decomposition of cost differences into the first five sources is reported in tables 11, 12, and 13 (a and b), for the check, ACH, and Fedwire operations, respectively.

For check processing, cost efficiency appears to be the largest single factor in explaining unit cost differences, but scale economies, input prices, and the operating environment also account for some large cost differences (see table 11). In general, these results are very similar to those reported by Bauer (1993), who used data for 1983-90. Our biggest departure from Bauer (1993) is that environmental effects play a larger role for more processing sites in our findings. For example, the coefficient on the IBM indicator variable rose from Bauer's estimate of 0.0925 to 0.205; thus, Unisys sites appear to have a significant cost advantage.

Cost efficiency and output effects drive the results for ACH services (see table 12). The existence of large-scale economies places smaller processing sites at a significant cost disadvantage. However, it is worth noting that the logarithmic differences for the cost efficiency and output effects usually take opposite signs, implying that the less scale-efficient sites make up for this disadvantage by being more cost efficient, and vice versa. Given that data processing inputs, which are priced nationally, account for about 75 percent of the costs of this service, the processing sites show relatively little difference on this score.

Two sets of results are reported for Fedwire, one which includes *PS*2 in the analysis (table 13a) and one which excludes it (table 13b). The first set of results indicates that *PS*2's superior cost efficiency appears to offset its large disadvantages of scale. Recall, however, that the relative effects of scale economies and cost efficiency on *PS*2's observed costs is suspect, given that *PS*2 is the sole source of data for the upper third of the observed range of output levels. In general, the results for Fedwire are similar to those for ACH services, though environmental factors appear to account for a bit more of the observed unit cost differences with Fedwire. As with ACH services, the penalty for failing to fully exploit scale economies can be large. The input price effect accounts for a very small share; again, this is not surprising, given that data processing inputs account for more than 85 percent of Fedwire costs.

VI. Conclusions

We estimate cost functions for the check, ACH, and Fedwire services provided by the Federal Reserve to derive estimates of marginal costs, scale economies, cost efficiency, and technological change over the period 1990-94. There are wide differences in performance across processing sites, even after controlling for volume, input prices, and various environmental variables.

Scale economies appear to have been exhausted for all but the 12 smallest check processing sites, indicating that some additional consolidation may be in order, particularly if volume declines are projected to continue. However, one cannot decide whether it would be wise to reallocate volume among processing sites, or even to close some sites, by looking at costs alone; one must also consider the demand for check processing services. For example, by locating closer to their customers, processing sites can offer higher quality service, receiving checks later and delivering them earlier. Closing a processing site could lead to lower quality service and loss of volume. Customers may be more than willing to pay the higher processing costs at these suboptimally sized sites. Of course, the move towards electronic check presentment and imaging make the processing site's location much less important. All of the ACH processing sites were found to have statistically significant scale economies, which appears to justify the Reserve Banks' plan to consolidate to one processing site with one backup site. The decision to consolidate the processing of all but the largest Fedwire site receives some support from our findings, as there may be significant scale economies throughout the relevant range of output.

There appears to be a great deal of dispersion in the operating performances of the various processing sites for all three payments services considered in this paper. This suggests that the costs of providing these services could be reduced considerably if all sites were to move to the best-practice frontier. No single site's performance dominated across services. In fact, there appears to be no tendency for a site's cost efficiency in one service to spill over to other services.

The electronic services (ACH and Fedwire) have both experienced rapid technological change over the last five years, while check processing costs have risen over that period. The first finding is consistent with the rapid decline in the price of computer and communication equipment, key inputs into electronic services. Check processing, on the other hand, is largely dependent on labor and the speed at which paper checks can be read through check reader-sorters, neither of which has benefited much from the productivity improvements caused by recent technological change.

Clearly, more empirical research is needed on how new technologies affect the efficiency of the payments system. For example, scope economies among the various services, particularly between ACH and Fedwire transfers, 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 still recovers costs, the demand side of the payment-service market--including cross-elasticities between payment instruments--needs to be more fully understood.

The emergence of new payment instruments and nationwide branching will greatly increase the competitive pressure on the Federal Reserve Banks, and they will need to compete both on quality and price in providing payment services.

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Table 1: Cost Shares for Payment Services

	Check	**ACH**	**Fedwire**
Labor	0.493	0.213	0.139
Materials	0.275	0.408	0.320
Communication and Transit	0.170	0.354	0.523
Building	0.062	0.025	0.019

Source: Authors' calculations.

