Technology Investment, Firm Performance and Market Value: Evidence from Banks

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Abstract

Despite the importance of technology investment to the U.S. industries, research on its impact at the firm level has been limited. This paper examines the impact of technology investment on firm performance and market value using a unique dataset on technology spending by U.S. banks. We first document that banks increasingly invested in technology from 2000-2017 and did not cut technology spending even when experiencing negative performance shocks. Controlling for firm size, less profitable banks spent more on technology, suggesting that the expanded technology spending is less likely due to better firm performance. Meanwhile, operating performance and market value are positively correlated with lagged technology spending, and the positive correlation is primarily driven by large banks. Interestingly, while technology spending increases asset turnover, it only improves the profit margin for large banks, implying that technology investment affects operating performance by improving operational efficiency rather than by increasing sales. These results suggest that technology investment helps improve operational efficiency and increase market value of large firms, but not much for small firms.

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1. Introduction

The past two decades have witnessed the rapid growth in adoption of innovative technology by U.S. firms. Many believe that, due to the dramatic changes in the technological environment and market structure, firms must actively invest in new technology to provide higher quality products, deliver better customer services, boost revenue and cut costs in order to stay competitive in the market. Firms that are unable or unwilling to adopt advanced technologies are at a significant disadvantage against their competitors. An important decision faced by managers today is not about whether or not they should embrace advanced technologies, but rather about when to adopt them (Hall and Khan, 2003).

The banking industry has long been one of the most technology-intensive industries in the U.S. (Triplett and Bosworth, 2006). In recent years, technology investment by U.S. banks, including investment in information and financial technologies, has increased at a faster pace even though many of banks have experienced slow revenue growth and strived to cut operating expenses after the financial crisis.[1] For instance, data on the U.S. listed commercial banks used in this paper indicate that the median technology spending per bank more than doubled since 2000 (see Figure 1). Moreover, in 2015, four of the ten biggest technology spenders worldwide were U.S. banks (Bank of America, Citigroup, JP Morgan Chase & Co. and Wells Fargo).[2]

With the rapid growth in technology investment over the past two decades, many studies have been conducted to assess the impact of the use of technology in the banking industry. Research suggests that technology progress significantly influences operations, production, and service quality of U.S. banks (Haynes and Thompson, 2000; Berger, 2003; Frame and White, 2014). Moreover, adoption of new technology by banks is shown affects market competition, consolidation in the industry, and is likely to create significant regulatory challenges (Berger, 2003; Philippon, 2015). While there is a growing

[1] See an article from *Reuters* on September 28, 2016, "Banks Adopting Blockchain 'Dramatically Faster' than Expected: IBM" as well as an article from *Financial Times* on January 20, 2016, "Big US bank revenue growth is flat as a pancake".
[2] See a *Wall Street Journal* article on April 21, 2016, "Wal-Mart Spent $10.5 Billion on Information Technology in 2015".

literature on the impact of technological progress and adoption of new technology, little research has been done regarding the effects of technology investment on U.S. banks at the firm level.[3]

Given the profound impact of technological changes, this paper examines the effects of technology investment on firm performance and market value using a sample of U.S. listed commercial banks. The first research question is to what extent expanded technology investment influences the operating performance of firms. According to Matt Zames, COO of JP Morgan Chase & Co., technology is "an essential core competency and a key differentiator to drive future growth" in all of their businesses.[4] Adoption of new technology helps banks identify new business areas, improve the quality of client services, restructure their business models, improve operational efficiency, and increase competitiveness in the marketplace.[5] Thus, one would expect technology investment to have a positive long-term impact on bank performance by either increasing revenues and/or improving operational efficiency. However, others contend that technology acts as a double-edged sword and it is often costly to invest in financial technology such as cybersecurity, robo-advising and data analytics, especially for small banks (Dahl, Meyer, and Wiggins, 2017).[6] Moreover, encroaching automation could wipe out a significant portion of bank profits as fewer fees can be charged for payments such as checks and wires, and revenue from wealth management could drop as well. Thus, the net effect of expanded technology investment on firm performance is ultimately an empirical question.

In addition, if adoption of new technology can improve operational efficiency, provide better service to customers (Melnick, Nayyar, Pinedo, and Seshadri, 2000), and lead to performance gains, one

[3] A few studies in the literature examine the effects of use of internet on output and performance of U.S. banks. These studies either focus on community banks (DeYoung, Lang, and Nolle, 2007) or use survey data before the "digital network" age (Prasad and Harket, 1997).
[4] See page 52 in the 2015 Annual Report of JPMorgan Chase & Co.
[5] For example, distributed ledger technology (DLT) was developed to transform payments, clearing, and settlement (PCS) processes (Mills et al., 2016). Also, cloud computing, big data analytics, cyber security, API banking, online and mobile banking, and blockchain enable banks to grow future business. See an article from *Business Insider* on February 7, 2017, "These are the top trends that will define the banking industry in 2017."
[6] See an article from *Wall Street Journal* on January 18, 2017, "Technology Will Help-And Hurt-Bank Results, Studies Say."

would expect that expanded technology investment should enhance the market value of firms. However, due to managerial entrenchment issues, it is possible that managers undertake non-positive net present value (NPV) projects when making technology investment decisions (Fiordelisi and Molyneux, 2010) that could hurt firms in the long run.[7] Thus, another interesting question is does expanded technology investment increase or destroy the market value of banks? These two questions are of interest to practitioners, academics, and policymakers as evidenced by the extensive media coverage and industrial reports regarding the use of technology by banks in recent years.

One reason for the limited research regarding the impact of technology investment on operating performance and market value at the firm level is the lack of reliable, comprehensive data about technology investment, as firms are not required to disclose the relevant information to the public. As technology becomes more important to the banking industry, many listed banks have disclosed information on technology spending in their 10K reports. S&P Global Market Intelligence takes a "deep dive" into the banking sector and collects memo items and supplemental financial schedules from U.S. listed commercial banks. The technology spending data include expenses paid for communications, data processing, internet banking, equipment, software purchases and subscriptions to cloud-based services. This unique data set allows us to examine the previously posed two important questions using data on firm-level technology spending as a proxy for technology investment. Table A2 in the appendix provides some examples to detail technology spending data.

Based on a sample of U.S. listed commercial banks from 2000-2017, we find a dramatic growth in technology spending by banks. The median technology and communication expense per bank (in 2017 dollars) grew from $1.12 million in 2000 to $2.95 million in 2017 (see Figure 1) and it increased almost monotonically over the period. When gross total assets (GTA) is used to group the banks into two subsets, a similar growth pattern is found for both small and large banks. The median technology spending of

[7] See Myers and Majluf (1984), Stulz (1990), and Armstrong and Vashishtha (2012), among many others.

small banks (large banks) increased from $0.49 million ($2.50 million) to $1.32 million ($6.54 million) during the sample period.

An important empirical issue is the potential endogeneity between technology investment and firm performance, as one could argue that firms with better performance are more likely and able to adopt new technology. To investigate this issue, we first take a closer look at how technology spending is related to bank performance during the recent financial crisis. If technology investment is largely determined by banks' operating performance, one would expect the technology investment to drop significantly over the financial crisis. Interestingly, the results indicate that the median technology spending per bank monotonically grew from $1.63 million in 2007 to $1.94 million in 2012 (see Figure 1). In addition, when we plot two technology spending ratios (i.e., Tech Expenses/Total Assets and Tech Expenses/Loans & Deposits) along with the bank performance measures over the sample period, we find there is a "*V*" shape for bank performance measures. However, the median technology spending ratios consistently increased from 2007-2014 (see Figure 2). While almost all of the banks experienced a negative performance shock and banks strived to cut their expenses during the crisis, the technology spending for small and large banks continued to grow at a steady pace.

Moreover, we examine technology spending measures for those firms experiencing a negative performance shock at the firm-level (see Figure 3). The results indicate that there is no clear pattern for those banks experiencing a negative performance shock in year *t* to cut their technology spending in the next few years suggesting that a negative performance shock does not seem to significantly affect the technology spending of banks. Furthermore, we sort the banks into quintiles based on their time-series average ROA and compare the time-series averages of the technology spending measures in each quintile. Controlling for firm size by total assets, less profitable banks tend to spend more heavily on technology relative to more profitable banks (see Figure 4). Taken together, these findings suggest that expanded technology spending of U.S. banks is less likely to be determined by firm performance.

Next, we find that the performance measures of banks are positively and significantly correlated with the lagged technology spending measures. Interestingly, the positive correlation is primarily driven by large banks, and there is little evidence concerning the positive correlation based on small banks. The results on small banks are consistent with Hunter and Timme (1986) and Prasad and Harket (1997). A possible interpretation of the results is as follows. Technology investment is often lumpy and costly (e.g., cybersecurity), but banks must adopt new technology in order to stay competitive. To some extent, small banks are "forced" to use some of new technologies even though it may not be "optimal" for them to do so from a pure operational efficiency standpoint. Thus, financial performance of small banks may not necessarily be improved. In contrast, large banks can better capture the benefits from adoption of advanced technology due to the economies of scale.

To examine the channel driving the correlation between firm performance and technology spending, we decompose ROA into two components: Profit Margin, measuring profitability from sales, and Asset Turnover, measuring sales volume effect. We investigate the correlation between the two components and the lagged technology spending measures. The results indicate that Asset Turnover is positively and significantly associated with the lagged technology spending measures in the three samples (full, small, and large) indicating that technology investment does help increase sales and revenues for both large and small banks. However, in only the large bank sample, Profit Margin is positively and significantly associated with the lagged technology spending measures. Moreover, the magnitude of the coefficients on Profit Margin for large banks is much higher than that on Asset Turnover. These results provide further evidence that the use of technology does not necessarily improve performance of small banks. Thus, technology investment is likely to affect firm performance by improving operational efficiency, rather than by increasing sales volume and revenue. It appears that large banks benefit from expanded technology investment through efficiency gains and cost reductions resulting from the economies of scale.

Furthermore, additional robustness checks indicate that the positive correlation between firm performance and lagged technology spending measures still hold when too-big-to-fail banks are excluded and when banks with a relatively small amount of technology spending are excluded. More importantly, when long lags of the technology spending measures are used, the results indicate that the positive correlation holds for the large bank group up to four lags.

Taken together, these findings suggest that the expanded technology spending by banks is more of a necessity, instead of a strategic choice, and technology investment helps improve the financial performance of large banks. It is worth noting that despite our attempts to investigate the endogeneity issue between bank performance and technology spending, we acknowledge it remains an empirical issue for future research due to the data limitations we face.

Regarding the effect of technology investment on firm value, we find that bank market value, measured as the market-to-book equity ratio and *Q*, is positively and significantly associated with their lagged technology spending measures for large banks. However, there is little evidence regarding the correlation between bank market value and the lagged technology spending measures for small banks. This finding suggests that shareholders of large banks do recognize the benefits from expanded technology spending.

