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Cost reductions in electronic payments: The roles of consolidation, economies of scale, and technical change

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Abstract

Unfettered nationwide bank branching raises the issue of whether consolidation of banks' "back-office" operations, such as their payment processing, reduces operating costs. Whether centralized processing of payments reduces costs depends on the size and range of scale economies, the relative prices of data processing and telecommunication inputs, and changes in technology in addition to the number of sites operated. While consolidating payment operations into fewer sites may reduce average data processing costs, those cost savings may be more than offset by associated increases in telecommunications expenses. To investigate the potential effects of consolidation on future banking operations, we look at the experience of the Federal Reserve in consolidating its Fedwire electronic funds transfer operation over 1979 to 1996. Previous research suggested that scale economies in Fedwire payment processing were minimal and that the observed declines in average Fedwire production costs were largely attributable to technical advance. Our estimates suggest more nearly the opposite. We find that the Fedwire funds transfer operation exhibited large scale economies but little technical advance beyond that already embodied in the technology-adjusted input prices of data

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processing and telecommunication inputs. We also find that the consolidation of Fedwire into fewer offices contributed around one-fourth of the overall reduction in Fedwire average cost.

JEL classification: L8; L23; G21; M11

Keywords: Consolidation savings; Scale economies; Fedwire

1. Introduction

Banks process deposits and payments, disburse credit, and calculate account balances of their household, business, and public sector customers. Processing the information associated with these "back-office" activities is a significant source of bank cost. Back office costs include the costs of operating data processing offices and the costs of telecommunication between the processing office and each of the bank's branches and other processing sites.

As banks merge and branch over wider geographic areas, they face decisions about how much to consolidate back-office operations. Banks with geographically-limited service areas typically establish a single information processing site. Banks that operate statewide sometimes process deposit, payment, and other information on a centralized basis. Larger banks may opt instead for distributed processing at several sites. In making such decisions, banks that operate fewer, larger back-office operations potentially reduce average data processing costs at the expense of higher telecommunication costs. Consolidating data processing sites reduces costs if there are important economies of scale in data processing. The greater use of telecommunication facilities that consolidation entails raises expenses but this impact is reduced if the real cost of telecommunication and data processing inputs falls over time. Consequently, larger economies of scale in data processing and lower input prices provide greater incentives for banks to centralize back office operations, such as payment processing.

The Federal Reserve System operates an electronic funds transfer system, Fedwire, that is similar in many respects to the electronic payment operations operated by banks. [1] Because of these similarities, because Fedwire consolidated its payment operations into fewer processing sites since the 1970s, and because of the availability of a considerable amount of data, we studied the Fedwire (funds) transfer operation to gain insight into some of the incentives banks may have to consolidate their back-office operations with the advent of

[1] Fedwire also operates a book-entry securities transfer operation. We only studied the funds transfer part of Fedwire.

nationwide banking. Quarterly data on Fedwire operations over 1979–1996 were used to estimate scale economies, technical change, and the cost effect of consolidation. [2]

Prior to 1990, the Federal Reserve processed Fedwire payment transfers at 12 electronic payment processing sites and had a back-up site. By 1996 these 12 sites had been consolidated to a single, centralized site with two back-ups. The Federal Reserve also operated 36 customer service offices prior to 1980. By 1996 the 36 offices were consolidated into 12, one at each Federal Reserve District head office.

The 1979–1996 period also brought other changes that could importantly affect payment production costs. The number of Fedwire transfers more than quadrupled and the prices of data processing and telecommunication inputs fell substantially relative to the general price level. These prices also changed substantially relative to each other. In addition, technical change swept over the financial services industry. Thus, our study covers a period where there was a considerable increase in Fedwire output, important changes in the level and relative prices of Fedwire inputs, and a dramatic consolidation of Fedwire processing and customer service offices.

To provide context for our study, Section 2 notes the types, volumes, and trends in electronic payments in the US while Section 3 summarizes econometric studies of payments costs. Although scale economies and technical change have been estimated for Fedwire operations, paper checks, and other payment methods, the cost effects of consolidation of payment operations have not yet been rigorously examined or estimated econometrically.

A time-line of Fedwire consolidations is presented in Section 4 and the considerable decline in Fedwire average cost over 1979–1996 is illustrated. The price of data processing inputs declined absolutely and relative to the price of telecommunication. Overall, expenditures on data processing rose relative to those for telecommunication. Section 5 presents the cost function used to estimate scale economies, technical change, and the cost effect of consolidation. It also discusses the variables used, especially the three different specifications of technical change. Appendix A contains additional details about the data we used. Econometric results are presented in Section 6. Section 7 lays out our conclusion that scale economies are large and technical change, beyond that already embodied in the technology-adjusted input prices, was minimal. Importantly, consolidation of Fedwire offices appears to have reduced costs.

[2] Scale economies represent increasing returns to scale where costs rise less than proportionally with the level of output so that the scale cost elasticity is less than 1.00.

2. Electronic payment volumes and trends

In the late 1990s, electronic payments accounted for about 25% of all noncash transactions in the United States and (paper) checks accounted for the remaining 75% (Bank of International Settlements, 1997). Credit cards were the most frequently used electronic payment instrument, accounting for 19% of all noncash payments. Automatic clearinghouse payments (3.5%), debit card payments (3.0%), and wire transfers (0.1%) had much smaller shares of noncash payments. The number of checks written per person in the US was expected to peak by the end of the 1990s; it was already trending down in most other developed countries by the middle of the 1990s.

Forecasts suggest that by the year 2010 between 45 and 58% of noncash payments in the US may be electronic (Humphrey et al., 1998). Use of historical US data points toward the lower future share; a higher share is forecasted if the US shifts from paper to electronics at speeds more like those experienced in the United Kingdom, France, and Canada. The higher share is more likely if state governments follow the federal government's example and mandate that all of their payments be electronic, which will be the case for federal payments starting in 1999. Although checks will still command a large share of noncash payments by 2010, their use at the point of sale or for bill payments will in the future result in many of them being truncated at an early stage and collected electronically. Although paper will initiate the transactions, electronics will do most of the work in finishing the transactions.

3. Empirical studies of payments

Table 1 presents a list of the empirical payment cost studies that have investigated scale economies and/or technical change in the payment area. Nearly all of these studies have used data on the operation of the Federal Reserve System's payment operations, as publicly available data on bank payment operations are almost impossible to obtain.

Early payment studies (Walker, 1978; Humphrey, 1981a, 1981b, 1982, 1984, 1985; Zimmerman, 1981; Belton, 1984; Dotsey, 1991) typically estimated whether payment processing exhibited economies of scale. They used standard or least-squares techniques and typically specified cost functions as translog, quadratic, or log-linear. These early studies used cross-section data and thus were not able to estimate the possible influence of technical change on costs.

More recently, other studies have focussed on frontier analysis to determine if an efficient level, or scale, of output was being produced (Bauer, 1993; Bauer and Hancock, 1993, 1995; Bauer and Ferrier, 1996). Production is scale efficient if it takes place at minimum average cost. For a given level of output, typically measured by the number of payment items processed, cost inefficiency means that either more of each input was used than was required by the technology or that inputs were used in sub-optimal proportions. Bauer and Ferrier (1996) specified a hybrid-translog Fourier functional form for their frontier study, which offers a close global approximation to any underlying functional form (Gallant, 1981). Humphrey (1994) used a composite cost and profit function to study the technology of ATMs, a functional form that provides more stable estimates of scope economies (Pulley and Braunstein, 1992).

Fedwire studies: Table 1 lists three studies that estimated cost functions for Fedwire transfers. Based on cross-section data for 1979, Humphrey (1982) found little indication of economies of scale in electronic transfers. The four offices with the smallest volumes faced increasing returns to scale, but 98% of Fedwire transfers in 1979 were processed at offices that faced costs insignificantly different from those implied by constant returns to scale. Unfortunately, this finding was probably due more to the way that costs for centrally-processed, interdistrict transfers were allocated back to the various offices than to the absence of economies of scale. [3] The second study applied a translog cost function to 1977, 1978, and 1979 cross-sections of data for Federal Reserve Districts (Humphrey (1984)). The estimated average cost curves for Fedwire operations were slightly U-shaped for both groups of offices, indicating that scale economies would be exhausted eventually.