Table 2: Hybrid Parameter Estimates for Check Processing

	Parameter Estimate	*t*-statistic
Intercept	14.878	19.88
$\ln y_{FOR}$	-1.262	-2.63
$(\ln y_{FOR})^2$	-3.934	-2.71
$\ln y_{FOR} \ln w_L$	-0.042	-6.63
$\ln y_{FOR} \ln w_M$	0.004	0.65
$\ln y_{FOR} \ln w_B$	-0.011	-6.89
$\ln y_{FOR} \ln w_T$	0.049	12.35
$\ln y_{FOR} \ln y_{RET}$	-0.120	-2.13
$\ln y_{RET}$	0.432	1.50
$(\ln y_{RET})^2$	1.201	1.83
$\ln y_{RET} \ln w_L$	0.071	14.27
$\ln y_{RET} \ln w_M$	-0.022	-4.18
$\ln y_{RET} \ln w_B$	0.010	7.56
$\ln y_{RET} \ln w_T$	-0.060	-18.78
$\cos(z_{FOR})$	2.166	3.04
$\sin(z_{FOR})$	-0.501	-3.77
$\cos(2z_{FOR})$	0.480	3.61
$\sin(2z_{FOR})$	-0.068	-1.34
$\cos(3z_{FOR})$	0.183	5.14
$\sin(3z_{FOR})$	0.124	5.00
$\cos(z_{RET})$	-0.935	-1.49
$\sin(z_{RET})$	-0.314	-3.17
$\cos(2z_{RET})$	-0.152	-1.31
$\sin(2z_{RET})$	-0.072	-1.82
$\cos(3z_{RET})$	-0.118	-3.65
$\sin(3z_{RET})$	-0.072	-2.91
$\cos(z_{FOR}+z_{RET})$	-0.098	-2.18
$\sin(z_{FOR}+z_{RET})$	-0.115	-2.53
$\cos(2z_{FOR}+z_{RET})$	-0.143	-3.40
$\sin(2z_{FOR}+z_{RET})$	-0.237	-4.85
$\cos(z_{FOR}+2z_{RET})$	0.146	3.74
$\sin(z_{FOR}+2z_{RET})$	0.112	2.28
Year	0.017	6.56
Q_2	-0.017	-2.15
Q_3	-0.029	-3.51
Q_4	-0.054	-6.60
$\ln w_L$	0.505	248.74
$\ln w_M$	0.271	126.47
$\ln w_B$	0.063	119.82
$\ln w_T$	0.161	127.60
$\ln IPR$	0.157	3.70
IBM	0.205	6.10
$\ln EP$	0.091	7.66

Table 2: Hybrid Parameter Estimates for Check Processing (continued)

	Parameter Estimate	*t*-statistic
$(\ln EP)^2$	-0.061	-9.96
$(\ln wL)^2$	0.085	7.53
$\ln w_L \ln w_M$	0.024	3.37
$\ln w_L \ln w_B$	0.013	3.12
$\ln w_L \ln w_T$	-0.122	-12.46
$(\ln w_M)^2$	-0.003	-0.38
$\ln w_M \ln w_B$	0.004	1.65
$\ln w_M \ln w_T$	-0.025	-4.86
$(\ln w_B)^2$	0.001	0.19
$\ln w_B \ln w_T$	-0.018	-3.42
$(\ln w_T)^2$	0.165	13.66
PS_2	-0.086	-2.43
PS_3	-0.229	-4.51
PS_4	-0.223	-10.74
PS_5	-0.077	-4.25
PS_6	-0.457	-19.36
PS_7	-0.252	-9.94
PS_8	-0.475	-10.62
PS_9	-0.136	-2.85
PS_{10}	-0.246	-5.48
PS_{11}	-0.673	-12.50
PS_{12}	-0.394	-10.10
BRANCH	-0.055	-4.11
RCPC	-0.088	-5.50
NTRMNGLE	0.122	5.26
GOVCK	0.034	2.77

Source: Authors' calculations.

Table 3: Hybrid Parameter Estimates for ACH Processing

	Parameter Estimate	*t*-statistic
Intercept	12.670	11.65
$\ln y_{ACH}$	0.450	1.39
$(\ln y_{ACH})^2$	4.677	0.96
$\ln EP$	-0.130	-2.26
$(\ln EP)^2$	-0.070	-1.05
$PEER$	0.010	0.23
PGI	0.010	0.06
$\ln w_L$	0.210	65.37
$\ln w_M$	0.400	84.79
$\ln w_B$	0.030	49.07
$\ln w_T$	0.360	59.21
$\ln y_{ACH} \ln w_L$	-0.010	-0.78
$\ln y_{ACH} \ln w_M$	-0.030	-2.08
$\ln y_{ACH} \ln w_B$	0.000	0.72
$\ln y_{ACH} \ln w_T$	0.030	2.06
$\cos(z_{ACH})$	-1.170	-0.92
$\sin(z_{ACH})$	-0.070	-0.36
$\cos(2z_{ACH})$	-0.180	-0.79
$\sin(2z_{ACH})$	-0.010	-0.20
$\cos(3z_{ACH})$	0.000	0.08
$\sin(3z_{ACH})$	0.000	-0.04
$(\ln w_L)^2$	-0.010	-0.68
$\ln w_L \ln w_M$	0.020	2.56
$\ln w_L \ln w_B$	-0.010	-8.51
$\ln w_L \ln w_T$	-0.010	-0.71
$(\ln w_M)^2$	0.020	1.00
$\ln w_M \ln w_B$	0.000	-1.47
$\ln w_M \ln w_T$	-0.040	-1.62
$(\ln w_B)^2$	0.010	1.89
$\ln w_B \ln w_T$	0.010	1.83
$(\ln w_T)^2$	0.040	1.32
Q_2	0.010	0.39
Q_3	0.000	-0.06
Q_4	0.000	-0.08
$YEAR$	-0.100	-4.10
PS_3	-0.410	-7.71
PS_4	0.030	0.35
PS_5	0.260	2.52
PS_6	0.418	3.81
PS_7	0.474	3.73
PS_8	0.000	0.01
PS_9	0.033	0.57
PS_{10}	0.149	1.33

Table 3: Hybrid Parameter Estimates for ACH Processing (continued)

	Parameter Estimate	*t*-statistic
PS_{11}	0.223	3.27
PS_{12}	0.418	4.16
PS_{13}	-0.124	-2.27

Source: Authors' calculations.