Overall, the results in the paper suggest that investment in technology particularly benefits large banks by improving their financial performance and increasing firm value. However, there is little evidence that financial performance and the market value of small banks are significantly improved by expanded technology spending. These findings provide insight for managers to make efficient capital allocation decisions, and have important implications for policymakers to modify regulations regarding use of information and financial technologies.

This paper makes the following contributions to the literature. First, this paper is one of the first studies examining the extent to which technology investment influences firm performance and market value using firm-level technology spending data of U.S. listed banks. Previous studies have largely

focused on the impact of technology innovations (proxied by the number of patents) or research and development (R&D) expenses on corporate decisions and valuation. Thus, this paper provides a different perspective to examine the impact of technology on firms, and the findings suggest that firms are more likely to benefit from expanded technology investment through efficiency gains rather than increase in sales volume.

Second, this paper helps to explain the "IT performance paradox" in the literature (e.g., Haynes and Thompson, 2000; Mithas, Tafti, Bardhan, and Goh, 2012). Many studies based on data from manufacturing firms indicates that there is no relationship between technology investment and firm performance, while others find a strong positive correlation. We find there is a firm size effect. While there is no significant correlation between firm performance and technology investment for small banks, a positive correlation exists for large banks. It implies that use of technology is more of a necessity for small firms in order to stay competitive in the market. As it is often expensive to adopt advanced technology, small firms may not benefit from technology investment the same as large firms.

Finally, this paper examines the relationship between technology spending and firm value. The findings suggest that the market does value technology investment by large banks, perhaps because technology can improve the quality of client service, create new lines of business, and improve operating efficiency. Thus, this paper fills a gap in the literature as to whether technology investment enhances or destroys the firm value.

The rest of the paper is organized as follows. Section 2 discusses the background and literature. Section 3 describes the data and research methodologies. The empirical results are presented in Section 4. Section 5 presents the results of the robustness checks, while Section 6 provides our conclusions.

2. Background and Literature

In banking literature, following the seminal work by Sealey and Lindley (1977), many studies examine the impact of technology changes and progress on bank production and services, as well as the

market structure of the banking industry. Hunter and Timme (1986) investigate the impact of technical changes on bank production and scale economies. Using bank holding company data collected from the Bank Compustat file from 1972-1982, they find that technical changes exhibit positive scale bias. In other words, large banks are more likely to fully exploit operating scale economies and remain competitive in deposit markets based on their operating efficiencies resulting from the use of new technology.

Petersen and Rajan (2002) examine the distance between small firms and their lenders based on a sample obtained from the 1993 National Survey of Small Business Finance (NSSBF). Their findings suggest that information technology provides greater information availability to small firms and reduces the costs of processing small business loans that contribute to a longer distance between small firms and their lenders. They conclude that there is indirect evidence that information technology does increase bank productivity.

Berger (2003) examines technological progress and its effects on productivity growth and the market structure of the banking industry. Based on banking data from various sources from 1984-2001, their study suggests that technology (primarily Internet banking, electronic payment technology, and information exchanges) significantly improve the quality of banking services and increase bank productivity. Specifically, consumers benefit from improved "front-office" technology (those directly dealing with customers) and "back-office" technology (those invisible to customers) that help to reduce costs and improve lending capacity. Moreover, the paper suggests that technological progress has a significant impact on the market structure of U.S. banks and helps facilitate banking consolidation. This view is also supported by Pang (2018) who proposes a theoretical model to identify the winners and losers of the advances in bank information technology.

Based on various proxies for use of technology, a few studies investigate the different effects of technology on bank investment. For example, Saloner and Shepard (1995) find that adoption of automated teller machines (ATMs) delays the decline in the number of branches for banks. Ferrari,

Verboven, and Degryse (2010) examine the investment and demand of ATMs and determine that banks substantially underinvest in ATMs.

Using either survey data, data from small community banks, or data from European banks, a few studies examine the effects of technology on the financial performance of banks. An early study by Prasad and Harket (1997) examines the contributions of information technology (IT) on profitability in U.S. retail banking. Based on a survey dataset of U.S. retail banking institutions from 1993-1995, they find that an increase in IT investment does not benefit banks' productivity and financial performance. They argue, since there is no "barrier to entry" in terms of IT in the retail banking industry, small retail banks must adopt new technology in order to stay in the competition, even though it is not in the best interest of them to use the technology based on cost-benefit considerations. Thus, use of IT may not necessarily have a positive relationship with bank performance.

A more recent study by DeYoung, Lang, and Noelle (2007) employs U.S. community bank data from 1999-2001 to study the impact of transactional banking websites on bank performance. They determine that internet adoption improves performance for community banks, primarily through increased revenues from deposit service charges. In contrast, Arnaboldi and Claeys (2010) find little evidence of economies of scope on use of technology by European banks. They confirm that there is little gain from internet banking investment based on a panel of the 60 largest European banking groups from 1995-2005. Moreover, based on a sample of 737 European banks from 1995-2000, Beccalli (2007) investigates whether IT investment improves bank performance. The paper also finds little relationship between IT investment and bank performance or efficiency. However, their research demonstrates that investments related to IT service from external providers (e.g., consulting services, training, and education) have a positive impact on financial performance, while investments in hardware and software are negatively related to banks' profits. In short, the results from these papers suggest that there is mixed evidence about the effect of use of technology on bank performance.

In addition, Martin-Oliver and Salas-Fumas (2008) and Martin-Oliver, Ruano, and Salas-Fumas (2013) use data from Spanish commercial banks to examine the impact of technology investment prior to the financial crisis. They find some evidence that technology investment influences the productivity and performance of Spanish banks. Sullivan and Wang (2013) study the endogenous diffusion and impact of Internet banking, which is believed to be a cost-saving technological innovation. They suggest that large banks could take advantage of being early adopters and could increase in size at the time when the innovation was initially introduced. While the focus is to assess the impact of technology on the financial industry in terms of financial stability and access to services, Philippon (2015) provides some evidence that the adoption of financial technology does not reduce the intermediation costs for banks.

There are also studies that examine the economic benefits of technology adoption using data from manufacturing firms and the results are mixed and inconclusive. Berndt and Morrison (1995) find limited evidence of a positive relationship between firm performance and their ratios of high-tech capital to physical capital stock in U.S. manufacturing industries from 1968-1986. Hitt and Brynjolfsson (1996) confirm little relationship between firms' use of information technology and their performance. More recently, a positive and statistically significant technology and performance relationship is noted in Mithas et al. (2012) whose sample is more than 400 large global firms. They also find that IT-enabled revenue growth, but not operating cost reduction, significantly contributes to this positive relationship. [8]

Most of the studies in the banking literature focus on the effects of technology on bank productivity, quality of services, and the market structure. While there are a few papers that examine the relationship between technology investment and bank performance, the extant research is largely based on limited survey data from U.S. banks or short-term data prior to the "network" era of computing that cannot evaluate the effects of technology investment in the banking industry during the past decade.

[8] Other studies in the literature include Brynjolfsson (1993). A detailed review of the literature can be found in Brynjolfsson and Yang (1996) and Draca, Sadun, and Van Reenen (2007).

For studies based on data from European banks, one can argue that significant differences exist between the U.S. banking system and the European banking system (e.g., market structure and regulations, sample period, and size of the industry).[9] Thus, the results based on European bank data may not be applicable to the U.S. banking industry. Also, previous literature largely use proxies for technology usage, such as the number of ATMs and transaction website adoption for information technology. There is little research based on direct firm-level technology spending data from U.S. listed banks. More importantly, the results regarding financial performance and technology spending are largely mixed in the literature, suggesting that further research on this issue is warranted.

Using technology spending data from Fortune 1000 companies around the year 2000 (Y2K), Anderson, Banker, and Ravindran (2006) find technology investment increases firm value. Yet, there is little research in the banking literature as to how technology investment influences the firm value of banks, while the impact of other factors on bank value have been widely examined including bank deregulation (Marcus, 1984), diversification (Elsas, Hackethal, and Holzhäuser, 2010), and equity capital (Mehran and Thakor, 2011). If banks can provide better customer service via technology (Melnick et al., 2000) and bank performance is positively related to their technology spending, the market value of banks should also be positively correlated with their technology spending. Meanwhile, not all technology investments are placed on positive NPV projects as bank managers may have potential managerial entrenchment issues (Fiordelisi and Molyneux, 2010). Thus, the relationship between bank value and technology investment becomes an empirical question.

The banking literature also notes significant differences in portfolio composition and technology adoption strategies for small and large banks (Berger and Udell, 2002; Berger and DeYoung, 2006; Berger and Bouwman, 2013). In addition, it is well known that there exist economies of scale in

[9] The GDP of Spain in 2015 is roughly 6.6% of the GDP of the U.S. The total assets of Spanish banks in 2016 is about €2.7 trillion based on a BBVA research report and the total assets of U.S. commercial banks at the same year is $12 trillion based on FRED economic data.

technology investment (Katz and Shapiro, 1986; Harris and Katz, 1991; Hall and Khan, 2003), which implies that technology investment could have different effects on firms with different size. Thus, it is meaningful to examine the impact of technology spending on both large and small banks.

To what extent is the use of technology exogenously determined? Previous research suggests that technology has profoundly changed the way that traditional business is conducted and technological advances have become an exogenous driving force in the economy (Greenwood, Hercowitz, and Krusell, 1997; Hansen and Prescott, 2002).[10] Additionally, the innovation and adoption of technology from the world technology frontier of firms drives the economic growth (Acemoglu, Aghion, and Zilibotti, 2006; Madsen, 2014).

With the rapid technological progress across the banking industry, many believe that banks must adopt new technology in order to stay competitive, while others argue that adoption of technology may be driven by certain firm characteristics. Hall and Khan (2003) contend that the choice of technology adoption is between adopting it now or deferring the decision until later, but it is not a choice between adopting and not adopting. To stay competitive and better serve customers, banks should invest or adopt new technology at some point in time. Hernândez-Murillo, Llobet, and Fuentes (2010) investigate the determinants of banks' decisions to adopt a transactional website for their customers. Using a panel of commercial banks in the U.S. from 2003-2006, they find that while bank-specific characteristics are important in banks' adoption decisions, market competition plays a prominent role consistent with the notion that the adoption of technology is a necessity in order for banks to remain competitive. Overall, previous research seems to support that the use of technology by banks can be exogenously determined.

3. Data and Research Methodology

[10] Technology is often assumed as exogenous in the neoclassical growth model (Grossman and Helpman, 1994) and in the real business-cycle theory (Kydland and Prescott, 1982; Greenwood, Hercowitz, and Huffman, 1988; Gali, 1999).