The third study of Fedwire costs used a panel of quarterly 1990–1994 data for Federal Reserve Districts, employed a frontier estimation technique, and estimated both translog and hybrid-translog Fourier cost functions (Bauer and Ferrier, 1996). The results mimicked those of the two earlier studies: the two smallest-volume processing sites exhibited scale economies, the largest-volume site exhibited scale diseconomies, and the other sites operated approximately with constant returns to scale. [4] This study also reported very rapid technical advance: estimated technical change reduced Fedwire production costs by about 6% annually. None of the studies listed in Table 1 directly considered how, apart from scale economies, the consolidation of payment processing operations may affect production costs, which is one task of this paper.

[3] In the Federal Reserve accounting records, interdistrict transfer expenses were allocated back to the 12 Federal Reserve Districts in proportion to their interdistrict transfers sent and received. They were allocated at the observed national average cost. This accounting procedure biases econometric estimates toward finding constant returns to scale.

[4] When Bauer and Ferrier (1996) omitted the site with the largest volume from their sample, all of the remaining eleven sites experienced scale economies. They argued that this reversal of results was due to the difficulty of disentangling effects of cost inefficiency from those for scale economies.

Table 1
Summary of selected econometric studies of payment costs

Payment provider	Functional form(s)	Estimation technique	Factors that were considererd				
Payment method:			Technical change	Input prices	Scale	Cost efficiency	Consoli-dation
Authors (Date)							
Federal Reserve							
Fedwire funds:							
Humphrey (1982)	Translog	Standard	No	Yes	Yes	No	No
Humphrey (1984)	Translog	Standard	No	Yes	Yes	No	No
Bauer and Ferrier (1996)	Translog/Fourier	Frontier	Yes	Yes	Yes	Yes	No
Book-entry securities:							
Belton (1984)	Quadratic/Translog	Standard	No	No	Yes	No	No
Automated clearing house:							
Humphrey (1981b)	Cobb–Douglas Translog	Standard	No	Yes	Yes	No	No
Zimmerman (1981)	Quadratic	Standard	No	Yes	Yes	No	No
Humphrey (1982)	Translog	Standard	No		Yes	No	No
Humphrey (1985)	Translog	Standard	No	Yes	Yes	No	No
Bauer and Hancock (1995)	Translog	Frontier	Yes	Yes	Yes	Yes	N0
Bauer and Ferrier (1996)	Translog/Fourier	Frontier	Yes	Yes	Yes	Yes	No
Check processing:							
Humphrey (1981a)	Translog	Standard	No	Yes	Yes	No	No
Zimmerman (1981)	Quadratic	Standard	No	Yes	Yes	No	No
Humphrey (1982)	Translog	Standard	Yes	Yes	Yes	No	No
Humphrey (1985)	Translog	Standard	No	Yes	Yes	No	No
Bauer (1993)	Translog	Frontier	Yes	Yes	Yes	Yes	No
Bauer and Hancock (1995)	Translog	Frontier	Yes	Yes	Yes	Yes	No
Bauer and Ferrier (1996)	Translog/Fourier	Frontier	Yes	Yes	Yes	Yes	No

Cash:							
Zimmerman (1981)	Quadratic	Standard	No	Yes	Yes	No	No
Dotsey (1991)	Translog	Standard	No	Yes	Yes	No	No
Bauer, et al. (1997).	Translog	Frontier	Yes	Yes	Yes	Yes	No
Commercial banks							
Automated teller machine transactions:							
Walker (1978)	Log Linear	Standard	No	No	Yes	No	No
Humphrey (1994)	Composite with Box–Cox Transformation	Standard	No	Yes	Yes	No	No

4. Consolidation of Fedwire operations

A time-line of Fedwire consolidations: The number of Fedwire data processing sites and customer service offices over 1979–1996 are shown at the top of the vertical lines in Fig. 1. The lines themselves indicate the years that various consolidations occurred. There were 12 data processing sites (one at each Federal Reserve Bank) in 1979 and a back-up site was added in 1985 for a total of 13. The number of data processing sites rose to 15 when inter-District (but not intra-District) wire transfers began to be processed at a centralized facility, but fell thereafter. There were only three data processing sites after the 1995 consolidation when both inter-District and intra-District processing was centralized to 1 site plus 2 back-ups. Customer services offices experienced a similar consolidation. These offices fell from 36 (located at the 12 Federal Reserve Banks and their branches) in 1979 to 30 in 1980. Successive consolidations reduced their number to 12 in 1995 (one at each Federal Reserve Bank).

Changes over time in the share of data processing expenses in total cost reflected major changes the Federal Reserve System's computing strategy. In

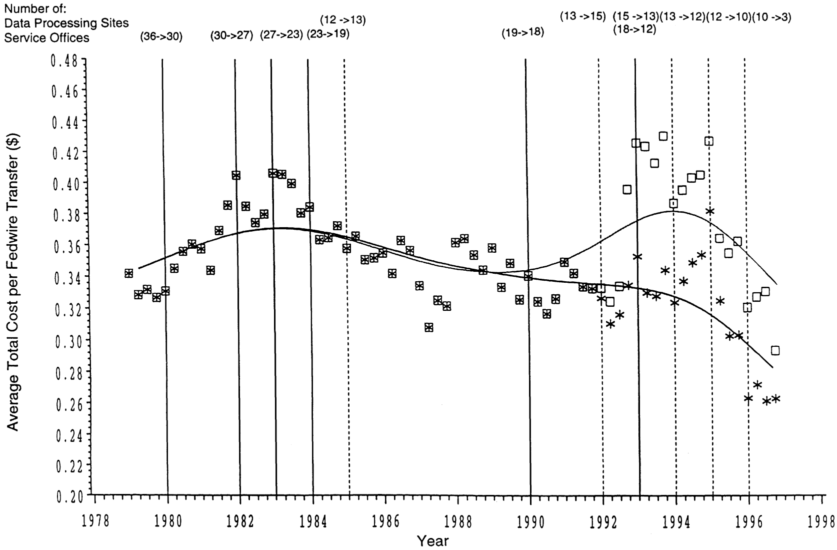

Fig. 1. Fedwire consolidations and average cost per Fedwire transfer. *Note*: Scatter plots of average cost with and without transition costs for 1979:Q1–1997:Q3. Vertical markers indicate years with consolidation activity. The smooth lines are parametric cubic splines with continuous second derivatives. The method used a piecewise third-degree polynomial for each set of adjacent points. The polynomial passes through the plotted points and matches the first and second derivatives of neighboring segments at the points (see Reinsch, 1967).

an attempt to reduce costs, during the 1970s and 1980s the then 12 independent Reserve Bank automation programs were standardized with respect to core business application software, computer hardware, operating systems, system availability, and disaster recovery methods. Later, in 1991, the Federal Reserve Automation Service (FRAS) was established to provide for centralized management for Fedwire payment operations. The next year FRAS began to incur expenses as it purchased data processing equipment for its centralized operations and devoted employee time to its special Automation Consolidation project, which was to consolidate Fedwire mainframe computer operations into only three sites. Through 1994, FRAS used staff to bring the differing District operations in line with the coming, single standard (Board of Governors of the Federal Reserve System, 1995). By the end of 1994, four Reserve Banks used the centralized data processing operation; by the end of 1995, 11 Reserve Banks had converted. The last and largest office (New York) converted in 1997.

Incentives to consolidate Fedwire: Three factors provided incentives to consolidate Fedwire operations: (i) technical changes, (ii) scale economies, and (iii) public policy issues. Technical changes greatly raised the processing speed of data processing computers that handled Fedwire transfers. Other changes increased transmission speed and improved telecommunication security between banks and Federal Reserve District offices. These advances lowered the real cost of data processing and made banks' communications to more-distant Federal Reserve offices cheaper, safer, and more reliable.