Table 4a: Translog Parameter Estimates for Fedwire (with PS_2)

	Parameter Estimate	t-statistic
Intercept	1.219	0.12
$\ln y_{FED}$	0.837	3.33
$(\ln y_{FED})^2$	0.549	2.76
$\ln w_L$	0.137	58.28
$\ln w_M$	0.334	47.03
$\ln w_B$	0.021	39.85
$\ln w_T$	0.509	64.99
$\ln y_{FED} \ln w_L$	-0.029	-6.25
$\ln y_{FED} \ln w_M$	0.029	2.45
$\ln y_{FED} \ln w_B$	0.006	5.85
$\ln y_{FED} \ln w_T$	-0.006	-0.46
$(\ln w_L)^2$	0.095	5.58
$\ln w_L \ln w_M$	0.127	4.84
$\ln w_L \ln w_B$	-0.002	-0.53
$\ln w_L \ln w_T$	-0.220	-6.08
$(\ln w_M)^2$	0.306	3.31
$\ln w_M \ln w_B$	-0.013	-1.81
$\ln w_M \ln w_T$	-0.421	-4.07
$(\ln w_B)^2$	0.007	1.77
$\ln w_B \ln w_T$	0.008	0.84
$(\ln w_T)^2$	0.633	5.03
$YEAR$	-0.056	-4.09
$\ln ONLINE$	2.494	1.13
$\ln CUST$	0.144	0.66
EXT	0.000	1.52
PS_2	-0.798	-1.88
PS_3	-0.202	-1.66
PS_4	-0.571	-6.04
PS_5	-0.211	-1.75
PS_6	-0.105	-0.70
PS_7	-0.171	-0.68
PS_8	-0.173	-0.63
PS_9	-0.041	-0.13
PS_{10}	-0.226	-1.00
PS_{11}	0.136	0.76
PS_{12}	-0.461	-1.91
Q_2	-0.043	-1.83
Q_3	-0.063	-2.49
Q_4	-0.072	-2.75

Source: Authors' calculations.

Table 4b: Translog Parameter Estimates for Fedwire (without PS_2)

	Parameter Estimate	t-statistic
Intercept	1.145	0.11
$\ln y_{FED}$	0.758	2.79
$(\ln y_{FED})^2$	0.151	0.53
$\ln w_L$	0.139	53.95
$\ln w_M$	0.320	44.62
$\ln w_B$	0.019	39.50
$\ln w_T$	0.523	66.49
$\ln y_{FED} \ln w_L$	-0.029	-4.66
$\ln y_{FED} \ln w_M$	-0.025	-1.55
$\ln y_{FED} \ln w_B$	0.001	1.13
$\ln y_{FED} \ln w_T$	0.052	2.84
$(\ln w_L)^2$	0.094	5.22
$\ln w_L \ln w_M$	0.107	3.78
$\ln w_L \ln w_B$	-0.004	-1.08
$\ln w_L \ln w_T$	-0.197	-5.18
$(\ln w_M)^2$	0.421	4.40
$\ln w_M \ln w_B$	-0.009	-1.43
$\ln w_M \ln w_T$	-0.518	-4.90
$(\ln w_B)^2$	0.003	0.81
$\ln w_B \ln w_T$	0.011	1.33
$(\ln w_T)^2$	0.704	5.50
$YEAR$	-0.064	-4.46
$\ln ONLINE$	2.501	1.10
$\ln CUST$	0.134	0.59
EXT	0.0002	1.68
PS_3	-0.209	-1.66
PS_4	-0.574	-5.88
PS_5	-0.224	-1.79
PS_6	-0.095	-0.61
PS_7	-0.045	-0.17
PS_8	-0.083	-0.29
PS_9	0.049	0.15
PS_{10}	-0.230	-0.98
PS_{11}	0.121	0.65
PS_{12}	-0.262	-0.99
Q_2	-0.045	-1.76
Q_3	-0.065	-2.40
Q_4	-0.080	-2.87

Source: Authors' calculations.

Table 5: Estimates of Unit Costs, Marginal Costs, and Cost Elasticities for Check