3.1 Data Description

The firm-level data set for this study is obtained from the Compustat banking database and the S&P Global Market Intelligence (formally SNL Financial) banking database from 2000-2017 for U.S. listed commercial banks (SIC Code: 60). Specifically, the annual technology and communication expense data are collected from the S&P Global Market Intelligence. Other annual financial information is obtained from Compustat.[11]

We recognize that technology and communication expenses include physical technology equipment, software, and services. However, it is challenging to disentangle the components of this expense from the database. The technology expense from the S&P Global Market Intelligence is primarily constructed based on U.S. GAAP Standard Statement of Financial Accounting Standards (FAS) No. 86 and includes expenses paid for communications, such as telephone and fax usage charges, internet data plans, internet plans, data processing, technology equipment as well as software purchases and subscriptions to cloud-based services. On the financial reports and bank regulatory filings of banks, these expenses are usually reported as technology and communications expenses, data processing expenses, Internet banking expenses, and ATM expenses, etc. Table A2 in the appendix provides detailed descriptions of the technology expenses, along with some typical examples indicating their original sources and compositions.

In terms of performance measures of banks, two commonly used ratios are used: Return on Assets (ROA) and Return on Equity (ROE), which are defined as earnings before extraordinary items plus depreciation and amortization divided by the book value of assets and by the book value of equity, respectively. To assess which channel of technology spending affects bank performance, ROA is decomposed into two components: Profit Margin and Asset Turnover. Profit Margin is measured as

[11] If an accounting item is missing in year t, it is replaced by estimates from this formula: $Info_{i,t}^{x} = \left(Info_{i,t+1}^{x} + Info_{i,t-1}^{x}\right)/2$, where $Info_{i,t}^{x}$ is the information of x (total assets, technology expense, etc.) of bank i in year t.

earnings before extraordinary items plus depreciation and amortization divided by the sum of interest income and noninterest income, while Asset Turnover is measured as the sum of interest income and noninterest income divided by the book value of assets. For the market value of banks, we use the market-to-book equity ratio (market-to-book), defined as share prices as of the fiscal year-end times common shares outstanding divided by the book value of equity, and *Q* as in Lamont and Polk (2002), measured as share prices as of the fiscal year-end times common shares outstanding plus total assets minus the book value of equity, to total assets. Table A1 in the appendix provides detailed descriptions of the variables used in this paper.

As large banks may spend more on technology, we adjust for firm size making it meaningful to compare technology spending among banks. Thus, controlling for firm size, two technology ratios (technology expense/total assets and technology expense/total loan and deposit) are included as independent variables in the regressions.[12]

Since lagged variables are included in the regressions, banks with fewer than two consecutive years of technology expenses and total assets information are excluded. Observations with missing values of the key variables are also excluded. All of the variables are winsorized at the 1% and 99% tails of the distributions to mitigate the effect of outliers. The final sample consists of 8,706 bank-year observations for 994 banks from 2000-2017.

Table 1 reports the summary statistics of the key variables used in this paper. The total assets of the banks have a mean of $7.1 billion and a median of $0.9 billion. The typical bank has an average market capitalization of $1.1 billion and a median of $0.1 billion. The mean and median of the technology expenses is $14.3 million and $1.5 million, respectively. In terms of the performance measures, the mean Return on Assets is 0.82% and the median is 0.94%, while the mean Return on

[12] It is possible that the technology expense variable does not include all technology investment. By normalizing the technology expense variable using firm size and including bank fixed effects in the regression, the measurement error problem is mitigated. It also alleviates the problem resulting from an increase in bank size, especially from mergers and acquisitions.

Equity is 8.28% and the median is 9.77%. For measures of firm value, the average market-to-book equity ratio is 1.33 and the median is 1.21, and the average *Q* is 1.03 and the median *Q* is 1.02. Regarding the technology expense measures, the mean (median) ratio of technology expense over total assets and over total loans and deposits are 0.18% (0.17%) and 0.13% (0.12%), respectively.

[Insert Table 1 here]

3.2 Empirical Specifications for the Correlation between Performance and Technology Spending

In this subsection, we discuss the empirical specification to assess the relationship between bank performance and technology spending. Return on Assets (ROA) and Return on Equity (ROE) are used as the performance measures. ROA demonstrates how well a firm can generate a return on its assets and indicates whether a bank's assets are productive and well managed. ROE is the measure of company performance in the views of analysts and investors. We regress the ROA and ROE of banks on their previous year's technology spending measures, controlling for several firm characteristics based on the full sample, small bank, and large bank sample, respectively. A fixed effects model is used with heteroskedasticity-robust standard errors clustered at the firm level as in Equation (1):

$$Perf_{i,t} = \beta_0 + \beta_1 Tech_{i,t-1} + \beta_2 LnSize_{i,t-1} + \beta_3 Leverage_{i,t-1} + \beta_4 Loans/Assets_{i,t-1} + \beta_5 Deposits/Assets_{i,t-1} + \beta_6 Deposits/Liability_{i,t-1} + \eta_i + \alpha_t + \varepsilon_t \quad (1)$$

where $Perf_{i,t}$ is either the ROA or ROE of bank i at year t, $Tech_{i,t-1}$ is either the ratio of technology expense over total assets or the ratio of technology expense over total loans and deposits of bank i at year *t-1*. $LnSize_{i,t-1}$ is the previous year's natural log of the market capitalization of equity following Cheng, Hong, and Scheinkman (2015). $Leverage_{i,t-1}$ is the previous year's book assets to equity ratio,

as in Adrian and Shin (2009). $Loans\ /\ Assets_{i,t-1}$ is the previous year's total loans to total assets ratio. $Deposits\ /\ Assets_{i,t-1}$ is the previous year's total deposits to total assets ratio, $Deposits\ /\ Liability_{i,t-1}$ is the previous year's total deposits to total liabilities ratio, and η_i and α_t represent firm and year fixed effects, respectively.

ROA can be expressed as the product of Profit Margin and Asset Turnover. This decomposition is widely used in the literature (Muscarella and Vetsuypens, 1990; Jansen, Ramnath, and Yohn, 2012) and can be found in financial statement analysis textbooks (e.g., Healy and Palepu, 2012). Intuitively, Profit Margin indicates how much of every dollar of revenue a bank keeps in earnings. It reflects a bank's operating efficiency and profitability. Asset Turnover measures asset utilization indicating how well a company can deploy its assets in generating revenue. Some firms may emphasize high Profit Margin to improve their ROA, while others pay closer attention to Asset Turnover or both. The existing literature provides little evidence regarding the relationship between bank technology investments and Profit Margin and/or Asset Turnover.

To examine the specific channel that technology spending influences bank performance, we posit the following equation to study the relationship between the two components and technology spending:

$$ROA\ Comp_{i,t} = \beta_0 + \beta_1 Tech_{i,t-1} + \beta_2 LnSize_{i,t-1} + \beta_3 Leverage_{i,t-1} + \beta_4 Loans/Assets_{i,t-1} + \beta_5 Deposits/Assets_{i,t-1} + \beta_6 Deposits/Liability_{i,t-1} + \eta_i + \alpha_t + \varepsilon_t \quad (2)$$

The dependent variable, $ROA\ Comp_{i,t}$, is either $ProfitMargin_{i,t}$ (defined as earnings before extraordinary items plus depreciation and amortization divided by the sum of interest income and noninterest income) or $Asset\ Turnover_{i,t}$ (defined as the sum of interest income and noninterest income divided by the book value of assets) of bank i at year t. Other variables are as previously defined.

3.3 Firm Value and Technology

In this subsection, we discuss the methodology to examine the relationship between technology investment and firm value. In value-based management (VBM) theory, the primary objective of a firm is to increase the wealth of its shareholders (Ittner and Larcker, 2001). Firm managers should first consider the interests of shareholders when making investment decisions. Thus, sound technology investment decisions should help maximize firm value. In addition, if technology investment influences the financial performance of banks, there should exist a positive relationship between firm value and technology investment.

To empirically examine the relationship, we run a similar regression as in Equation (1):

$$FirmValue_{i,t} = \beta_0 + \beta_1 Tech_{i,t-1} + \beta_2 LnSize_{i,t-1} + \beta_3 Leverage_{i,t-1} + \beta_4 Loans/Assets_{i,t-1} + \beta_5 Deposits/Assets_{i,t-1} + \beta_6 Deposits/Liability_{i,t-1} + \eta_i + \alpha_t + \varepsilon_t \quad (3)$$

The dependent variable is the market-to-book equity ratio or the Q of bank i at year t and the other variables are as previously defined. Here, the market-to-book equity ratio is defined as share prices (common shares outstanding at the fiscal year-end) divided by the book value of equity. Q is the ratio of the market value, measured as share prices as of the fiscal year-end times common shares outstanding plus total assets minus the book value of equity, to its total assets as in Lamont and Polk (2002).

4. Empirical Results

4.1 The Growth of Technology Spending and Its Relationship with Firm Performance

First, we find dramatic growth in technology spending by banks from 2000-2017. The median technology and communication expense per bank (in 2017 dollars) grew from $1.12 million in 2000 to $2.95 million in 2017 (see Figure 1). The trend is almost monotonically increasing during this period.

We then group the banks into two subsets based on their gross total assets (GTA). For small banks, whose time-series average of GTA is up to $1 billion, the median rose from $0.49 million to $1.32 million, while for large banks, whose time-series average of GTA exceeds $1 billion, the median grew from $2.50 million to $6.54 million. This finding indicates that there exists a steady increase in a bank's technology spending each year over this period.

[Insert Figure 1 here]

To assess whether banks with better financial performance are more likely to adopt new technology, we take a closer look at how technology spending is related to bank performance during the financial crisis. The argument is that if technology spending is largely determined by a bank's financial performance, then technology spending should have dropped significantly during the financial crisis. We find that the median technology spending per bank grew from $1.63 million in 2007 to $1.94 million in 2012 (see Figure 1), although the median bank performance measures experienced a significant drop starting from 2007. Also, the median technology spending measures (Tech Expenses/Total Assets and Tech Expenses/Loans & Deposits) gradually increased from 2007 until 2014 (see Figure 2), while there is a clear "V" shape for bank performance measures over the sample period.