Expanded scale economies in Fedwire operations likely originated from at least two sources. First, distributed Fedwire operations may have been sub-optimally small, so that consolidating operations into fewer processing sites would have reduced total costs. As well, distributed processing made enhancements to Fedwire operations difficult to coordinate, expensive to implement, and prone to operational difficulties. Second, standardizing Fedwire's software applications and use of computer hardware eliminated the common practice of each Federal Reserve District developing and maintaining its own computer software and hardware to suit perceived local interests (Gilbert et al., 1997). [5]

Policy issues, such as the growth of statewide and regional bank branching and the increasing likelihood of nationwide branching, may have also played a role in consolidation. Even before nationwide branching became a reality,

[5] The equipment used to connect banks with the Federal Reserve was also standardized and the 12 separate intra-district communication networks were replaced with a single, nationally-managed network (Fednet). Format changes have also been implemented making it less costly for commercial banks to re-route funds transfer information received on CHIPS or SWIFT over Fedwire (Federal Reserve Bank of New York, 1995).

many larger banks greatly expanded their geographical service areas via mergers and expansions, often operating across more than one Federal Reserve District. As a result, these banks had an increased interest in having the Federal Reserve consolidate its operations and they pushed for a restructuring that would better serve their needs.

Fedwire consolidation and average cost: The "square" symbols in Fig. 1 plot the average cost of a Fedwire transfer over 1979–1996. The "asterisk" symbols plot a measure of average cost that excluded consolidation transition costs. Transition costs include various re-organization expenses and the imputed cost of duplicate capacity resulting from the transition from one data processing system to an updated one. These costs were segregated from normal Fedwire costs after 1992. The cost series that excludes transition costs (asterisks) reflects better the longer-run average costs of Fedwire operations.

The most striking feature of Fig. 1 is the downward trend in (nominal-dollar) Fedwire average production costs. Average cost fell from about $0.34 per transaction in 1979 to about $0.29 in 1996, a drop of 14%. The cost series that excluded transition expenses, and is more representative of long-run costs, fell by 24% (from about $0.34 in 1979 to about $0.26 in 1996). In real terms, of course, both reductions were even larger. Relative to the GDP deflator, which rose by 98% from 1979 to 1996, costs with and without transition costs fell by 57% and 61%, respectively.

The solid lines in Fig. 1 were fitted using parametric cubic splines. [6] Both fitted lines indicate that costs tended to rise during consolidations and then tended to fall afterward to levels below their pre-transition levels. Waves of rising then falling costs were most evident around 1982 and 1994, the periods when the numbers of data processing sites and service offices declined the most.

Fedwire average cost that included transition costs, plotted with squares in Fig. 1, plus the Private Sector Adjustment Factor (PSAF) were the basis for setting Fedwire prices. Table 2 shows that Fedwire prices consisted of a basic transfer fee plus add-ons if the parties to the transfer were "off-line" or if they required a telephoned advice of credit. In addition, monthly "fixed fees" were charged for the telecommunication links that banks use to connect to Federal Reserve System offices. [7] Costs for on-line transfers were much lower than off-line transactions. Over time the prices charged for off-line transactions have been adjusted to reflect more closely this cost differential.

[6] See Reinsch (1967) and the SAS Institute (1990, p. 416).

[7] Fixed fees are fees for connections that establish and maintain bank-to-Federal Reserve System networks, dedicated computer-to-computer data-transmission links ($750 monthly), shared leased-line connections ($450 monthly), and simple dial-up connections ($75 monthly).

Table 2
Nominal dollar fee per Fedwire transfer (1982–1997)

	1982	1985	1989	1993	1997
Basic transfer fee	0.65	0.55	0.50	0.53	0.45
Off-line surcharge	3.50	5.50	5.50	10.00	10.00
Telephone advice	2.25	3.00	4.00	10.00	10.00

Source: Federal Reserve System, Division of Federal Reserve Bank Operations and Payment Systems.

The declines in average cost permitted the Federal Reserve System to lower the Fedwire basic transfer fee 44% from \$0.65 in 1982 to \$0.45 in 1997. [8] Relative to the GDP deflator, the transfer fee fell 57% from 1982 through 1997. [9] The fees that Fedwire charges banks are a small portion of the cost to banks of carrying out a Fedwire transfer. While the transfer fee paid by both sending and receiving banks was about \$1.00 in 1993, banks often charged their retail customers \$25 or more for a Fedwire transfer. Thus, the reduction in fees shown in Table 2 likely had little effect on banks' total cost of a transfer. As a result, the declines in Fedwire average production costs could hardly have been the reason for the 8.4% annual growth in the number of Fedwire transfers over the 1979–1996 period.

Prices of data processing and telecommunication equipment: Fig. 2 plots the prices of data-processing and telecommunication equipment. The dotted line, labeled P_{tc}(chained), plots the chain-weighted price of telecommunication equipment, which rose in nominal terms by 38% over the 1979–1996 period. The box symbols trace out the fixed-weight version of the same index. As shown, the weighting method made no difference to the resulting price index for telecommunication equipment.

The picture for the price of data processing equipment is quite different. The fixed-weight price index for data processing equipment, plotted with triangle symbols, fell moderately – declining 16% from 1979 through 1996. In contrast, the chain-weighted price index, plotted with a solid line, fell precipitously – declining 87% over the same period.

The nominal price of the other inputs used by Fedwire rose, as did the general price level. Labor used as a Fedwire input rose 246%, building and maintenance prices rose 217%, and materials and other input prices rose by about 100%. Because Fedwire's data processing and telecommunication inputs included the labor and other inputs used in data processing and telecommunication in addition to equipment, the prices of the data processing and telecommunication inputs did not decline as sharply as did the prices shown in

[8] Both the sender and receiver of a Fedwire transfer pay the basic transfer fee in Table 2.

[9] Some of the reduction in the basic transfer fee was offset by increases in other Fedwire fees shown in Table 2.

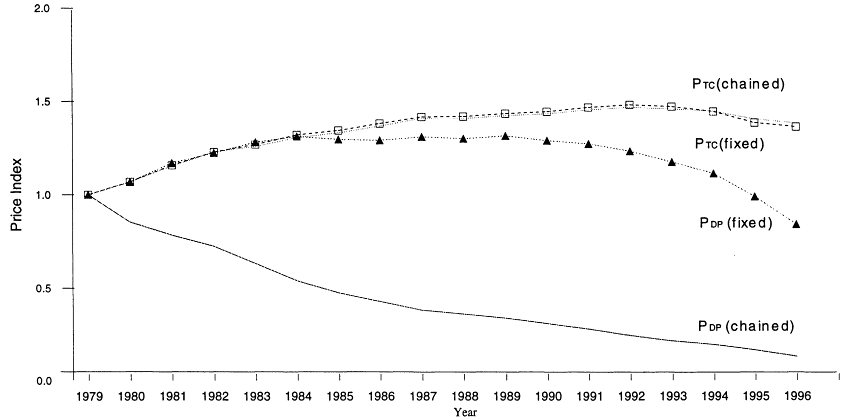

Fig. 2. The prices of data processing and telecommunication inputs. *Note*: Fixed-weight and chained-weight indexes, 1979–1996, 1979 = 1.0. *Source*: Bureau of Economic Analysis (1998). The fixed-weight indexes used 1992 weights.

Fig. 2. Nonetheless, Fig. 2 shows that technical change in data processing reduced its price and thereby helped lower Fedwire costs. [10]

Input cost shares: Fig. 3 plots the percentage shares of Fedwire costs attributable to each category of inputs: data processing, telecommunication, labor, and materials. [11] Together data processing and telecommunications inputs accounted for about three-fourths of Fedwire costs on average over the 1979–1996 period. In 1979, when Fedwire was distributing its processing across many offices, outlays for telecommunication were about seven times as large as outlays for data processing. During the 1980s, as data processing prices fell sharply, data processing quantities purchased by Fedwire rose dramatically resulting in a large rise in its expenditure share.

By 1990, the cost shares for data processing and telecommunication were nearly equal. However, after 1990, the data processing cost share dropped even as the price of data processing equipment continued to fall. The only other change evident from Fig. 3 is that the cost share of (non-data processing and non-telecommunication) labor had fallen from its 1979 value of about 26% to a little less than 12% of Fedwire costs. Cost shares for buildings (not shown) and materials were very small and relatively flat by comparison.