Processing Site	Hybrid						Translog				
		Marginal Cost		Cost Elasticity			Marginal Cost		Cost Elasticity		
	Unit Cost	Forward	Return	Overall	Upper	Lower	Forward	Return	Overall	Upper	Lower
S1	0.015	0.010	0.565	1.163	1.529	0.797	0.013	0.393	1.171	1.251	1.092
S2	0.020	0.013	0.515	1.060	1.192	0.927	0.016	0.394	1.123	1.167	1.078
S3	0.013	0.009	0.257	0.903	1.235	0.571	0.010	0.232	0.947	0.990	0.904
S4	0.026	0.014	0.618	0.891	1.038	0.744	0.021	0.562	1.106	1.155	1.056
S5	0.021	0.009	-0.056	0.399	0.556	0.242	0.013	0.062	0.654	0.714	0.594
S6	0.020	0.019	-0.597	0.696	0.958	0.435	0.012	-0.152	0.540	0.610	0.469
S7	0.019	0.013	0.153	0.811	1.020	0.601	0.014	0.369	1.010	1.050	0.969
S8	0.030	0.014	0.615	0.877	1.130	0.623	0.025	0.672	1.298	1.376	1.220
S9	0.019	0.012	0.402	0.968	1.067	0.869	0.013	0.216	0.856	0.891	0.822
S10	0.019	0.016	0.261	0.979	1.236	0.722	0.014	0.347	0.958	0.996	0.921
S11	0.022	0.018	0.183	0.937	1.211	0.662	0.014	0.164	0.754	0.830	0.679
S12	0.014	0.009	0.491	1.041	1.173	0.909	0.010	0.139	0.800	0.831	0.769
S13	0.022	0.012	0.719	1.065	1.213	0.916	0.018	0.477	1.152	1.208	1.096
S14	0.021	0.013	0.596	1.178	1.350	1.007	0.017	0.418	1.222	1.282	1.163
S15	0.021	0.019	0.192	1.054	1.147	0.961	0.016	0.363	1.021	1.051	0.990
S16	0.016	0.015	0.542	1.237	1.510	0.964	0.011	0.182	0.797	0.823	0.771
S17	0.019	0.011	0.264	0.777	0.936	0.618	0.015	0.396	1.062	1.108	1.016
S18	0.024	-0.013	0.550	-0.276	0.554	-1.107	0.012	-0.280	0.352	0.501	0.203
S19	0.022	0.024	-0.239	1.049	1.576	0.522	0.013	-0.645	0.441	0.509	0.372
S20	0.018	0.010	0.352	1.014	1.386	0.641	0.013	0.218	0.999	1.040	0.959
S21	0.017	0.010	0.224	0.826	1.007	0.646	0.012	0.201	0.896	0.939	0.853
S22	0.013	0.009	0.486	1.159	1.557	0.760	0.011	0.359	1.169	1.251	1.088
S23	0.028	0.026	0.207	1.030	1.146	0.914	0.021	0.516	0.993	1.025	0.962
S24	0.022	0.014	0.290	0.915	1.172	0.658	0.015	0.273	0.946	0.985	0.907
S25	0.014	0.014	0.149	1.065	1.370	0.760	0.007	-0.306	0.395	0.492	0.299
S26	0.016	0.013	-0.085	0.779	0.973	0.586	0.009	0.007	0.608	0.691	0.525
S27	0.028	0.020	0.243	0.970	1.544	0.396	0.024	0.463	1.322	1.383	1.262
S28	0.018	0.007	-0.044	0.316	0.911	-0.278	0.010	0.082	0.689	0.801	0.577
S29	0.021	0.005	-0.047	0.188	0.815	-0.440	0.012	0.092	0.685	0.799	0.571
S30	0.014	0.006	0.258	0.662	0.890	0.435	0.011	0.315	1.078	1.138	1.017
S31	0.016	0.008	0.010	0.510	0.814	0.206	0.011	0.081	0.709	0.741	0.676
S32	0.021	0.019	0.681	1.165	1.772	0.557	0.018	0.679	1.132	1.229	1.036

Table 5: Estimates of Unit Costs, Marginal Costs, and Cost Elasticities for Check (continued)

Processing Site	Hybrid						Translog				
		Marginal Cost		Cost Elasticity			Marginal Cost		Cost Elasticity		
	Unit Cost	Forward	Return	Overall	Upper	Lower	Forward	Return	Overall	Upper	Lower
S33	0.013	0.014	0.434	1.361	1.609	1.113	0.010	0.198	0.879	0.911	0.846
S34	0.014	0.010	0.234	0.867	1.174	0.561	0.011	0.280	0.966	1.009	0.924
S35	0.022	0.015	0.203	0.847	1.090	0.604	0.014	0.186	0.805	0.870	0.740
S36	0.022	0.016	0.047	0.767	0.929	0.604	0.013	0.065	0.647	0.723	0.570
S37	0.024	0.013	0.932	1.075	1.423	0.727	0.021	0.656	1.242	1.330	1.154
S38	0.017	0.012	0.215	0.871	1.090	0.652	0.011	0.111	0.728	0.800	0.655
S39	0.017	0.008	-0.030	0.474	0.629	0.319	0.010	0.055	0.653	0.716	0.590
S40	0.021	0.021	0.200	1.134	1.278	0.990	0.016	0.351	0.955	0.984	0.926
S41	0.019	0.015	0.161	0.923	1.162	0.684	0.012	0.096	0.682	0.767	0.597
S42	0.017	0.010	0.188	0.775	0.985	0.566	0.011	0.161	0.853	0.906	0.799
S43	0.027	0.021	0.572	1.218	1.382	1.054	0.021	0.442	1.095	1.130	1.061
S44	0.015	0.010	0.417	1.007	1.108	0.905	0.011	0.194	0.848	0.881	0.815
S45	0.023	0.014	0.254	0.802	1.076	0.528	0.016	0.239	0.878	0.932	0.824
S46	0.016	0.013	0.593	1.053	1.502	0.604	0.012	0.237	0.864	0.910	0.818
S47	0.020	0.020	0.330	1.182	1.386	0.978	0.015	0.333	0.929	0.961	0.897
Weighted Average	0.020	0.014	0.385	0.966	1.242	0.691	0.015	0.339	1.003	1.060	0.946

Source: Authors' calculations.

Table 6: Estimates of Unit Costs, Marginal Costs, and Cost Elasticities for ACH

		Hybrid				Translog			
Processing Site	Unit Cost	Marginal Cost	Upper	Lower	Cost Elasticity	Marginal Cost	Upper	Lower	Cost Elasticity
PS1	0.020	0.0117	0.024	-0.001	0.571	0.0094	0.015	0.004	0.460
PS3	0.015	0.0088	0.019	-0.001	0.584	0.0068	0.011	0.003	0.454
PS4	0.015	0.0066	0.014	-0.001	0.442	0.0072	0.010	0.004	0.480
PS5	0.016	0.0109	0.017	0.005	0.684	0.0077	0.011	0.004	0.485
PS6	0.017	0.0111	0.019	0.003	0.650	0.0084	0.012	0.005	0.493
PS7	0.019	0.0019	0.010	-0.006	0.101	0.0094	0.014	0.005	0.502
PS8	0.023	0.0184	0.035	0.002	0.785	0.0106	0.017	0.004	0.452
PS9	0.019	0.0053	0.012	-0.002	0.281	0.0086	0.013	0.004	0.458
PS10	0.016	0.0113	0.019	0.004	0.720	0.0076	0.011	0.004	0.485
PS11	0.022	0.0050	0.018	-0.008	0.225	0.0104	0.016	0.005	0.465
PS12	0.020	0.0142	0.024	0.004	0.724	0.0095	0.014	0.005	0.483
Weighted Average	0.017	0.009	0.017	0.000	0.478	0.0082	0.011	0.004	0.403

Source: Authors' calculations.