[Insert Figure 2 here]

Next, if bank performance strongly influences technology investment, one would expect technology spending to decrease when banks face significant financial hardships. Essentially, we examine how technology spending reacts on a negative performance shock. Two negative performance shock measures are used: 1) a bank's ROA becomes negative at year *t,* while it is positive in year *t-1*, and 2) a bank's ROA at year *t* is two standard deviations less than that of year *t-1*. In our sample, there

are 305 bank years that a bank's ROA becomes negative from a positive previous year, and there are 313 bank years that a bank's ROA drops two standard deviations from its previous year. We examine the technology spending trend three years before and after the negative performance shock year. [13]

Panel A of Figure 3 illustrates the pattern of the mean and the median of the technology spending measures. The results indicate that the mean and median technology spending measures (Tech Expenses/Total Assets and Tech Expenses/Total Loan & Deposits, respectively) after the year with a negative performance shock still increase monotonically in both cases. However, the mean (median) Tech Expenses/Total Assets ratio in year *t+3* is higher than the ratio in year *t-3* by 0.05 (0.05), with a *t*-statistic from the two sample *t*-test of 6.52 and a *z*-statistic from the two sample Wilcoxon rank-sum test of 5.71. The test results based on Tech Expenses/Total Loan & Deposits are similar.

Panel B reports the results based on another definition of a negative performance shock. Specifically, in year *t*, a bank experiences a negative performance shock if its ROA drops two standard deviations relative to the ROA in year *t-1*. Consistent with Panel A, the differences in the mean (median) technology spending measures between year *t-3* and year *t+3* are both 0.03% (0.02%) for Tech Expenses/Total Assets and Tech Expenses/Loans & Deposits, respectively. The *t*-test statistics and *z*-statistics are statistically significant at the 1% level for the two sample *t*-test and Wilcoxon rank-sum test. These results indicate that technology spending continues to increase even when banks experience a negative performance shock, suggesting that a negative shock on bank performance does not affect their technology spending.

[Insert Figure 3 here]

[13] We also apply the same analysis by measuring bank negative profitability shocks via ROE. The results are quantitatively similar with those presented in this panel. For brevity, these results are not reported, but are available upon request.

To examine whether technology spending of more profitable banks is higher than that of less profitable banks, we use a nonparametric approach by sorting the banks into quintiles based on their average ROA and ROE. We then report the mean and median of their technology spending measures in each quintile. To be sure our results are reliable, we only include banks with at least five consecutive year observations on ROA, ROE, and technology spending data.

Panel A of Figure 4 illustrates the mean and median of technology spending measures based on quintiles of ROA. There are 611 banks that have at least five years of ROA and technology spending information in the sample. Surprisingly, the results indicate that the mean and median of the technology spending measures for less profitable banks (Quintile 1) are higher than those of the more profitable banks (Quintile 5) during the sample period. In fact, the mean and median technology spending measures of the banks sorted by ROA tend to decrease from the first quintile to the fifth quintile. For example, the difference in the mean (median) of Tech Expenses/Total Assets between Quintile 1 and Quintile 5 is 0.03% (0.04%). The *t*-statistics from the two sample *t*-test is 11.16 and *z*-statistics from the two sample Wilcoxon rank-sum test is 11.49.

Similar results are found in Panel B, which consists of banks with non-missing ROA and technology spending information in each year over the sample period. For instance, the differences of the mean (median) between the two extreme quintiles are 0.03% (0.05%) and 0.02% (0.04%) for Tech Expenses/Total Assets and Tech Expenses/Loans and Deposits, respectively. Thus, it does not appear that more profitable banks invest more in technology during the sample period. Again, these findings suggest that financial performance is less likely to be a main driver for bank technology spending.

[Insert Figure 4 here]

4.2 Firm Performance and Technology Spending

In this section, we explore the correlation between bank performance, measured by Return on Assets (ROA) and Return on Equity (ROE), and their lagged technology spending measures, measured by Tech Expenses/Total Assets and Tech Expenses/Loans & Deposits, while controlling for firm size, capital structure, and portfolio composition in the previous year.

Table 2 reports the regression results based on Equation (1) (i.e., the basic regression of bank performance on the lagged technology investment measures). Panel A presents the results from the full sample. In Columns (1) and (2), when ROA is used as the dependent variable, the estimated coefficients of the previous year's technology spending measures are positive (0.60 and 0.85) and statistically significant at the 10% level. Similarly, with ROE as the dependent variable in Columns (3) and (4), the coefficients are also positive (10.59 and 15.14) and statistically significant at the 5% level. For the control variables, the results confirm that bank size is positively correlated with ROA and ROE indicating that large banks tend to have better performance. Moreover, firm leverage is negatively associated with ROA, which is not surprising. As expected, banks with a higher deposit/assets ratio tend to have higher ROE, while those with a higher deposit/total liabilities ratio tend to have lower ROE.

Panel B of Table 2 presents the results from the basic regression for the small bank sample and the large bank sample. For small banks [Columns (1)-(4)], the estimated coefficients of the previous year's technology spending measures are statistically insignificant. In contrast, the coefficients of the previous year's technology spending measures based on large banks are all positive (0.97 and 1.38 when the dependent variable is ROA; 16.39 and 23.09 when the dependent variable is ROE) and highly statistically significant at the 1% level. It is worth noting that the coefficients of the large banks are significantly greater than those of the full sample and the small banks. This highlights the importance of technology investment on performance for large banks.

[Insert Table 2 here]

The insignificant coefficients of the technology spending measures for small banks can partly explain the "IT performance paradox" stated in Beccalli (2007) whose sample consists of commercial banks from five European countries. The positive relationship between technology spending and performance for large banks is consistent with Mithas et al. (2012), a recent study whose sample contains more than 400 large global firms. Collectively, our results provide strong evidence that bank performance is positively related to their previous year's technology spending for large banks, but not small banks.

4.3 Channel of Technology Spending Influencing Firm Performance

The results presented in this subsection shed light on the mechanism in which a bank's performance is associated with its technology spending. As mentioned previously, we first decompose a bank's Return on Assets into two parts: Profit Margin, measuring operating efficiency and profitability, and Asset Turnover, measuring sales volume effect. The results from Equation (2) using the full sample are reported in Panel A of Table 3. When the dependent variable is Profit Margin, as in Columns (1) and (2), the estimated coefficients of the previous year's technology spending measures are positive, but statistically insignificant. While the dependent variable is Asset Turnover, as in Columns (3) and (4), the estimated coefficients are positive (1.88 and 2.78) and statistically significant at the 1% level. These results from the full sample suggest that Asset Turnover, but not Profit Margin, may be associated with their previous year's technology spending.

Panel B of Table 3 reports the results from Equation (2) using the small bank sample and the large bank sample. For small banks, the estimated coefficients of the previous year's technology spending measures are negative and statistically insignificant when the dependent variable is Profit Margin, as in Columns (1) and (2). However, when the dependent variable is Asset Turnover, as in Columns (3) and (4), all of the estimated coefficients of the previous year's technology spending measures are positive (1.64 and 2.44) and statistically significant at the 1% level. The results imply that

technology spending does help small banks to increase their revenue (higher Asset Turnover), but does not increase their ability to convert revenue into profit. Thus, the revenue generated from the technology investment of small banks may not fully cover their increased costs. In Columns (5) and (8) for the large banks, all the four estimated coefficients of the previous year's technology spending measures are positive and statistically significant at the 1% or 5% level. Note that the coefficients for Profit Margin (15.71 and 21.16) are much higher than those for Asset Turnover (1.96 and 2.89). These results imply that technology investment is likely to affect bank performance by improving operational efficiency rather than by increasing sales volume. Large banks can better capture the benefits from technology investment through efficiency gains and cost reduction resulting from the economies of scale, which suggests that bank size matters in such a relation.

[Insert Table 3 here]

4.4 Market Value and Technology Investment

This subsection examines the extent to which the technology investment of a bank is a source of value creation for its shareholders. The results from Equation (3) with the market-to-book ratio and *Q* as the dependent variables for the full sample are reported in Panel A of Table 4. The four coefficient estimates of the previous year's technology spending measures are all positive, but only one of the four is statistically significant at the 10% level.

However, the results from Panel B of Table 4 are striking. In Columns (1)-(4) for the small banks, the coefficient estimates of the technology spending measures are statistically insignificant. In contrast, the coefficient estimates of the technology spending measures for the large banks are positive (0.53 and 0.66 when the dependent variable is market-to-book; 0.04 and 0.05 when the dependent variable is *Q*) and statistically significant at the 5% or 10% level, as in Columns (5)-(8). The results are consistent with Anderson et al. (2006) who focus on Fortune 1000 firms and find that firm value increased, on average,

with Y2K spending on technology. In addition, the estimated coefficients of the technology spending measures in the large bank sample are greater than those in the full sample and small bank sample.

[Insert Table 4 here]

Collectively, these results provide evidence that bank value is positively associated with their previous year's technology spending related to total assets and total loans and deposits, respectively, in large banks.

5. Robustness Checks

This section presents a range of robustness checks, which provide additional supporting evidence for the main results in Section 4. The control variables used in this section are the same as those in the main regression models unless noted below.

5.1 Too-Big-To-Fail (TBTF) Banks Excluded from Large Banks

It is believed that the largest banks operate in very different models and under different degrees of government regulation, supervision, and support. To ensure our results concerning large banks are not determined by those TBTF banks, we conduct our analysis for the large bank sample excluding banks whose time-series average gross total assets exceed $50 billion. Those banks are usually called too-big-to-fail (TBTF) banks or systematically important financial institutions (SIFIs).

Panel A of Table 5 reports the regression results on Return on Assets, Return on Equity, Profit Margin, Asset Turnover, market-to-book, and *Q* of the banks on their previous year's technology spending measures with each column as a separate regression for the dependent variable indicated in the column header. The estimated coefficients are quantitatively similar to those presented in the previous tables and significance is found in similar cases except for *Q*. The findings about the relationship

between the performance and firm value of large banks and their technology investment measures remains unchanged when TBTF banks are dropped from the sample.

[Insert Table 5 here]

5.2 Alternative Technology Spending Levels

As argued in the previous section, some banks seem to benefit significantly from their technology investments only if the amount of their technology spending is large enough and can change their business model and significantly lower their operating cost due to the economies of scale. Other banks may not be able to capture the benefits of technology investments as technology investments are often lumpy and costly. We re-run our analysis using $1 million and $3 million as the cutoff point for technology expense, respectively.

Panels B and C of Table 5 report the results of the regressions of the performance and firm value measures on technology spending measures with the two cutoff points. The parameters for the lagged technology spending measures in the $3 million sample are larger and have higher statistical significance levels than those in the $1 million sample. These results support the main results in Section 4.

5.3 Long Lags of Technology Spending Measures

Panel D of Table 5 reports the regression results of Return on Assets and Return on Equity of banks on their previous one- to five-year technology spending measures using Equation (1) for large banks. Each column is a separate regression for the dependent variable indicated in the column header. The results indicate that bank performance of the large banks is associated with up to four-year lags of technology spending measures. These estimated coefficients are all positive and statistically significant at the 1% level. For instance, the coefficient for Tech Expenses/Total Assets is 1.24 when a two-year lag of the technology spending ratio is used. The *t*-statistics are highly statistically significant. These

results suggest that long lags of technology spending measures have significant effects on bank performance.