[10] Recall that the price indices we used for both data processing and telecommunications were adjusted for imputed technical change by the Bureau of Economic Analysis.

[11] Materials consist of the remaining input categories: travel, machines, supplies, and printing inputs other than those used for data processing and telecommunication.

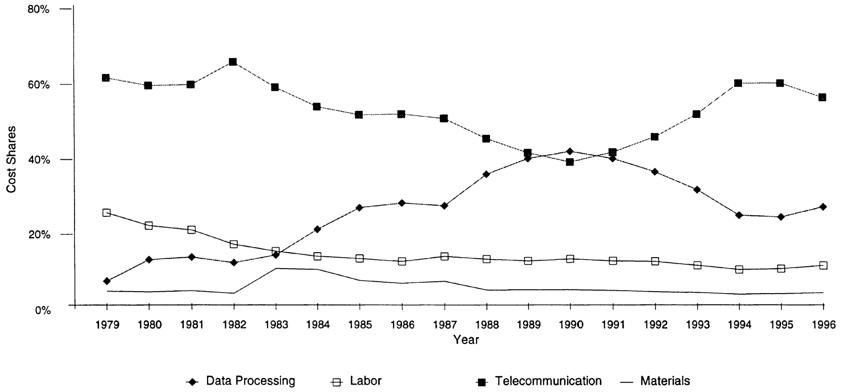

Fig. 3. Cost shares for Fedwire inputs.

Substituting toward data processing: Fig. 4 plots the ratio of the (chain-weighted) prices of data processing to telecommunication equipment. It also plots the ratio of the implied quantities of data processing to telecommunication. The square symbols plot the ratio of prices and the triangle symbols plot the ratio of quantities.

The ratio of the prices of data processing to telecommunication, $P_{\mathrm{dp}}/P_{\mathrm{tc}}$, fell 91% over the 1979–1996 period. As data processing prices fell relative to the prices of other inputs, Fedwire operations were shifted toward using larger quantities of data processing and smaller quantities of other inputs. Fig. 4 shows that the ratio of data processing to telecommunication quantities rose as the ratio of their prices fell.

This raises the question of why consolidation would reduce costs. After all, one way to shift toward more data processing and away from telecommunication would be to decentralize operations further and to use a distributed processing environment, rather than consolidate. The impetus to consolidate apparently arose from two sources: (1) considerable economies of scale in data processing operations and (2) the low cost of installing a centralized data processing site. The costs saved by consolidating data processing apparently exceeded the expense of the increased quantity of telecommunications inputs associated with consolidation. Thus, even though the price of data processing fell relative to telecommunication, costs were reduced by aggregating data processing and raising the use of the input whose relative price rose.

5. A cost function for Fedwire transfers and variables used in its estimation

We estimated a single equation translog cost function for Fedwire transfers,

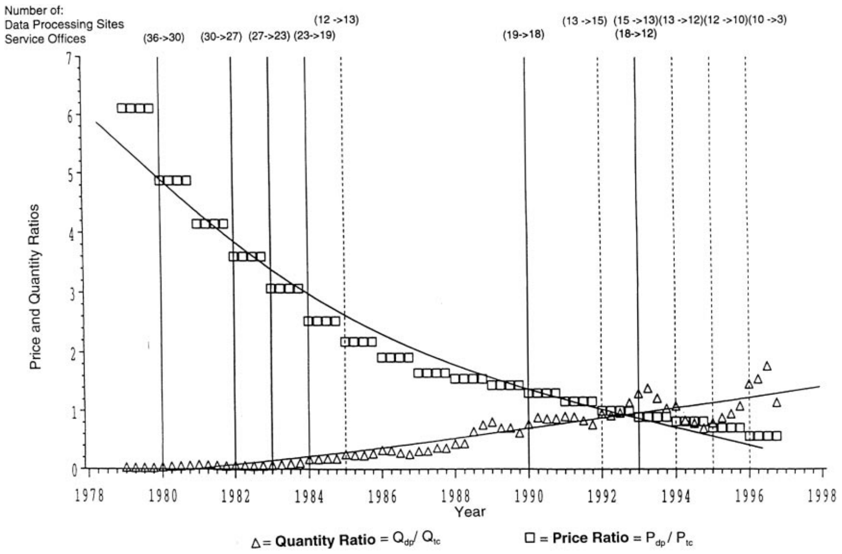

Fig. 4. Data processing and telecommunication equipment: relative price and quatity ratios. *Note*: Data pertained to 1979:Q1–1997:Q3. Vertical markers indicate years with consolidation activity, Chained Price indexes equal one in 1992. Quantities are derived by dividing each nominal expenditure by the relevant price index. The smooth lines are parametric cubic parametric cubic splines with continuous second derivatives. The method used a piecewise third-degree polynomial for each set of adjacent points. The polynomial passes through the plotted points and matches the first and second derivatives of neighboring segments at the points (see Reinsch, 1967).

$$\ln C = \beta \ln Q + \Sigma k_i \ln P_i + 1/2 \ln Q \ln Q + \Sigma\Sigma\zeta_{i,j} 1/2 \ln P_i \ln P_j + \Sigma\eta_i \ln P_i \ln Q + \alpha D_t + \delta S_{\mathrm{dp}} + \theta S_{\mathrm{so}} + \varepsilon, \quad (1)$$

where

C = total cost of Fedwire transfer operations;
Q = number of Fedwire transfers (output);
P_{dp} = price of data processing input;
P_{tc} = price of telecommunication input;
P_{l} = price of labor input;
P_{b} = price of buildings input;
P_{m} = price of materials and other inputs;
D_t = dummy variable(s) for technical change;
S_{dp} = the number of data processing sites; and
S_{so} = the number of customer service offices.

Our OLSQ regressions were estimated using 864 Federal Reserve District-level panel observations and again using 72 Federal Reserve System-level time-series observations aggregated from the District-level data. The District-level data included a dummy variable for each Federal Reserve District and correspondingly omitted the variable measuring the number of data processing sites (S_{dp}) but included the number of customer service offices (S_{so}) in the District. Quarterly data was used in both cases. Appendix A presents detailed descriptions of the data we used. Since our measure of technical change is somewhat novel, it is discussed here rather than in the Appendix.

Indicator variables for technical change: Three approaches were used to allow for disembodied technical change in the Fedwire cost function (1). Our preferred approach was to identify event-specific changes to Fedwire operations which could be interpreted as technical advances or changes. Five events were identified and were represented with five dummy variables (T_i). [12] The five changes were: upgrading the communications network in 1983 (FRCS80); development of standardized software for transfers in 1987 (RSA); installation of packet switching capability for transfers in 1989 (SL10); installation of a more sophisticated encryption system in 1990; and centralization of the processing of both intra-district and inter-district transfers in 1994 (FEDNET). [13]

Two other approaches to specifying technical change were also used for comparison. One was a simple linear time trend (t) and the other was a time-specific dummy variable (D_t) which equals 1.0 for each year but is zero for all prior and later years. The coefficients on t and D_t provide estimates of the extent to which costs changed over time apart from changes in scale, input prices, or the numbers of Fedwire offices performing data processing or servicing functions.

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[12] Each of these dummy variables took the value of zero before the technical advance occurred and one thereafter.

[13] The dummy variable for the FRCS-80, equaled zero prior to 1983 and was set equal to one beginning in 1983. In 1987 the Reserve Banks upgraded Fedwire software to allow a uniform application for transfers. The associated dummy variable, RSA, equaled zero prior to 1987 and was set equal to one beginning in 1987. In 1989 the Federal Reserve upgraded the SL10 packet switches in its communication network. The dummy variable SL10 equaled zero prior to January 1987, and one thereafter. In 1990, a more sophisticated encryption system was introduced. The dummy variable, LENCRYP, equaled zero prior to January 1990 and one thereafter. And in 1994, FRAS deployed Fednet, a communications network that replaced the FRCS-80 backbone network and the 12 Federal Reserve District networks that connected the Federal Reserve Districts to depository institutions. Fednet was designed to standardize service levels improve reliability, security, and disaster recovery. The dummy variable FEDNET equaled one after June 1994, and zero prior to that date. See Board of Governors of the Federal Reserve System (1994, p. 277).