Table 7: Estimates of Unit Costs, Marginal Costs, and Cost Elasticities for Fedwire

		With *PS2*				Without *PS2*			
Processing Site	Unit Cost	Marginal Cost	Upper	Lower	Cost Elasticity	Marginal Cost	Upper	Lower	Cost Elasticity
PS1	0.228	0.189	0.283	0.096	0.830	0.176	0.274	0.078	0.773
PS2	0.206	0.351	0.488	0.214	1.703	na	na	na	na
PS3	0.229	0.143	0.249	0.037	0.626	0.165	0.276	0.054	0.720
PS4	0.206	0.135	0.229	0.042	0.657	0.150	0.250	0.050	0.730
PS5	0.278	0.201	0.321	0.080	0.723	0.208	0.339	0.076	0.748
PS6	0.268	0.251	0.358	0.144	0.939	0.217	0.337	0.096	0.809
PS7	0.280	0.320	0.438	0.202	1.141	0.242	0.366	0.118	0.863
PS8	0.321	0.116	0.303	-0.071	0.361	0.210	0.382	0.038	0.653
PS9	0.357	0.119	0.333	-0.095	0.334	0.230	0.465	-0.006	0.643
PS10	0.252	0.176	0.288	0.065	0.699	0.188	0.361	0.015	0.745
PS11	0.304	0.240	0.367	0.112	0.788	0.233	0.372	0.094	0.766
PS12	0.220	0.272	0.370	0.174	1.240	0.194	0.290	0.098	0.883
Weighted Average	0.242	0.265	0.387	0.143	1.144	0.204	0.329	0.079	0.793

Source: Authors' calculations.

Table 8: Cost Efficiency by Service

Processing Site	Check		ACH		Fedwire	
	Hybrid	Translog	Hybrid	Translog	With *PS2*	Without *PS2*
PS1	0.510	0.598	0.665	0.699	0.450	0.563
PS2	0.556	0.628	na	na	1.000	na
PS3	0.641	0.762	1.000	1.000	0.551	0.694
PS4	0.637	0.745	0.648	0.639	0.797	1.000
PS5	0.551	0.622	0.513	0.505	0.556	0.704
PS6	0.806	0.936	0.438	0.445	0.500	0.619
PS7	0.656	0.767	0.414	0.416	0.535	0.589
PS8	0.820	0.974	0.665	0.632	0.536	0.612
PS9	0.584	0.662	0.643	0.644	0.469	0.536
PS10	0.652	0.748	0.573	0.555	0.565	0.709
PS11	1.000	1.000	0.532	0.514	0.393	0.499
PS12	0.756	0.855	0.438	0.442	0.714	0.731
Mean	0.681	0.775	0.594	0.590	0.589	0.660
Median	0.647	0.755	0.573	0.555	0.543	0.619
Standard Dev.	0.141	0.139	0.165	0.166	0.170	0.136

Source: Authors' calculations.

Table 9: Rank Correlation of the Cost Efficiency Estimates for the Three Services (significance levels in parentheses)

	Check		ACH		Fedwire	
Payment Service	Hybrid	Translog	Hybrid	Translog	With PS2	Without PS2
Check, Hybrid	1.000	0.960	-0.260	-0.313	-0.202	-0.263
	(0.000)	(0.000)	(0.440)	(0.348)	(0.552)	(0.435)
Check, Translog	0.960	1.000	-0.211	-0.266	-0.095	-0.179
	(0.000)	(0.000)	(0.534)	(0.429)	(0.782)	(0.599)
ACH, Hybrid	-0.260	-0.211	1.000	0.995	-0.024	0.130
	(0.440)	(0.534)	(0.000)	(0.000)	(0.945)	(0.703)
ACH, Translog	-0.313	-0.266	0.995	1.000	-0.036	0.115
	(0.348)	(0.429)	(0.000)	(0.000)	(0.916)	(0.737)
Fedwire, with PS2	-0.202	-0.095	-0.024	-0.036	1.000	0.928
	(0.552)	(0.782)	(0.945)	(0.916)	(0.000)	(0.000)
Fedwire, without PS2	-0.263	-0.179	0.130	0.115	0.928	1.000
	(0.435)	(0.599)	(0.703)	(0.737)	(0.000)	(0.000)

Source: Authors' calculations.

Table 10: Technological Change in Payment Service Provision

	Hybrid		Translog	
Payment Service	Time	*t*-statistic	Time	*t*-statistic
Check	0.017	6.56	0.018	6.67
ACH	-0.112	-6.35	-0.110	-4.66
	With PS2		**Without PS2**	
Payment Service	Time	*t*-statistic	Time	*t*-statistic
Fedwire	-0.056	-4.09	-0.064	-4.46

Source: Authors' calculations.