5.4 Further Discussion on Endogeneity between Firm Performance and Technology Spending

Overall, the use of technology by banks is likely to be driven by a number of factors such as the rapid technological progress, socialization of the banking industry (Terry, Schwartz, and Schwartz, 2015), competition from non-banking institutions (Buchak, Matvos, Piskorski, and Seru, 2017), risk of information breaching, and financial regulations and compliance. Thus, one can argue that bank technology investments is largely exogenously driven. Just like other firms in the manufacturing and service industries, banks must meet challenges from the rapid advancement of technology, such as mobile banking, cloud computing, and data security, in order to stay competitive in the market regardless as to whether they are willing or able to adapt. To a large extent, the competitive market environment "forces" banks to increasingly invest in technology to catch up with the technology advancements.

Despite the argument and our attempts to address the potential endogeneity between bank performance and technology investments, we acknowledge that the endogeneity concern is not completely eliminated. Further research should be conducted to provide additional evidence on this issue. Due to data limitations, it is challenging for us to employ other econometric techniques in empirical corporate finance to address the endogeneity issue (e.g., instrumental variables, difference-in-differences estimation, and regression discontinuity design). Thus, we consider this paper provides some preliminary evidence regarding a possible causal effect of technology investments on bank performance.

6. Conclusion

The rapid adoption of technology by U.S. firms over the past two decades has drawn great attention from academics, policymakers and practitioners. Despite the importance of technology

investment, research regarding its impact on public firms has been limited. To fill this gap, in this paper we examine the effect of technology investment on firm performance and market value, using a unique dataset from U.S. listed commercial banks from 2000-2017.

To meet the strong demand for agile and secure technology infrastructure and to stay competitive in the market, U.S. banks have significantly increased their technology spending during the past decades. This paper is one of the first studies to examine the extent to which expanded technology spending is related to the financial performance and firm value, using technology spending data from U.S. listed commercial banks.

We first document a strong growth pattern in technology investment in the banking industry. The technology spending of banks almost monotonically increased, even during the financial crisis. Banks experiencing negative performance shocks do not subsequently cut their technology spending. Thus, there is little evidence that bank technology spending is affected by negative performance shocks during the financial crisis and the slow revenue growth in the recent years. These findings suggest that adoption of new technology has become a necessity instead of a strategic choice for banks, as they must provide quality services to customers and improve their productivity in order to remain competitive in the market.

Moreover, the research indicates that there is a strong positive correlation between bank performance and their lagged technology spending measures. This positive correlation is primarily driven by large banks. While greater technology spending increases Asset Turnover for both small and large banks, it only improves the Profit Margin of large banks implying that technology investments affect bank performance by improving operational efficiency, rather than by increasing sales. It appears that large banks are more likely to enjoy the economies of scale from lumpy technology investments. Consistent with Prasad and Harker (1997), there is little evidence that the financial performance of small banks is related to expanded technology spending, perhaps because small banks primarily adopt technology in order to survive and it is very costly for them to invest in technology, such as cybersecurity.

The findings in the paper can partly explain the "IT performance paradox" in the literature, as we identify a size effect concerning the effects of technology spending on banks. The results also indicate that technology investment helps increase bank value for large banks. The paper fills a gap in the literature as to whether the use of technology enhances or destroys firm value.

This paper provides insights for managers with different firm sizes to make efficient capital allocation decisions. Also, the findings have implications for policymakers in terms of changing regulations related to the use of technology. As large firms are more likely to gain benefits from lumpy technology investments, they are likely to have a significant competitive advantage in the market given the rapid growth in technological advances. This may lead to further consolidation in the banking industry and influence small business lending. Meanwhile, regulators should consider whether the current legal system, capital requirements, and cost models would facilitate firms in keeping up with the technological advances. Given the evidence that the effects of technology investment differ between small banks and large banks, it becomes a critical issue whether those regulations should be different for small firms and large firms.

As one of the first empirical studies examining the effects of technology investments on firm performance and firm value, there are some limitations in the paper. Additional research on the causal relationship between technology spending and firm performance is warranted. Also, it will be fruitful to examine relationships between technology investments and financing decisions, corporate governance, and firm risk on U.S. financial institutions. Finally, as the literature primarily consists of empirical analysis, there is a strong need for theoretical work to explain the effects of technology investments on corporate decisions.

References

Acemoglu, D., Aghion, P., Zilibotti, F., 2006. Distance to frontier, selection, and economic growth. Journal of the European Economic Association 4(1), 37-74.

Adrian, T., Shin, H. S., 2009. Money, liquidity, and monetary policy. American Economic Review 99(2), 600-605.

Anderson, M. C., Banker, R. D., & Ravindran, S., 2006. Value implications of investments in information technology. Management Science 52(9), 1359-1376.

Armstrong, C. S., Vashishtha, R., 2012. Executive stock options, differential risk-taking incentives, and firm value. Journal of Financial Economics 104(1), 70-88.

Arnaboldi, F., Claeys, P., 2010. Innovation and performance of European banks adopting Internet. Unpublished working paper. Cass Business School Working Paper Series.

Beccalli, E., 2007. Does it investment improve bank performance? Evidence from Europe. Journal of Banking and Finance 31(7), 2205-2230.

Berger, A. N., 2003. The economic effects of technological progress: Evidence from the banking industry. Journal of Money, Credit, and Banking 35(2), 141-176.

Berger, A. N., Bouwman, C. H., 2013. How does capital affect bank performance during financial crises? Journal of Financial Economics 109(1), 146-176.

Berger, A. N., DeYoung, R., 2006. Technological progress and the geographic expansion of the banking industry. Journal of Money, Credit and Banking, 38(6), 1483-1513.

Berger, A. N., Udell, G. F., 2002. Small business credit availability and relationship lending: The importance of bank organizational structure. The Economic Journal 112(477), F32-F53.

Berndt, E. R., Morrison, C. J., 1995. High-tech capital formation and economic performance in U.S. manufacturing industries an exploratory analysis. Journal of Econometrics 65(1), 9-43.

Brynjolfsson, E., 1993. The productivity paradox of information technology. Communications of the ACM 36(12), 66-77.

Brynjolfsson, E., Yang, S., 1996. Information technology and productivity: A review of the literature. Advances in Computers, 43, 179-214.

Buchak, G., Matvos, G., Piskorski, T., Seru, A., 2017. FinTech, regulatory arbitrage, and the rise of shadow banks. National Bureau of Economic Research Working Paper (No. w23288).

Cheng, I. H., Hong, H., Scheinkman, J. A., 2015. Yesterday's heroes: Compensation and risk at financial firms. Journal of Finance 70(2), 839-879.

Dahl, D., Meyer, A., & Wiggins, N. (2017). How fast will banks adopt new technology this time? The Regional Economist. Fourth Quarter 2017.

DeYoung, R., Lang, W. W., Nolle, D. L., 2007. How the Internet affects output and performance at community banks. Journal of Banking and Finance 31(4), 1033-1060.

Draca, M., Sadun, R., Van Reenen, J., 2007. Productivity and ICT: A review of the evidence. In: Mansell, R. (Eds.), The Oxford Handbook of Information and Communication Technologies. Oxford, UK, Oxford University Press, 100-147.

Elsas, R., Hackethal, A., Holzhäuser, M., 2010. The anatomy of bank diversification. Journal of Banking and Finance 34(6), 1274-1287.

Ferrari, S., Verboven, F., Degryse, H., 2010. Investment and usage of new technologies: Evidence from a shared ATM network. American Economic Review 100(3), 1046-1079.

Fiordelisi, F., Molyneux, P., 2010. The determinants of firm value in European banking. Journal of Banking and Finance 34(6), 1189-1200.

Frame, W. S., White, L. J., 2014. Technological change, financial innovation, and diffusion in banking. In: Berger, A. N., Molyneux, P., and Wilson, J. O. S. (Ed.) The Oxford Handbook of Banking, 2nd Edition, Oxford University Press, Oxford, UK.

Gali, J.. 1999. Technology, employment, and the business cycle: Do technology shocks explain aggregate fluctuations? American Economic Review 89(1), 249-271.

Greenwood, J., Hercowitz, Z., Huffman, G. W., 1988. Investment, capacity utilization, and the real business cycle. American Economic Review 78(3), 402-417.

Greenwood, J., Hercowitz, Z., Krusell, P., 1997. Long-run implications of investment-specific technological change American Economic Review 87(3), 342-362.

Grossman, G. M., Helpman, E., 1994. Endogenous innovation in theory of growth. Journal of Economic Perspectives 8(1), 23-44.

Hall, B. H. H., Khan, B., 2003. New Economy Handbook, Chapter Adoption of New Technology. Elsevier Science, Amsterdam.

Hansen, G. D., Prescott, E. C., 2002. Malthus to Solow. American Economic Review 92(4), 1205-1217.

Harris, S. E., Katz, J. L., 1991. Firm size and the information technology investment intensity of life insurers. MIS Quarterly 15(3), 333-352.

Haynes, M., Thompson, S., 2000. The productivity impact of IT deployment: An empirical evaluation of ATM introduction. Oxford Bulletin of Economics and Statistics 62(5), 607-619.

Healy, P. M., Palepu, K. G., 2012. Business Analysis Valuation: Using Financial Statements. Cengage Learning.

Hernández-Murillo, R., Llobet, G., Fuentes, R., 2010. Strategic online banking adoption. Journal of Banking and Finance 34(7), 1650-1663.

Hitt, L. M., Brynjolfsson, E., 1996. Productivity, business performance, and consumer surplus: Three different measures of information technology value. MIS Quarterly 20(2), 121-142.

Hunter, W. C., Timme, S. G., 1986. Technical change, organizational form, and the structure of bank production. Journal of Money, Credit and Banking 18(2), 152-166.

Ittner, C. D., Larcker, D. F., 2001. Assessing empirical research in managerial accounting: A value-based management perspective. Journal of Accounting and Economics 32(1), 349-410.

Jansen, I. P., Ramnath, S., Yohn, T. L., 2012. A diagnostic for earnings management using changes in asset turnover and profit margin. Contemporary Accounting Research 29(1), 221-251.

Katz, M. L., Shapiro, C., 1986. Technology adoption in the presence of network externalities. Journal of Political Economy 94(4), 822-841.

Kydland, F. E., Prescott, E. C., 1982. Time to build and aggregate fluctuations. Econometrica 50(6), 1345-1370.

Lamont, O. A., Polk, C., 2002. Does diversification destroy value? Evidence from the industry shocks. Journal of Financial Economics 63(1), 51-77.

Madsen, J. B., 2014. Human capital and the world technology frontier. Review of Economics and Statistics 96(4), 676-692.