6. Estimated scale economies, technical change, and consolidation cost savings

As shown in Eq. (1), the standard translog specification includes the square of the logarithm of output. However, the squared output term was never statistically significant in our regressions and the correlation between the $\ln Q$ and $1/2(\ln Q)^2$ variables was 0.9999. We found no evidence against the hypothesis of a constant scale cost elasticity and therefore our reported results were all based on regressions that omitted the square of the logarithm of output.

Including the output squared term in regressions using System-wide aggregate time-series data (with degrees of freedom of 33 to 49, depending on the specification of technical change) often produced estimates that implied negative marginal costs. Rather than U-shaped average cost curves, those estimates suggested inverted U-shaped average cost curves, which seemed unlikely to have prevailed. Adding the output squared term to regressions on the District-level panel data (with degrees of freedom of 825 to 841) changed the estimated scale cost elasticities negligibly.

Scale economies: Earlier econometric cost studies of Fedwire operations found little evidence of scale economies (Bauer and Ferrier, 1996; Humphrey, 1982, 1984) with most transfers being processed in operations with constant returns to scale. Our econometric results, which use data from a much longer time span, suggest that there are considerable scale economies for Fedwire operations and these results are more consistent with estimates of scale elasticities for other Federal Reserve electronic payment services. [14]

Table 3 presents our estimated scale cost elasticities and estimates for disembodied technical change. Regardless of which technical change variable we used, the estimated scale cost elasticities based on panel data hovered around one-half when the District-level data set was used. [15] As noted above, the District-level data set was quite large (864 panel observations) and hence contained more variation than the System-level aggregated data (72 time-series observations). Perhaps as a result, the scale economies estimated with the ag-

[14] Both Bauer and Hancock (1995) and Bauer and Ferrier (1996) found that the Federal Reserve's automated clearinghouse operations had significant scale economies.

[15] Based on the regression coefficients and the actual values of the price variables used in Eq. (1), we calculated a scale cost elasticity estimate for each quarter in our 1979–1996 estimation period. Table 3 shows the averages across time of those quarterly elasticities. For the District-level data, where degrees of freedom were less of a concern, we additionally used the generalized least squares (GLS) and within techniques for estimating a cost frontier. These techniques are described in Bauer and Hancock (1993). The translog cost function (1) and its corresponding share equations were both used in the implementation of these techniques. Despite their different assumptions regarding the correlation of the inefficiency terms with other regressors, both of these estimation techniques yielded estimates of scale economies that were not markedly different from those obtained using a single equation model estimated with OLSQ. We therefore present the OLSQ results.

Table 3
Estimated Fedwire scale cost elasticities and technical change 1979–1996

Technical change dummy variable	Scale cost elasticity			Annual technical change		
	Aggregate data transition costs		District panel data	Aggregate data transition costs		District panel data
	Included	Excluded		Included	Excluded	
Event-specific T_i	0.207	0.205	0.523	0.014	0.008	0.002
Time-trend t	−0.051	−0.020	0.500	−0.031	−0.032	−0.009
Time-specific D_t	−0.211	−0.055	0.524	−0.014	−0.007	0.006

gregated data were unstable across the three different technical change specifications (even becoming mildly negative in two instances). For our preferred specification of technical change (T_i), the scale economy estimate was positive and suggested a cost elasticity of 0.20.

Due to the low degrees of freedom and apparent instability of the scale estimates with the aggregate data, we deleted the 10 estimated own and cross-price interaction terms specified in Eq. (1) and reestimated the model. With more degrees of freedom, in the worst case only rising from 33 to 43, all the reestimated scale cost elasticities were positive and much closer to the average value of 0.51 found with the District-level data (and shown in Table 3). The new scale economies ranged from 0.28 to 0.42 when transition costs were excluded and from 0.44 to 0.88 when these expenses were included. Consequently, a scale cost elasticity on the order of one-half is supported in this study.

Technical change: The right half of Table 3 shows the estimated annual rates of disembodied technical change in Fedwire production. [16] We place the most confidence in the results shown at the top row of Table 3, which was based on the event-specific technical change approach (T_i) and thus incorporates our a priori information about when Fedwire's data processing and telecommunication technology actually changed. Though T_i probably could not capture all the technical advances achieved by Fedwire, it would likely correspond more closely to those that did take place and to those that did not than the alternative dummy variables, t and D_t.

[16] We calculated the average annual percentage rate of technical change from the estimated coefficients. The coefficients on the five dummy variables for the event-specific technical changes to Fedwire indicate the percentage change in costs attributable to those changes. The average annual percentage rate of technical change was calculated by summing the 5 estimated coefficients and then dividing that sum by 17 (= 1996–1979). The linear time trend, t, ranged from 1 to 72 for the 18 years of quarterly data. The associated coefficient was multiplied by 4 to obtain the estimated annual technical change. For the time-specific index (D_t), each year's index was specified as (0.4, 0.8, 1.2, 1.6) so that the coefficient estimates reflect an annual rather than a quarterly change.

The top row of Table 3 suggested that technical change was plausibly signed and sized. The estimate based on aggregate data that excluded transition costs suggested that technical change was 0.8 to 1.4% annually, which is not very far from the average, national, private-sector, productivity growth over this period of about 1.1% . The results based on applying the t_i specification for technical change to panel data pointed toward average technical change of nearly zero (0.2% annually).

Regardless of which technical change variable was used, our results show smaller values for technical change on Fedwire than that which was previously estimated by Bauer and Ferrier (1996). This earlier study suggested that technical change averaged 6% a year, and they found almost no scale economies. We considered two reasons why our results would markedly differ from those reported in Bauer and Ferrier (1996). First, the Bauer and Ferrier (1996) study used a relatively short five year panel data set. Second, we used input prices – for data processing and telecommunications – that have been adjusted for technical change in the industries producing these products.

When we used the same five years of data as did Bauer and Ferrier (1996) to estimate our cost function models (with the three different approaches for measuring technical change), we did not find much evidence of long-run economies of scale nor did we find much evidence of technical progress. A glance at Fig. 1 suggests that the System-level average cost curve during this period was relatively flat. However, when we used fixed-weighted price indexes for data processing and telecommunications equipment to construct our input prices in conjunction with a time-trend to measure technical change (not our chain-type indexes), we obtained technical change estimates in the range that was reported by Bauer and Ferrier (1996). This holds regardless of whether we used the five-year period for our District-level panel data, our 1979–1996 period District-level panel data, or System-level time-series data. Interestingly, the use of the fixed-weighted price indexes did not materially affect our estimate of technical change when our other two measures of technical change (T_i and D_t) were employed. These findings suggest that the reduction in the real prices of these two important inputs over our 1979–1996 period stemmed primarily from technical advances in the computing and telecommunications industries and that Bauer and Ferrier's usage of fixed-weighted indexes accounted for their larger estimate of apparent disembodied technical change for Fedwire.

Cost effects of consolidation: The number of Federal Reserve data processing sites (S_{dp}) and customer service offices (S_{so}) were used as our measures of operational consolidation. The first two rows of Table 4 presents estimates of the percentage change in Fedwire costs that resulted from closing a single data processing site and a single customer service office. These estimates are based on the S_{dp} and S_{so} coefficients estimated in Eq. (1) using our

Table 4
Effects on costs of office consolidation

Aggregate data (1979–1996)	
Percentage change in costs due to:	
1. Closing one data processing site	−0.798
2. Closing one customer service office	0.026
3. Closing 9 data processing sites and 24 customer service offices	−6.571

Note: Cost model with event-specific technical change and transition costs excluded.

preferred measure of technical change; namely, the event-specific measure T_i. Cost are reduced by 0.8% for each data processing site closed but raised by 0.03% for each customer service office closed. Since nine data processing and 24 service offices were closed due to Fedwire consolidation, it is estimated that costs fell by around 6.5% overall from this source alone. This represents one-fourth of the total 24% reduction in Fedwire average cost over 1979–1996.