Table 11: Check Processing Unit Cost Decomposition, Hybrid Cost Function (Processing Site Means Relative to Overall Sample Means, 1990-1994)

		Logarithmic Differences from Sample Mean					
Processing Site	Unit Cost ($)	Unit Cost	Cost Efficiency	Total Output	Direct Input Price	Effect of Interactions	Effect of Environment
S1	0.015	-0.247	-0.166	-0.124	0.049	-0.002	0.048
S2	0.020	0.066	0.214	0.013	0.029	0.001	-0.159
S3	0.013	-0.382	-0.166	-0.088	-0.038	0.005	-0.085
S4	0.026	0.318	0.291	-0.048	0.222	0.000	-0.099
S5	0.021	0.094	0.205	-0.027	0.019	-0.003	-0.047
S6	0.020	0.063	0.214	0.113	-0.104	-0.004	-0.164
S7	0.019	-0.023	0.214	-0.060	-0.043	0.000	-0.158
S8	0.030	0.441	0.039	0.113	0.100	0.005	0.075
S9	0.019	-0.022	0.068	-0.068	-0.047	0.000	-0.108
S10	0.019	-0.008	0.068	-0.082	-0.036	0.001	-0.055
S11	0.022	0.165	0.214	0.059	-0.045	-0.003	-0.182
S12	0.014	-0.316	0.068	-0.155	-0.087	0.001	-0.257
S13	0.022	0.166	0.205	-0.004	0.147	-0.001	-0.096
S14	0.021	0.096	-0.383	0.111	0.023	0.000	0.380
S15	0.021	0.112	0.045	-0.022	-0.010	0.000	0.178
S16	0.016	-0.204	0.039	-0.136	-0.134	-0.008	-0.100
S17	0.019	0.009	0.039	-0.061	0.024	-0.001	-0.056
S18	0.024	0.227	-0.383	0.619	-0.103	-0.006	0.084
S19	0.022	0.142	0.155	0.146	-0.191	0.010	-0.015
S20	0.018	-0.061	-0.383	0.083	-0.026	-0.001	0.259
S21	0.017	-0.115	0.039	-0.001	-0.136	-0.001	-0.114
S22	0.013	-0.383	-0.166	-0.148	0.033	0.000	-0.121
S23	0.028	0.394	0.205	-0.053	0.234	-0.001	0.138
S24	0.022	0.133	0.045	0.006	0.059	0.001	0.261
S25	0.014	-0.333	0.291	0.138	0.145	0.006	-0.796
S26	0.016	-0.198	-0.184	0.049	-0.099	0.004	0.139
S27	0.028	0.398	-0.103	0.269	0.080	0.003	0.151
S28	0.018	-0.065	-0.184	0.129	-0.042	-0.001	0.168
S29	0.021	0.093	-0.184	0.167	-0.089	-0.002	0.105
S30	0.014	-0.341	-0.166	-0.131	-0.016	0.000	-0.092
S31	0.016	-0.147	0.039	-0.200	-0.087	-0.002	0.027
S32	0.021	0.114	0.155	-0.241	0.072	0.000	0.193
S33	0.013	-0.349	-0.166	-0.123	-0.012	0.005	-0.074
S34	0.014	-0.282	-0.166	-0.077	0.014	0.000	-0.071
S35	0.022	0.134	0.045	0.049	-0.073	-0.001	0.187
S36	0.022	0.128	0.045	0.030	-0.105	-0.003	0.179
S37	0.024	0.250	0.062	-0.049	-0.027	-0.002	0.219
S38	0.017	-0.102	0.068	0.024	-0.030	-0.001	-0.155
S39	0.017	-0.136	-0.103	-0.009	0.023	-0.005	-0.050
S40	0.021	0.090	0.214	-0.051	-0.022	0.000	-0.032
S41	0.019	0.015	-0.103	0.053	-0.005	-0.002	0.012
S42	0.017	-0.130	-0.383	0.026	-0.072	-0.001	0.290
S43	0.027	0.346	-0.103	0.061	0.128	0.002	0.209

Table 11: Check Processing Unit Cost Decomposition, Hybrid Cost Function (continued)

		Logarithmic Differences from Sample Mean					
Processing Site	Unit Cost ($)	Unit Cost	Cost Efficiency	Total Output	Direct Input Price	Effect of Interactions	Effect of Environment
S44	0.015	-0.213	-0.103	-0.092	0.061	-0.003	-0.035
S45	0.023	0.199	-0.184	0.041	0.017	0.000	0.270
S46	0.016	-0.170	0.205	-0.174	0.057	0.009	-0.210
S47	0.020	0.033	0.291	-0.075	0.140	0.000	-0.239
Standard Dev.	0.004	0.219	0.191	0.140	0.091	0.003	0.199

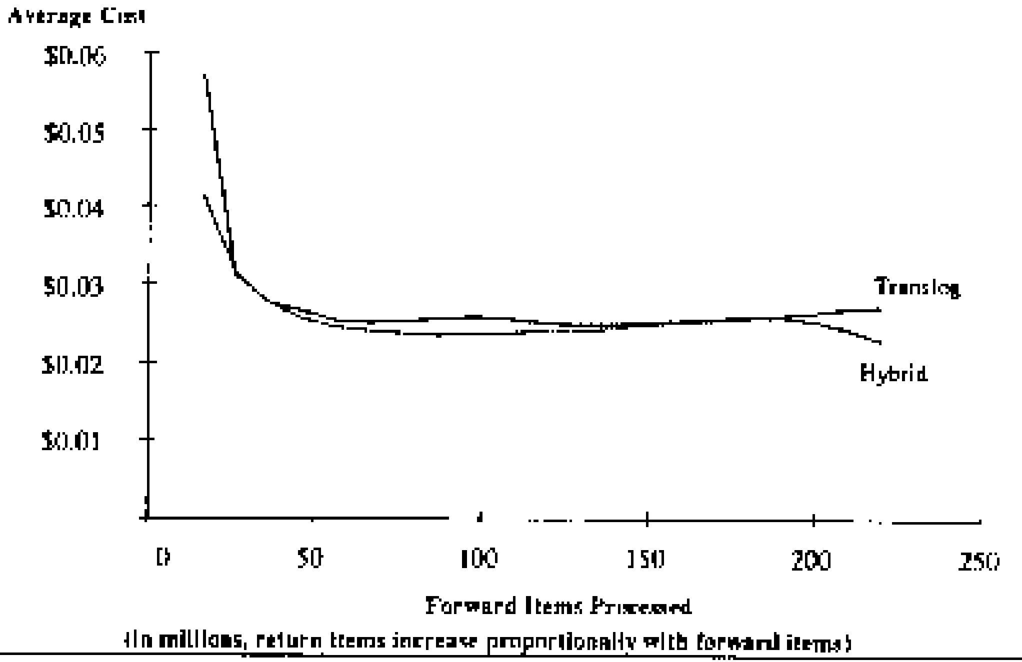
Source: Authors' calculations.

Table 12: ACH Unit Cost Decomposition, Hybrid Cost Function
(Processing Site Means Relative to Overall Sample Means, 1990-1994)

Processing Site	Unit Cost ($)	Logarithmic Differences from Sample Mean					
		Unit Cost	Cost Efficiency	Total Output	Direct Input Price	Environmental Effect	Effect of Interactions
PS1	0.0204	0.112	-0.122	0.191	0.003	0.058	-0.001
PS3	0.0150	-0.195	-0.530	0.192	0.084	0.076	0.001
PS4	0.0149	-0.203	-0.096	-0.037	-0.079	0.023	0.000
PS5	0.0160	-0.135	0.137	-0.123	-0.087	-0.001	0.000
PS6	0.0171	-0.066	0.296	-0.212	-0.019	-0.049	0.001
PS7	0.0188	0.028	0.352	-0.366	0.005	-0.059	0.000
PS8	0.0234	0.248	-0.122	0.295	-0.007	-0.006	-0.001
PS9	0.0188	0.030	-0.089	0.101	0.072	-0.007	0.002
PS10	0.0157	-0.149	0.026	-0.140	-0.002	-0.054	0.000
PS11	0.0224	0.203	0.100	0.071	0.006	-0.004	0.000
PS12	0.0196	0.072	0.296	-0.185	0.072	-0.027	-0.001
Standard Dev.	0.0029	0.157	0.255	0.205	0.056	0.044	0.001

Source: Authors' calculations.

Figure 1: Check Processing



Source: Authors' calculations.

Table 13a: Fedwire Unit Cost Decomposition, with PS2
(Processing Site Mean Relative to Overall Sample Means, 1990-1994)

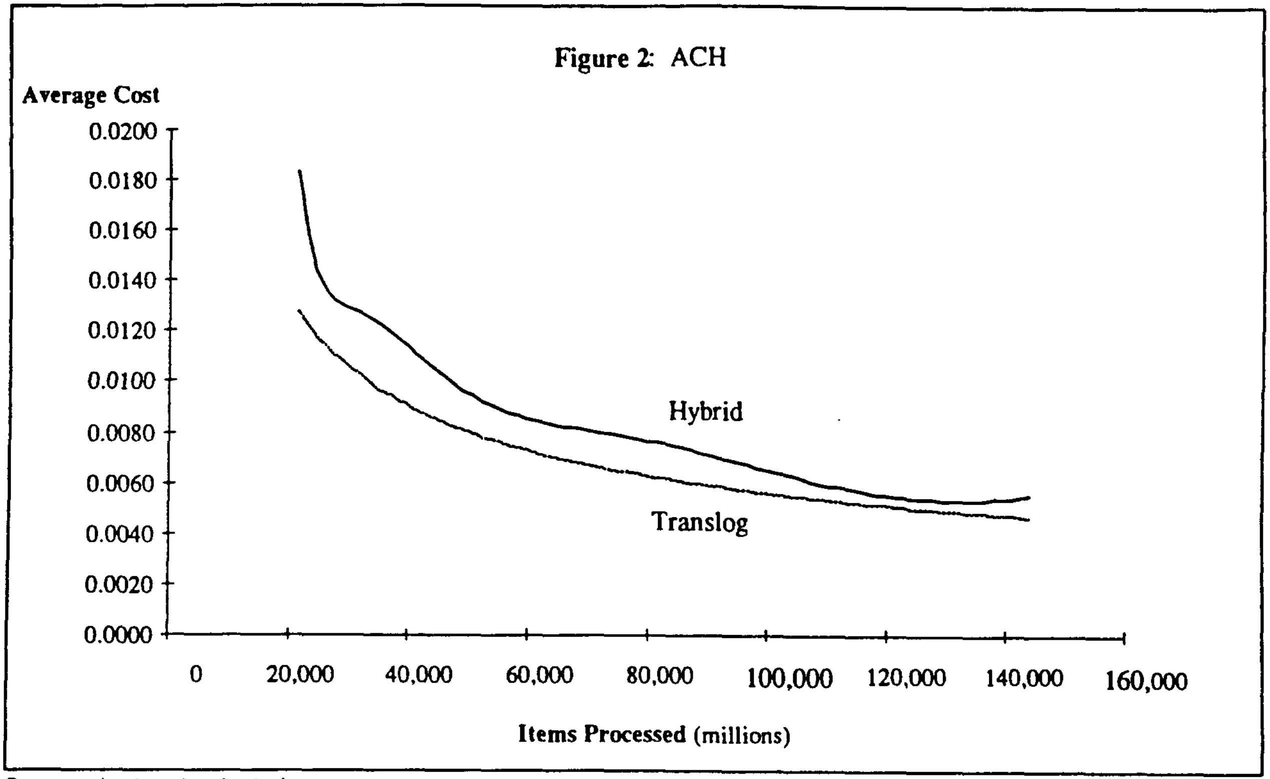
		Logarithmic Differences from Sample Mean					
Office	Unit Cost ($)	Unit Cost	Cost Efficiency	Total Output	Direct Input Price	Environmental Effect	Effect of Interactions
PS1	0.228	-0.126	0.235	-0.122	0.036	-0.070	0.001
PS2	0.206	-0.227	-0.562	0.311	0.042	0.040	-0.009
PS3	0.229	-0.123	0.033	-0.020	0.004	-0.129	0.001
PS4	0.206	-0.228	-0.335	-0.039	-0.005	-0.061	0.001
PS5	0.278	0.072	0.025	-0.077	-0.006	-0.013	0.001
PS6	0.268	0.035	0.131	-0.144	-0.027	0.031	0.001
PS7	0.280	0.081	0.064	-0.128	-0.007	0.080	-0.001
PS8	0.321	0.217	0.062	0.223	-0.048	-0.035	0.002
PS9	0.357	0.324	0.194	0.263	-0.009	0.001	-0.003
PS10	0.252	-0.024	0.009	-0.065	-0.036	0.056	0.001
PS11	0.304	0.163	0.371	-0.106	-0.011	0.034	0.001
PS12	0.220	-0.163	-0.226	-0.096	0.066	0.066	0.004
Standard Dev.	0.048	0.179	0.259	0.165	0.033	0.063	0.003