7. Summary and conclusions

Banks face fewer geographical constraints than in the past and can now branch nationwide. If they expand by internal growth or by merger, they will face decisions on whether or not to consolidate their back-office operations. We sought insight into the effects of consolidating banks' back-office operations by studying the experience of the Federal Reserve in consolidating Fedwire payment operations.

From 1979 to 1996, the period during which Fedwire drastically reduced the numbers of its data processing sites and customer service offices, average Fedwire cost fell about 24% – in real terms, it fell 62%. We estimated how much Fedwire costs were affected by operational consolidation, as well as by scale economies and technical change. Our preferred specification implied that Fedwire consolidation reduced costs by around 6%, or one-fourth of the total reduction of 24%.

Our estimates, whether based on Federal Reserve District-level panel data or System-level aggregated time-series data, indicated that Fedwire exhibited large economies of scale. The District panel data suggested a scale cost elasticity of about one-half; the aggregate data suggested it was about one-fifth. A more parsimonious estimation with System-level data, however, gave scale cost elasticities much closer to the District-level results. Although we have more confidence in the District-level results, both sets of estimates suggest that average costs would fall markedly with the volume of output.

The more weight that is placed on the District, as opposed to the aggregate, level data and results, the more our estimates suggested that the decline in Fedwire costs did not stem from disembodied technical advance in the Fedwire operation. Technical advance appears to have been rapid in areas related to financial services, and indeed our prices for data processing and telecommunication inputs suggested that this is where the technical advance occurred. Their technical advances lowered the cost of Fedwire's largest inputs, rather than being expressed as technical change in the Fedwire cost function (see Appendix B).

Our estimates showed little indication that scale economies in Fedwire operations have yet been exhausted. If electronic payments via Fedwire continue to grow rapidly, production costs of Fedwire funds transfers ought to decline considerably. Absent reasons for technical advance to slow in the data processing and telecommunication industries, the prices of their outputs will continue to fall, and we may expect further reductions in Fedwire costs and fees.

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Appendix A. Data

Output quantities. The quantity of output (Q) was the total number of Fedwire transfers sent and received at each data processing site. Planning and Control System (PACS) reports information on the number of transfers that originated in each District, the number of inter-District originations, and the sum of total originations and inter-District receipts. The number of intra-District originations (equal to intra-District receipts) were obtained by subtracting inter-District originations from total originations. The number of total transfers processed at each site was defined as the sum of originations (inter- and intra-District) and receipts (inter-and intra-District). Because we counted both the origination and receipt of transfers, this number is twice the number of transfers processed; alternatively, this is the number of times that Fedwire transfers changed balances in accounts at the Federal Reserve Banks. Since both the sending and the receiving depository institutions were charged a fee for a Fedwire transfer, this measure of output is consistent with the way that Fedwire transfer prices are quoted.

Total costs. The total costs for Fedwire (*C*) included direct and support costs. [17] Total costs consisted of expenditures for the following inputs: data processing (dp), telecommunication (tc), labor (l), buildings and their maintenance (b) and materials (m). Data for the expenditures on these inputs came from PACS.

Data processing inputs. The prices of data processing and telecommunication inputs reflected not only the cost of data processing and telecommunications equipment, but also the costs of the labor, buildings, printing, supplies, shipping, travel, and managerial overhead attributed to producing the data processing and telecommunication service inputs to Fedwire. Expenditures for data processing included centralized and local data processing costs, data system support costs, centralized end-user automation costs, and apportioned Federal Reserve Automation Services (FRAS) infrastructure costs. [18]

Operating and transition costs associated with the early 1990s consolidation were allocated partly to the Fedwire transfer operations and the remainder to the Fedwire book-entry securities operations. These costs were allocated in proportion to the share of data processing costs each of these two operations incurred during the four-quarter period just prior to the consolidation (1991:Q4–1992:Q3). Operating costs were defined as the costs of the data processing applications that were actually in use. The costs of duplicate, or excess, capacity were defined as all remaining costs.

Two price indexes were constructed for the input of data processing service, which consisted of equipment and the support services used to produce data processing services for Fedwire. One index was based on a chain-weighted price index for information processing and related equipment (i.e., office, computing, and accounting machinery); the second price index for data processing service

[17] Our measure of total costs excluded (1) imputed costs that are part of the Private Sector Adjustment Factor (PSAF) and (2) some overhead costs and District project costs. The Monetary Control Act of 1980 requires the Federal Reserve to establish fees that over the long run recover all the direct and indirect costs of providing services to depository institutions, as well as imputed costs, such as the income taxes that would have been paid and the pre-tax return on equity that would have been earned had the Federal Reserve-provided services been provided by a private sector firm. These imputed costs are collectively known as the PSAF. District project costs are typically those incurred by individual Federal Reserve Districts in conjunction with special building projects or software enhancements that were also used by other Districts.

[18] FRAS infrastructure costs were apportioned to data processing costs and communications costs using each component's share of total expenditures on data processing and communications exclusive of these infrastructure costs.

was based on a fixed-weight implicit price deflator for equipment. [19] Fig. 2 in the text plots both price indexes for data processing equipment. [20] Not surprisingly, in light of the size of the shifts in the relative prices of various types of data processing equipment, the two equipment price indexes differ markedly.

One possible reason for this divergence was that the weights in the chain-weighted index rose over time for equipment sub-categories within the equipment category whose prices fell and quantities rose relative to other sub-categories. [21] Another possible reason was that the composition of purchases across sub-categories may have changed apart from changes in relative prices. Thus, the chain-weighted index, which based weights on expenditures for the surrounding years, reflects more accurately changes in prices for the entire category of data processing equipment. In contrast, the fixed-weight index was based on 1992 weights. A third reason for the difference between the two equipment price indexes may be that the chain-weighted indexes used prices adjusted via a hedonic regression technique that allowed for changing bundles of characteristics.

The data system support services operation primarily developed software. We used expenditures for labor and the hours worked in data system support services of each Federal Reserve District to construct the price index for labor used in data system support services. We used that as a price index for data system support services.

We used the price indexes and quantities for equipment and for data system support services in each Federal Reserve District to construct two Divisia price indexes for the data processing service in each Federal Reserve District. One Divisia index used the chain-weighted price index and the other used the fixed-weight price index for equipment. [22] The (geometrically-averaged) weights in the Divisia indexes for each period were the current expenditure shares of each of the two components.

[19] These equipment price indexes both pertained to "Private Purchases of Producers' Durable Equipment". Both came from the Bureau of Economic Analysis. (The chained indexes came from STATUSA.)

[20] See Sadée (1996) for a discussion of the samples used and the types of computer and peripheral equipment included. The chain-type index used annual weights from the 10-digit level harmonized codes from the merchandise trade data.

[21] See Triplett (1992) for a discussion of the chain index procedure. See Bureau of Economic Analysis (1996) for a discussion of how chain-type measures and definitional and classification changes have affected the National Income and Product Account tables.

[22] Divisia indexes have several desirable properties as index numbers: (1) Divisia indexes are chained Laspeyres Indexes; (2) Divisia indexes are also chained Paasche and Fisher Ideal indexes; (3) Divisia indexes are symmetric in prices and quantities; and (4) Divisia indexes are exact or "Superlative" indexes for a homogeneous translog aggregator function. For a discussion about the index number properties of Divisias see Diewert (1976).

We then constructed a second-level Divisia index for each District by combining each District's Divisia price index for data processing service with a District-specific Divisia price index, which was based on the mean of the District data in 1979. This produced a multilateral Divisia index for each District. We constructed a Divisia index for the price of data processing services at the System level by using the expenditures and prices for the 12 Federal Reserve Districts on equipment and data system support services.

Telecommunication inputs. The costs to the Fedwire transfer operation of telecommunication arose from data and voice communications. Telecommunication costs included both centralized and local data communication costs, FRAS, National Management Control Center costs, communications costs, and apportioned FRAS infrastructure costs. [23] In January 1983, the Federal Reserve installed FRCS-80, a backbone network. It is possible that some of the telecommunication costs reported for 1982 were incurred in the testing and building of this network. In 1990, the Federal Reserve Districts installed a new, centrally-managed communications network to replace FRCS-80, as well as the 12 separate, intra-District networks.

As our measure of the price of telecommunication inputs, we used the chain-weighted and fixed-weight price indexes for communications equipment published by the Bureau of Economic Analysis. These data, which came from the National Income and Product Accounts, did not vary across Federal Reserve Districts. (Fig. 2 in the text plots both price indexes for telecommunication.)

Labor, buildings, and materials inputs. The costs of labor inputs included salaries, and retirement and other benefits. These costs fell from 26% to a little less than 12% of total Fedwire costs over the 1979–1996 period.

We constructed a separate index for the price of labor in each Federal Reserve District by dividing expenditures for labor by quantity of labor, for which we used the number of full-time equivalent employees. We constructed a Divisia index for the price of labor at the System level from the price and quantities of labor used in each Federal Reserve District.

Building costs included building insurance, taxes on real estate, depreciation, utilities, rent, and housekeeping services. The recorded share of building costs in total costs was less than 3%. One reason PACS recorded such low numbers was that there were no interest expenses associated with the financing of buildings since the Federal Reserve pays for them out of current earnings. [24]

As a proxy for the price of buildings, we used indexes for replacement cost of buildings, which were available for each Federal Reserve Bank city from the

[23] We apportioned FRAS infrastructure costs to data processing and telecommunication costs according to each component's share of total expenditures.

[24] The PSAF included imputed interest expenses for financing the purchase of buildings. See Board of Governors of the Federal Reserve System (1992).

R.S. Means Company. [25] We adjusted the per-square-foot replacement cost for depreciation, which we assumed followed a 32-year, straight line schedule. For the System-wide price of (the services provided by) buildings, we calculated a Divisia price index from the data on building expenditures of each Federal Reserve District and the proxy for the District price of buildings.

The costs of materials inputs included the costs of forms, parts, supplies, equipment that was expensed rather than capitalized, equipment rentals, equipment repairs and maintenance, shipping and postage, travel, and printing and duplicating. Taken together, materials costs totaled only 2–3% of costs.

In a manner analogous to the way we handled the price of data processing services, we constructed separate Divisia indexes of the price of materials for the District and for the System levels. We estimated the price of equipment and related items using formulas for the service price of capital goods presented by Hall and Jorgenson (1967). We used the yield on Aaa corporate bonds as the relevant nominal interest rate. We approximated capital gains (and losses) with the percentage rate of change of the chain-weighted implicit price deflator for GDP. [26] We assumed a four-year, straight-line depreciation schedule. For the price of shipping and travel expenditures, we used the chain-weighted price index for aircraft as a proxy. [27] For the catch-all category “other materials”, we used the chain-weighted implicit price deflator for GDP.

As we did for data processing services, we constructed multilateral chain-type Divisia price indexes for materials for each Federal Reserve District from each District’s expenditures on and price indexes for each component of materials. We calculated a multilateral Divisia index for the System level price of materials following the same procedure that we used for data processing services.

Appendix B. Fedwire cost function parameter estimates

[25] Data on replacement costs for buildings were taken from Means (1992).

[26] The interest rate on Aaa corporate bonds came from Board of Governors of the Federal Reserve System, 1979–1997, Table A26. The implicit price deflator series for gross domestic product are published in Council of Economic Advisors (1997).

[27] These data are published in Table 7.8 of the National Income and Product Accounts entitled “Chain-type Quantity and Price Indexes for Private Purchases of Producers’ Durable Equipment by Type”.

Variables	Specification of technical change								
	Time-specific			Time trend			Event-specific		
	Aggregate data transition costs		District panel data	Aggregate data transition costs		District panel data	Aggregate data transition costs		District panel data
	Included	Excluded		Included	Excluded		Included	Excluded	
Intercept	–	–	–	−17.794	−70.654	55.636	−30.696	−107.711	46.935
				(−0.291)	(−1.282)	(2.643)	(−0.471)	(1.833)	(2.243)
ln Q	1.654	2.043	1.755	2.030	4.893	1.390	3.043	7.452	0.968
	(2.480)	(3.384)	(1.515)	(0.570)	(1.527)	(1.204)	(0.773)	(2.098)	(0.823)
ln PL	227.784	204.269	2.115	144.891	103.548	−11.287	146.567	115.664	−8.745
	(3.272)	(3.243)	(1.094)	(2.496)	(1.982)	(−2.071)	(2.747)	(2.401)	(−1.610)
ln PM	−125.906	−138.731	−29.514	−12.146	27.047	−12.343	32.703	85.876	−11.295
	(−0.674)	(−0.821)	(−3.392)	(−0.102)	(0.253)	(−1.177)	(0.276)	(0.802)	(−1.047)
ln PK	−159.144	−132.808	−9.853	−112.725	7.901	−4.405	−147.578	−10.547	−5.575
	(−0.755)	(−0.696)	(−1.990)	(−0.801)	(0.062)	(−0.727)	(−1.138)	(−0.090)	(−0.921)
ln Ptc	(−1.721)	11.593	44.867	−71.207	−220.599	36.733	−94.532	−303.813	35.656
	(0.045)	(0.333)	(4.417)	(−0.421)	(−1.448)	(3.506)	(−0.542)	(−1.928)	(3.288)
ln Pdp	59.988	56.677	−6.616	52.187	83.103	−7.698	63.840	113.820	−9.041
	(1.954)	(2.040)	(−2.350)	(1.037)	(1.834)	(−2.628)	(1.236)	(2.441)	(−3.006)
ln PLQ	−12.137	−11.705	−0.329	−7.154	−6.108	−0.287	−7.423	−6.949	−0.242
	(−3.131)	(−3.337)	(−2.195)	(−2.213)	(−2.099)	(−1.908)	(−2.522)	(−2.616)	(−1.593)
ln PMQ	4.234	3.583	1.895	−0.155	−1.493	1.475	−3.684	−6.584	1.495
	(0.391)	(0.366)	(4.498)	(−0.023)	(−0.246)	(3.562)	(−0.533)	(−1.055)	(3.576)
ln PKQ	7.839	7.368	0.682	5.457	0.036	0.862	7.708	1.606	0.893
	(0.611)	(0.635)	(2.818)	(0.666)	(0.005)	(3.613)	(1.015)	(0.234)	(3.738)
ln PtcQ	3.887	5.188	−2.972	4.350	11.964	−2.780	7.047	18.495	−2.922
	(1.407)	(2.076)	(−7.143)	(0.461)	(1.409)	(−6.765)	(0.680)	(1.977)	(−6.911)
ln PdpQ	−3.822	−4.435	0.723	−2.497	−4.399	0.730	−3.648	−6.567	0.776
	(−1.844)	(−2.365)	(6.652)	(−0.910)	(−1.781)	(6.747)	(−1.245)	(−2.482)	(6.980)
ln PL2	10.559	−1.384	0.218	24.928	16.549	1.837	26.503	19.504	1.483
	(0.853)	(−0.124)	(0.439)	(2.602)	(1.919)	(2.310)	(2.838)	(2.313)	(1.870)