Source: Authors' calculations.

Table 13b: Fedwire Unit Cost Decomposition, without PS2
(Processing Site Mean Relative to Overall Sample Means, 1990-1994)

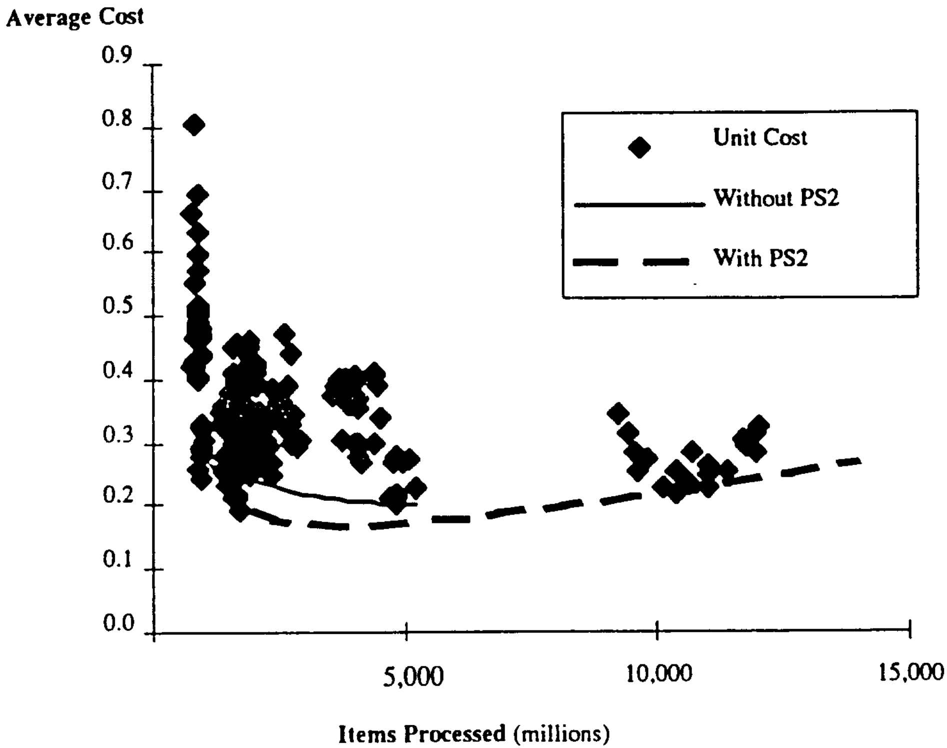
		Logarithmic Differences from Sample Mean					
Office	Unit Cost ($)	Unit Cost	Cost Efficiency	Total Output	Direct Input Price	Environmental Effect	Effect of Interactions
PS1	0.228	-0.147	0.141	-0.050	0.040	-0.064	0.000
PS3	0.229	-0.144	-0.068	0.044	0.008	-0.118	0.002
PS4	0.206	-0.249	-0.433	0.030	-0.001	-0.052	0.001
PS5	0.278	0.052	-0.083	-0.002	-0.002	-0.009	0.001
PS6	0.268	0.014	0.046	-0.090	-0.023	0.039	0.002
PS7	0.280	0.060	0.096	-0.152	-0.002	0.078	0.000
PS8	0.321	0.196	0.058	0.196	-0.043	-0.032	-0.002
PS9	0.357	0.303	0.191	0.217	-0.006	0.005	-0.001
PS10	0.252	-0.045	-0.089	0.009	-0.032	0.053	0.001
PS11	0.304	0.143	0.262	-0.031	-0.007	0.032	0.001
PS12	0.220	-0.183	-0.121	-0.171	0.069	0.067	-0.004
Standard Dev.	0.047	0.172	0.190	0.123	0.031	0.061	0.002

Source: Authors' calculations.



Source: Authors' calculations.

Figure 3: Fedwire



Source: Authors' calculations.