Continued

Variables	Specification of technical change								
	Time-specific			Time trend			Event-specific		
	Aggregate data transition costs		District panel data	Aggregate data transition costs		District panel data	Aggregate data transition costs		District panel data
	Included	Excluded		Included	Excluded		Included	Excluded	
ln PLPM	−5.216	−1.167	2.612	−1.511	10.656	1.364	−2.004	12.994	1.372
	(−3.100)	(−0.077)	(1.865)	(−0.112)	(0.876)	(0.857)	(−0.162)	(1.164)	(0.850)
ln PLPB	−50.694)	−9.094	−0.657	−74.974	−31.739	−1.647	−70.467	−33.313	−1.557
	(−1.976)	(−0.392)	(−1.073)	(−3.171)	(−1.492)	(−2.169)	(−2.944)	(−1.542)	(−2.045)
ln PLPC	72.489	29.202	−1.902	72.272	8.165	−1.460	62.824	1.946	−1.277
	(2.497)	(1.112)	(−1.311)	(3.231)	(0.406)	(−0.971)	(2.678)	(0.092)	(−0.827)
ln PLPD	−27.138	−17.558	−0.270	−20.716	−3.631	−0.094	−16.856	−1.132	−0.020
	(−2.448)	(−1.750)	(−0.744)	(−2.385)	(−0.464)	(−0.254)	(−2.008)	(−0.149)	(−0.053)
ln PM2	(−234.202)	−211.799	−24.325	−151.031	−143.143	−30.486	−64.899	−65.461	−32.044
	(−2.011)	(−2.010)	(−4.582)	(−2.902)	(−3.119)	(−6.296)	(−1.229)	(−1.373)	(−6.493)
ln PBPM	354.599	373.696	−6.424	186.487	131.755	−3.368	124.828	98.228	−3.772
	(2.732)	(3.181)	(−3.534)	(2.610)	(2.049)	(−1.763)	(1.833)	(1.598)	(−1.954)
ln PMPC	−173.430	−235.988	30.222	−60.588	−18.308	35.867	−84.266	−71.421	37.979
	(−1.352)	(−2.034)	(6.145)	(−0.853)	(−0.286)	(7.999)	(−1.113)	(−1.045)	(8.261)
ln PMPD	58.249	75.257	−2.084	26.644	19.041	−3.377	26.341	25.660	−3.535
	(1.497)	(2.137)	(−1.991)	(1.358)	(1.078)	(−3.235)	(1.382)	(1.492)	(−3.370)
ln PB2	−241.881	−346.801	8.433	−55.074	−107.703	7.280	−0.292	−83.952	7.560
	(−1.686)	(−2.672)	(4.436)	(−0.632)	(−1.373)	(3.877)	(−0.004)	(−1.228)	(3.958)
ln PBPC	−47.791	−1.286	−1.511	−38.314	36.786	−2.503	−45.538	47.640	−2.549
	(−0.562)	(−0.017)	(−0.790)	(−0.905)	(0.965)	(−1.275)	(−1.075)	(1.245)	(−1.287)
ln PBPD	−14.234	−16.515	0.159	−18.124	−29.099	0.239	−8.530	−28.603	0.318
	(−0.512)	(−0.657)	(0.276)	(−1.272)	(−2.269)	(0.417)	(−0.577)	(−2.145)	(0.543)
ln PC2	150.451	245.026	−27.731	−4.380	−53.820	−34.140	54.282	5.307	−36.276
	(1.098)	(1.977)	(−5.278)	(−0.051)	(−0.695)	(−7.156)	(0.568)	(0.061)	(−7.339)
ln PCPD	−1.720	−36.954	0.923	31.010	27.176	2.235	12.697	16.529	2.123
	(−0.055)	(−1.306)	(0.817)	(1.232)	(1.200)	(1.968)	(0.499)	(0.719)	(1.865)

ln PD2	−15.157	−4.230	1.272	−18.814	−13.487	0.997	−13.652	−12.454	1.114
	(−1.686)	(−0.520)	(3.064)	(−2.033)	(−1.619)	(2.369)	(−1.501)	(−1.517)	(2.689)
OFFP	0.048	0.031	–	0.017	0.010	–	0.016	0.008	–
	(2.311)	(1.680)		(2.073)	(1.346)		(1.770)	(0.955)	
OFFS	0.004	0.008	–	−0.005	0.002	–	−0.005	−0.000	–
	(0.603)	(1.209)		(−0.998)	(0.379)		(−0.901)	(−0.055)	
D79 0.003	0.015	−0.026	–	–	–	–	–	–	
	(−0.022)	(0.125)	(−0.697)						
D80	0.042	0.057	0.036	–	–	–	–	–	–
	(0.578)	(0.861)	(1.209)						
D81	0.043	0.064	0.033	–	–	–	–	–	–
	(0.633)	(1.056)	(1.147)						
D82	0.025	0.042	0.029	–	–	–	–	–	–
	(0.406)	(0.755)	(1.106)						
D83	−0.019	−0.025	−0.051	–	–	–	–	–	–
	(−0.442)	(−0.615)	(−2.008)						
D84	−0.011	−0.026	−0.019	–	–	–	–	–	–
	(−0.186)	(−0.483)	(−0.737)						
D85	0.005	−0.008	−0.017	–	–	–	–	–	–
	(0.056)	(−0.110)	(−0.653)						
D86	0.001	0.018	0.038	–	–	–	–	–	–
	(0.024)	(0.378)	(1.514)						
D87	−0.018	−0.008	−0.038	–	–	–	–	–	–
	(−0.489)	(−0.249)	(−1.421)						
D88	0.001	−0.001	0.037	–	–	–	–	–	–
	(0.038)	(−0.044)	(1.419)						
D89	−0.002	−0.010	−0.031	–	–	–	–	–	–
	(−0.058)	(−0.330)	(−1.200)						
D90	0.006	0.001	−0.051	–	–	–	–	–	–
	(0.175)	(0.023)	(−1.968)						
D91	0.042	0.046	0.031	–	–	–	–	–	–
	(1.305)	(1.589)	(1.198)						

Continued

Variables	Specification of technical change								
	Time-specific			Time trend			Event-specific		
	Aggregate data transition costs		District panel data	Aggregate data transition costs		District panel data	Aggregate data transition costs		District panel data
	Included	Excluded		Included	Excluded		Included	Excluded	
D92	0.042	0.023	−0.016	–	–	–	–	–	–
	(0.978)	(0.584)	(−0.615)						
D93	0.282	0.244	0.018	–	–	–	–	–	–
	(3.978)	(3.806)	(0.651)						
D94	0.169	0.138	−0.014	–	–	–	–	–	–
	(4.395)	(3.968)	(−0.503)						
D95	0.080	−0.002	−0.028	–	–	–	–	–	–
	(1.980)	(−0.063)	(−0.882)						
D96	0.228	0.139	−0.131	–	–	–	–	–	–
	(2.116)	(1.427)	(−3.350)						
t	–	–	–	0.008	0.008	0.002	–	–	–
				(1.068)	(1.200)	(1.251)			
T(ENCRYP-TION)	–	–	–	–	–	–	(−0.024)	−0.000	0.016
							−0.781	(−0.013)	(0.536)
T(SL10)	–	–	–	–	–	–	−0.079	−0.051	−0.032
							(−1.922)	(−1.385)	(−1.073)
T(FRCS-80)	–	–	–	–	–	–	−0.160	−0.101	−0.053
							(−2.032)	(−1.426)	(−1.644)
T(RSA)	–	–	–	–	–	–	−0.066	−0.087	0.007
							(−1.096)	(−1.610)	(0.290)
T(FEDNET)	–	–	–	–	–	–	0.093	0.098	0.027
							(2.636)	(3.097)	(0.739)
D2	–	–	(0.559)	–	–	0.540	–	–	0.448
			(5.318)			(4.631)			(4.363)
D3	–	–	−0.079	–	–	−0.146	–	–	−0.117
			(−1.689)			(−3.007)			(−2.465)

D4	–	–	−0.037	–	–	−0.101	–	–	−0.059
			(−0.854)			(−2.160)			(−1.294)
D5	–	–	−0.002	–	–	−0.155	–	–	−0.078
			(−0.032)			(−2.076)			(−0.986)
D6	–	–	0.130	–	–	0.015	–	–	−0.045
			(1.395)			(0.172)			(−0.486)
D7	–	–	0.578	–	–	0.523	–	–	0.533
			(7.843)			(7.461)			(7.474)
D8	–	–	−0.117	–	–	(−0.220)	–	–	−0.182
			(−1.893)			−3.471			(−2.938)
D9	–	–	0.281	–	–	(0.205)	–	–	0.255
			(4.237)			(2.880)			(3.893)
D10	–	–	0.032	–	–	−0.072	–	–	−0.041
			(0.496)			(−1.186)			(−0.645)
D11	–	–	0.230	–	–	0.133	–	–	0.177
			(3.155)			(1.952)			(2.425)
D12	–	–	0.227	–	–	0.095	–	–	0.038
			(0.399)			(1.546)			(0.637)
Service	–	–	−0.016	–	–	−0.012	–	–	−0.013
offices			(−1.951)			(−1.570)			(−1.579)
RSME	0.031	0.028	0.157	0.038	0.035	0.160	0.034	0.031	0.160

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