Marcus, A. J., 1984. Deregulation and bank financial policy. Journal of Banking and Finance 8(4), 557-565.

Martín-Oliver, A., Ruano, S., Salas-Fumás, V., 2013. Why high productivity growth of banks preceded the financial crisis. Journal of Financial Intermediation 22(4), 688-712.

Martín-Oliver, A., Salas-Fumás, V., 2008. The output and profit contribution of information technology and advertising investments in banks. Journal of Financial Intermediation 17(2), 229-255.

Mehran, H., Thakor, A., 2011. Bank capital and value in the cross-section. Review of Financial Studies 24(4), 1019-1067.

Melnick, E. L., Nayyar, P. R., Pinedo, M. L., Seshadri, S., 2000. Creating value in financial services. In: Creating Value in Financial Services. San Francisco, CA, Springer. 1-22.

Mills, D., Wang, K., Malone, B., Ravi, A., Marquardt, J., Chen, C., Badev, A., Brezinski, T., Fahy, L., Liao, K., Kargenian, V., Ellithorpe, M., Ng, W., Baird, M., 2016. Distributed ledger technology in payments, clearing, and settlement, Finance and Economics Discussion Series 2016-095. Washington: Board of Governors of the Federal Reserve System.

Mithas, S., Tafti, A., Bardhan, I., Goh, J. M., 2012. Information technology and firm performance: Mechanisms and empirical evidence. MIS Quarterly 36(1), 205-224.

Muscarella, C. J., Vetsuypens, M. R., 1990. Efficiency and organizational structure: A study of reverse LBOs. Journal of Finance 45(5), 1389-1413.

Myers, S. C., Majluf, N. S., 1984. Corporate financing and investment decisions when firms have information that investors do not have. Journal of Financial Economics 13(2), 187-221.

Pang, H., 2018, The impact of information technology on U.S. commercial banks: Who is the winner/loser? Unpublished working paper. Arizona State University.

Petersen, M. A., Rajan, R. G., 2002. Does distance still matter? The information revolution in small business lending. Journal of Finance 57(6), 2533-2570.

Philippon, T., 2015. Has the U.S. finance industry become less efficient? On theory and measurement of financial intermediation. American Economic Review 105(4), 1408-1438.

Prasad, B., Harker, P. T., 1997. Examining the contribution of information technology toward productivity and performance in U.S. retail banking. Unpublished Working paper. The Wharton Financial Institutions Center Working Papers 97(9).

Saloner, G., Shepard, A., 1995. Adoption of technologies with network effects: An empirical examination of the adoption of teller machines. RAND Journal of Economics 26(3), 479-501.

Sealey, C. W., Lindley, J. T., 1977. Inputs, outputs, and a theory of production and cost at depository financial institutions. Journal of Finance 32(4), 1251-1266.

Stulz, R., 1990. Managerial discretion and optimal financing policies. Journal of Financial Economics 26(1), 3-27.

Sullivan, R. J., Wang, Z, 2013. Internet Banking: An Exploration in Technology Diffusion and Impact. FRB Richmond Working Paper No. 13-10.

Terry, H. M., Schwartz, D., Schwartz, T., 2015. The Future of Finance: The Socialization of Finance. Goldman Sachs Investment Research, 3.

Triplett, J. E., Bosworth, B. P., 2006. 'Baumol's disease' has been cured: IT and multifactor productivity in U.S. services industries, The New Economy and Beyond: Past, Present, and Future, 34-71.

Table 1. Summary Statistics

This table reports the summary statistics of the key variables used in this paper. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

	Mean	Median	Std. Dev.	Min	Max	Obs.
Total Assets ($B)	7.09	0.92	29.46	0.09	247.26	8,706
Market Capitalization ($B)	1.14	0.10	4.96	0.00	42.48	8,343
Technology Expense ($M)	14.31	1.50	70.08	0.12	598.00	8,706
Leverage	11.16	10.56	4.05	4.28	32.47	8,706
Loans/Assets	0.67	0.68	0.12	0.26	0.89	8,706
Deposits/Assets	0.77	0.79	0.09	0.47	0.91	8,706
Deposits/Liability	0.86	0.88	0.10	0.51	1.00	8,706
Return on Assets (%)	0.82	0.94	0.83	-3.43	2.46	7,974
Return on Equity (%)	8.28	9.77	11.89	-67.23	30.42	7,974
Profit Margin (%)	18.87	23.42	21.29	-103.49	47.81	7,974
Asset Turnover (%)	4.18	4.08	1.03	1.95	8.13	8,703
Firm Value (Market-to-Book)	1.33	1.21	0.64	0.23	3.60	8,308
Firm Value *(Q)*	1.03	1.02	0.06	0.93	1.22	8,343
Tech Expense/Total Assets (%)	0.18	0.17	0.10	0.03	0.49	8,706
Tech Expense/Loans & Deposits (%)	0.13	0.12	0.07	0.02	0.37	8,706

Table 2. Performance and Technology Investment

This table reports the results of the regressions of bank performance measures (Return on Assets and Return on Equity) on their technology investment measures (Tech Expense/Total Assets, and Tech Expense/Loans & Deposits) in the previous year in our sample from 2000-2017. The standard errors are clustered at the firm level. *t*-statistics based on robust standard errors are in brackets. Significance at the 1%, 5%, or 10% levels are presented as*, **, or ***, respectively. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

Panel A. All Banks				
Variables	(1) Return on Assets	(2) Return on Assets	(3) Return on Equity	(4) Return on Equity
Tech Expense/Total Assets, *t-1*	0.60*		10.59**	
	[1.90]		[2.03]	
Tech Expense/Loans & Deposits, *t-1*		0.85*		15.14**
		[1.84]		[1.98]
Log Market Capitalization, *t-1*	0.32***	0.32***	4.05***	4.04***
	[8.58]	[8.55]	[5.34]	[5.32]
Leverage, *t-1*	-0.02**	-0.02**	-0.16	-0.16
	[-2.06]	[-2.05]	[-0.94]	[-0.94]
Loans/Assets, *t-1*	-0.05	0.03	-2.95	-1.63
	[-0.24]	[0.13]	[-0.94]	[-0.52]
Deposits/Assets, *t-1*	1.61*	1.69*	56.22***	57.65***
	[1.81]	[1.90]	[3.64]	[3.72]
Deposits/Liability, *t-1*	-1.12	-1.13	-47.61***	-47.78***
	[-1.43]	[-1.44]	[-3.41]	[-3.42]
Constant	-0.33	-0.43	-4.01	-5.83
	[-1.06]	[-1.35]	[-0.73]	[-1.01]
Number of Observations	6,652	6,652	6,652	6,652
Number of Banks	912	912	912	912
Adjusted *R*-squared	0.29	0.29	0.21	0.21
Bank Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES

Panel B. Small Banks and Large Banks

	Small Banks				Large Banks			
Variables	(1) Return on Assets	(2) Return on Assets	(3) Return on Equity	(4) Return on Equity	(5) Return on Assets	(6) Return on Assets	(7) Return on Equity	(8) Return on Equity
Tech Expense/Total Assets, *t-1*	0.09		3.59		0.97***		16.36***	
	[0.16]		[0.42]		[3.23]		[3.35]	
Tech Expense/Loans & Deposits, *t-1*		0.13		5.98		1.38***		23.09***
		[0.16]		[0.47]		[3.36]		[3.43]
Log Market Capitalization, *t-1*	0.30***	0.30***	4.24***	4.26***	0.34***	0.34***	4.24***	4.22***
	[4.03]	[4.01]	[3.12]	[3.11]	[7.83]	[7.78]	[4.60]	[4.58]
Leverage, *t-1*	-0.01	-0.01	-0.25	-0.25	-0.02*	-0.02*	-0.10	-0.10
	[-1.28]	[-1.28]	[-0.88]	[-0.88]	[-1.71]	[-1.69]	[-0.52]	[-0.51]
Loans/Assets, *t-1*	0.34	0.35	1.47	2.00	-0.39*	-0.27	-6.34*	-4.35
	[1.03]	[1.10]	[0.28]	[0.39]	[-1.70]	[-1.18]	[-1.74]	[-1.19]
Deposits/Assets, *t-1*	1.50	1.51	47.34**	47.93**	1.38	1.51	63.44***	65.57***
	[1.26]	[1.26]	[2.18]	[2.20]	[1.06]	[1.16]	[2.73]	[2.82]
Deposits/Liability, *t-1*	-0.79	-0.79	-31.85*	-31.97*	-1.18	-1.19	-61.24***	-61.51***
	[-0.73]	[-0.73]	[-1.67]	[-1.67]	[-1.03]	[-1.04]	[-2.91]	[-2.92]
Constant	-0.47	-0.49	-10.14	-10.99	-0.21	-0.37	-0.74	-3.39
	[-0.98]	[-1.00]	[-1.49]	[-1.50]	[-0.51]	[-0.90]	[-0.10]	[-0.42]
Number of Observations	3,093	3,093	3,093	3,093	3,559	3,559	3,559	3,559
Number of Banks	467	467	467	467	445	445	445	445
Adjusted *R*-squared	0.24	0.24	0.17	0.17	0.34	0.34	0.25	0.25
Bank Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES

Table 3. Mechanism of the Effect of Technology Investment on Performance

This table reports the results of the regressions of the Profit Margin and Asset Turnover of banks on their technology investment measures (Tech Expense/Total Assets and Tech Expense/Loans & Deposits) in the previous year in our sample from 2000-2017. The standard errors are clustered at the firm level. *t*-statistics based on robust standard errors are in brackets. Significance at the 1%, 5% or 10% levels are presented as*, **, or ***, respectively. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

Panel A. All Banks				
Variables	(1) Profit Margin	(2) Profit Margin	(3) Asset Turnover	(4) Asset Turnover
Tech Expense/Total Assets, *t-1*	6.90		1.88***	
	[0.86]		[6.14]	
Tech Expense/Loans & Deposits, *t-1*		8.45		2.78***
		[0.73]		[6.29]
Log Market Capitalization, *t-1*	7.71***	7.68***	0.11***	0.11***
	[7.51]	[7.47]	[2.63]	[2.66]
Leverage, *t-1*	-0.43**	-0.43**	0.01	0.01
	[-2.03]	[-2.03]	[0.82]	[0.82]
Loans/Assets, *t-1*	-1.26	-0.53	0.52*	0.76**
	[-0.23]	[-0.10]	[1.74]	[2.50]
Deposits/Assets, *t-1*	45.44*	46.20*	-0.25	0.03
	[1.94]	[1.96]	[-0.21]	[0.02]
Deposits/Liability, *t-1*	-40.87**	-40.82**	1.50	1.45
	[-1.97]	[-1.97]	[1.48]	[1.43]
Constant	-1.31	-2.16	2.25***	1.91***
	[-0.16]	[-0.25]	[4.67]	[3.91]
Number of Observations	6,652	6,652	7,291	7,291
Number of Banks	912	912	963	963
Adjusted *R*-squared	0.28	0.28	0.14	0.14
Bank Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES

Panel B. Small Banks and Large Banks

	Small Banks				Large Banks			
Variables	(1) Profit Margin	(2) Profit Margin	(3) Asset Turnover	(4) Asset Turnover	(5) Profit Margin	(6) Profit Margin	(7) Asset Turnover	(8) Asset Turnover
Tech Expense/Total Assets, *t-1*	-3.97		1.64***		15.71**		1.96***	
	[-0.29]		[4.33]		[2.16]		[4.15]	
Tech Expense/Loans & Deposits, *t-1*		-6.84		2.44***		21.16**		2.89***
		[-0.34]		[4.14]		[2.11]		[4.47]
Log Market Capitalization, *t-1*	7.02***	6.99***	0.12**	0.12**	8.03***	8.00***	0.12**	0.12**
	[3.27]	[3.26]	[2.20]	[2.29]	[7.09]	[7.04]	[2.09]	[2.10]
Leverage, *t-1*	-0.51	-0.51	0.02*	0.02*	-0.40	-0.40	-0.00	-0.00
	[-1.54]	[-1.54]	[1.72]	[1.70]	[-1.48]	[-1.47]	[-0.19]	[-0.18]
Loans/Assets, *t-1*	10.53	9.92	0.58*	0.80***	-11.46*	-9.64	0.47	0.72
	[1.14]	[1.08]	[1.85]	[2.62]	[-1.75]	[-1.46]	[0.99]	[1.46]
Deposits/Assets, *t-1*	45.30	44.63	-1.02	-0.79	46.65	48.54	-0.24	0.06
	[1.50]	[1.47]	[-0.65]	[-0.50]	[1.31]	[1.35]	[-0.13]	[0.03]
Deposits/Liability, *t-1*	-30.40	-30.24	1.80	1.76	-50.23	-50.33	1.65	1.57
	[-1.11]	[-1.10]	[1.25]	[1.23]	[-1.62]	[-1.62]	[1.11]	[1.06]
Constant	-6.81	-5.81	2.25***	1.93***	3.01	0.72	2.29***	1.95**
	[-0.54]	[-0.44]	[4.08]	[3.63]	[0.28]	[0.07]	[2.99]	[2.48]
Number of Observations	3,093	3,093	3,311	3,311	3,559	3,559	3,980	3,980
Number of Banks	467	467	486	486	445	445	477	477
Adjusted *R*-squared	0.24	0.24	0.12	0.12	0.31	0.31	0.16	0.16
Bank Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES

Table 4. Firm Value and Technology Investment

This table reports the results of the regressions of bank value measures (market-to-book ratio and *Q*) on their technology investment measures (Tech Expense/Total Assets and Tech Expense/Loans & Deposits) in the previous year in our sample from 2000-2017. The standard errors are clustered at the firm level. *t*-statistics based on robust standard errors are in brackets. Significance at the 1%, 5% or 10% levels are presented as*, **, or ***, respectively. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

Panel A. All Banks				
Variables	(1) Market-to-Book	(2) Market-to-Book	(3) *Q*	(4) *Q*
Tech Expense/Total Assets, *t-1*	0.25		0.02	
	[1.64]		[1.27]	
Tech Expense/Loans & Deposits, *t-1*		0.30		0.02
		[1.42]		[1.13]
Log Market Capitalization, *t-1*	0.25***	0.25***	0.02***	0.02***
	[9.98]	[9.96]	[7.83]	[7.81]
Leverage, *t-1*	0.02***	0.02***	0.00**	0.00**
	[3.56]	[3.55]	[2.46]	[2.46]
Loans/Assets, *t-1*	0.09	0.12	0.00	0.01
	[0.52]	[0.67]	[0.32]	[0.44]
Deposits/Assets, *t-1*	2.94***	2.97***	0.23***	0.24***
	[4.73]	[4.76]	[4.21]	[4.24]
Deposits/Liability, *t-1*	-2.23***	-2.23***	-0.16***	-0.16***
	[-4.18]	[-4.17]	[-3.25]	[-3.25]
Constant	-0.18	-0.21	0.91***	0.91***
	[-0.89]	[-1.00]	[46.18]	[44.57]
Number of Observations	7,256	7,256	7,285	7,285
Number of Banks	962	962	963	963
Adjusted *R*-squared	0.56	0.56	0.56	0.56
Bank Fixed Effects	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES

Panel B. Small Banks and Large Banks

	Small Banks				Large Banks			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Market-to-Book	Market-to-Book	*Q*	*Q*	Market-to-Book	Market-to-Book	*Q*	*Q*
Tech Expense/Total Assets, *t-1*	-0.12		-0.01		0.53**		0.04**	
	[-0.64]		[-0.81]		[2.41]		[1.99]	
Tech Expense/Loans & Deposits, *t-1*		-0.16		-0.02		0.66**		0.05*
		[-0.60]		[-0.87]		[2.21]		[1.92]
Log Market Capitalization, *t-1*	0.21***	0.21***	0.02***	0.02***	0.29***	0.29***	0.02***	0.02***
	[4.41]	[4.43]	[4.50]	[4.50]	[9.44]	[9.39]	[6.73]	[6.70]
Leverage, *t-1*	0.02**	0.02**	0.00***	0.00***	0.02***	0.02***	0.00	0.00
	[2.16]	[2.16]	[2.80]	[2.80]	[2.70]	[2.70]	[0.80]	[0.80]
Loans/Assets, *t-1*	0.44	0.42	0.03	0.03	-0.20	-0.15	-0.02	-0.02
	[1.62]	[1.57]	[1.35]	[1.30]	[-1.09]	[-0.79]	[-1.27]	[-1.00]
Deposits/Assets, *t-1*	1.43	1.41	0.09	0.09	4.28***	4.33***	0.36***	0.36***
	[1.61]	[1.58]	[1.20]	[1.17]	[4.54]	[4.58]	[4.45]	[4.51]
Deposits/Liability, *t-1*	-0.96	-0.96	-0.04	-0.04	-3.41***	-3.40***	-0.27***	-0.27***
	[-1.39]	[-1.39]	[-0.68]	[-0.68]	[-4.06]	[-4.05]	[-3.64]	[-3.65]
Constant	-0.18	-0.16	0.89***	0.90***	-0.28	-0.34	0.92***	0.91***
	[-0.65]	[-0.56]	[36.17]	[35.11]	[-0.99]	[-1.16]	[32.35]	[31.19]
Number of Observations	3,293	3,293	3,305	3,305	3,963	3,963	3,980	3,980
Number of Banks	486	486	486	486	476	476	477	477
Adjusted *R*-squared	0.54	0.54	0.57	0.57	0.59	0.59	0.57	0.57
Bank Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES

Table 5. Robustness Checks

This table presents the results of the robustness checks. Panel A drops too-big-to-fail banks from large banks and reports the results of regressions of ROA, ROE, Profit Margin, Asset Turnover, market-to-book, and *Q* on their technology spending measures (Tech Expense/Total Assets, and Tech Expense/Loans & Deposits) in the previous year. Panels B and C keep firm-year observations whose technology expenses exceed $1 million and $3 million, respectively, and reports the results of regressions of ROA, ROE, Profit Margin, Asset Turnover, market-to-book, and *Q* on their technology spending measures in the previous year. Panel D includes large banks and reports the results of regressions of ROA and ROE on their previous one- to five-year technology expenses related to total assets and to total loans and deposits, respectively. Each cell is a separate regression for the dependent variable indicated in the column header and the independent variables indicated in the row label. The reported observations and firms are from regressions when the independent variable is the previous-year technology expense related to total assets. Control variables include the previous-year market cap, leverage, loans/assets, deposits/assets, and deposits/liability. The standard errors are clustered at the firm level. *t*-statistics based on robust standard errors are in brackets. Significance at the 1%, 5% or 10% levels are presented as*, **, or ***, respectively. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

Panel A. Performance, Firm Value and Technology Investment in Large Banks with Too-big-to-fail Banks Excluded

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Return on Assets	Return on Equity	Profit Margin	Asset Turnover	Market-to-Book	*Q*
Tech Expense/Total Assets, *t-1*	1.05***	18.19***	19.91***	1.81***	0.46**	0.03
	[3.33]	[3.45]	[2.60]	[3.71]	[2.04]	[1.55]
Tech Expense/Loans & Deposits, *t-1*	1.47***	25.78***	26.51**	2.76***	0.64**	0.05
	[3.34]	[3.50]	[2.46]	[4.05]	[2.01]	[1.58]
Number of Observations	3,362	3,362	3,362	3,747	3,730	3,747
Number of Banks	422	422	422	452	451	452
Control Variables	YES	YES	YES	YES	YES	YES
Bank Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES

Panel B. Performance, Firm Value and Technology Investment in Technology Expense > $1 Million Club Banks

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Return on Assets	Return on Equity	Profit Margin	Asset Turnover	Market-to-Book	*Q*
Tech Expense/Total Assets, *t-1*	0.75*	12.72*	10.55	1.86***	0.46**	0.03*
	[1.84]	[1.79]	[1.01]	[4.53]	[2.32]	[1.94]
Tech Expense/Loans & Deposits, *t-1*	1.01*	16.81	13.33	2.64***	0.55**	0.04*
	[1.74]	[1.63]	[0.90]	[4.72]	[2.02]	[1.77]
Number of Observations	4,121	4,121	4,121	4,563	4,543	4,560
Number of Banks	626	626	626	666	664	666
Control Variables	YES	YES	YES	YES	YES	YES
Bank Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES

Panel C. Performance, Firm Value and Technology Investment in Technology Expense > $3 Million Club Banks

Variables	(1) Return on Assets	(2) Return on Equity	(3) Profit Margin	(4) Asset Turnover	(5) Market-to-Book	(6) *Q*
Tech Expense/Total Assets, *t-1*	1.27***	21.19***	16.24	2.50***	0.61**	0.05*
	[2.62]	[2.96]	[1.32]	[3.88]	[2.26]	[1.92]
Tech Expense/Loans & Deposits, *t-1*	1.73***	28.85***	21.51	3.53***	0.67*	0.06*
	[2.73]	[3.08]	[1.32]	[4.12]	[1.86]	[1.73]
Number of Observations	1,926	1,926	1,926	2,203	2,194	2,203
Number of Banks	314	314	314	338	337	338
Control Variables	YES	YES	YES	YES	YES	YES
Bank Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES

Panel D. Performance and Multi-lagged Technology Investment in Large Banks

	Return on Assets					Return on Equity				
Variables	(1) *m=1*	(2) *m=2*	(3) *m=3*	(4) *m=4*	(5) *m=5*	(6) *m=1*	(7) *m=2*	(8) *m=3*	(9) *m=4*	(10) *m=5*
Tech Expense/Total Assets,	0.97***	1.24***	1.25***	1.36***	0.53	16.39***	18.68***	19.70***	18.94***	6.83
t-m	[3.23]	[3.92]	[3.48]	[3.60]	[1.36]	[3.35]	[4.14]	[3.85]	[3.78]	[1.16]
Tech Expense/Loans & Deposits,	1.38***	1.76***	1.70***	1.82***	0.67	23.09***	26.53***	26.83***	25.64***	7.95
t-m	[3.36]	[4.12]	[3.61]	[3.63]	[1.24]	[3.43]	[4.32]	[4.04]	[3.83]	[0.97]
Number of Observations	3,559	3,164	2,785	2,401	2,050	3,559	3,164	2,785	2,401	2,050
Number of Banks	445	428	411	376	336	445	428	411	376	336
Control Variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Bank Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

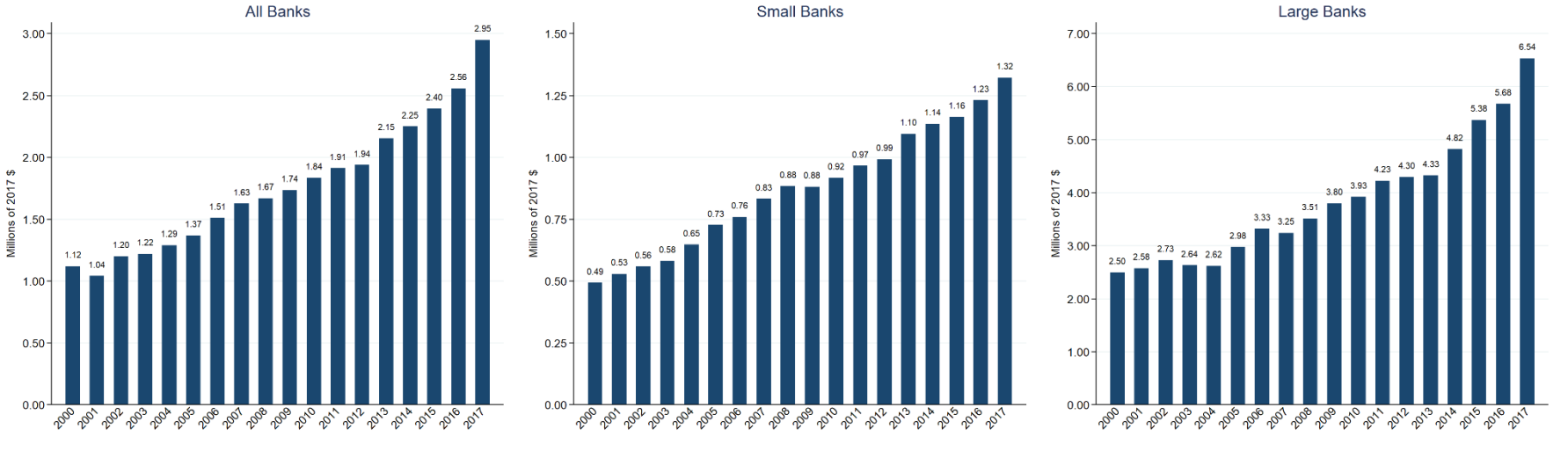

Figure 1. Bank Technology Spending Trends

This figure illustrates the trends of technology and communication expenses (based on median) of U.S listed commercial banks in our sample from 2000-2017. Technology and communication expense is converted to 2017 dollars using the GDP deflator. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

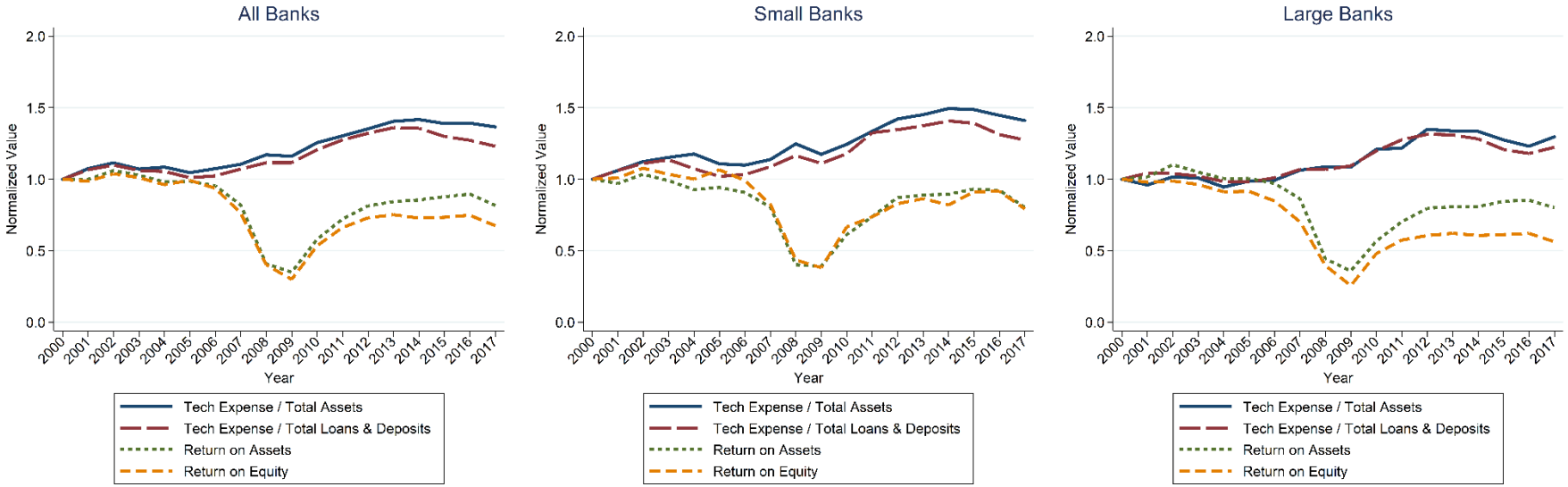

Figure 2. Performance and Technology Investment Over Time

This figure illustrates the medians of bank performance measures (Return on Assets and Return on Equity) and technology investment measures (Tech Expense/Total Assets and Tech Expense/Loans & Deposits) of U.S listed commercial banks in our sample from 2000-2017. All of the values are normalized to equal one in the year 2000. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

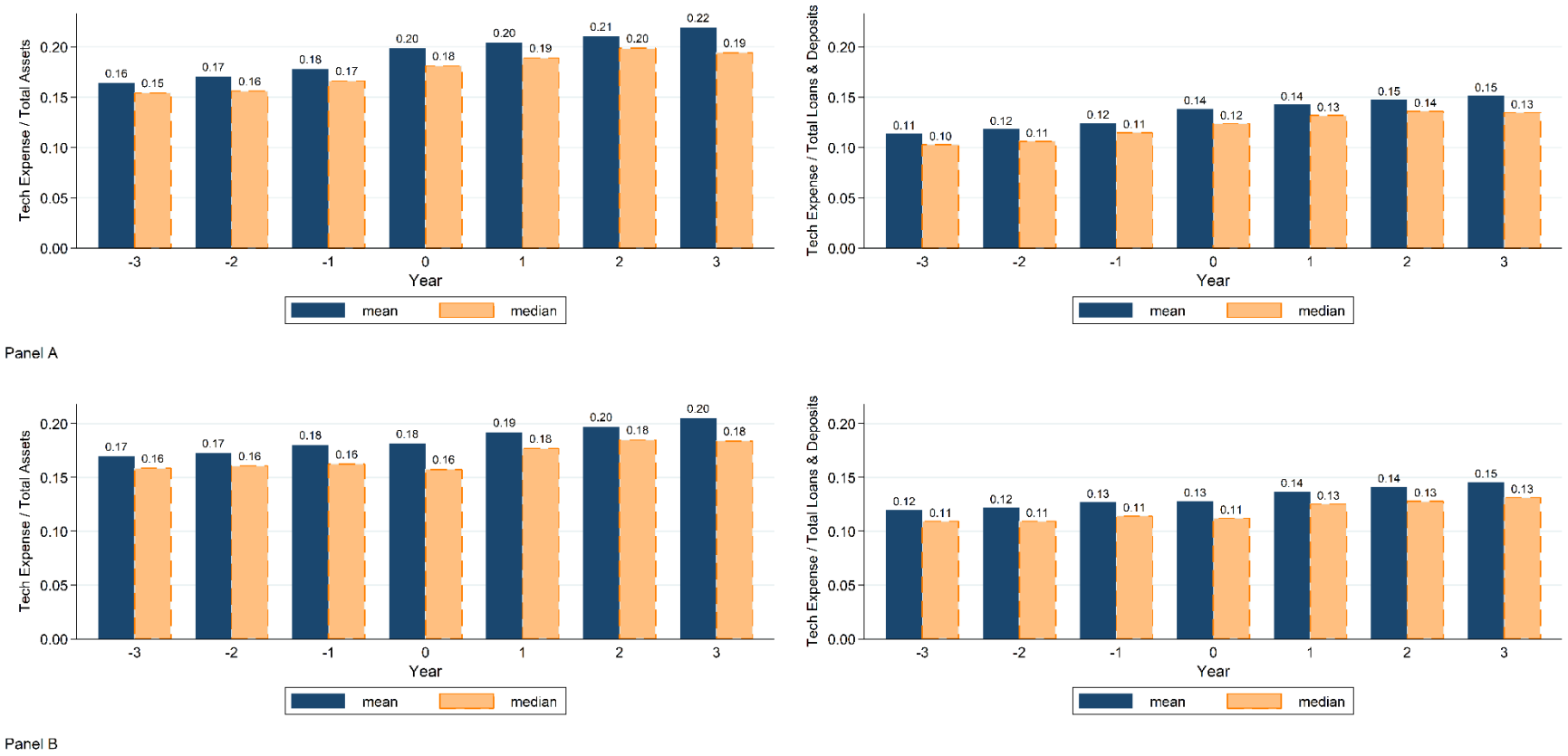

Figure 3. Performance Shock and Technology Investment

This figure illustrates the means and the medians of the bank technology investment measures (Tech Expense/Total Assets, and Tech Expense/Loans & Deposits) before and after three years of the bank performance shock. In Panel A, the performance shock of banks is defined as when Return on Assets becomes negative at a year, while it is positive in the previous year. In Panel B, the performance shock of banks is defined as when Return on Assets in a year becomes two standard deviations less than that in the previous year. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expenses and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

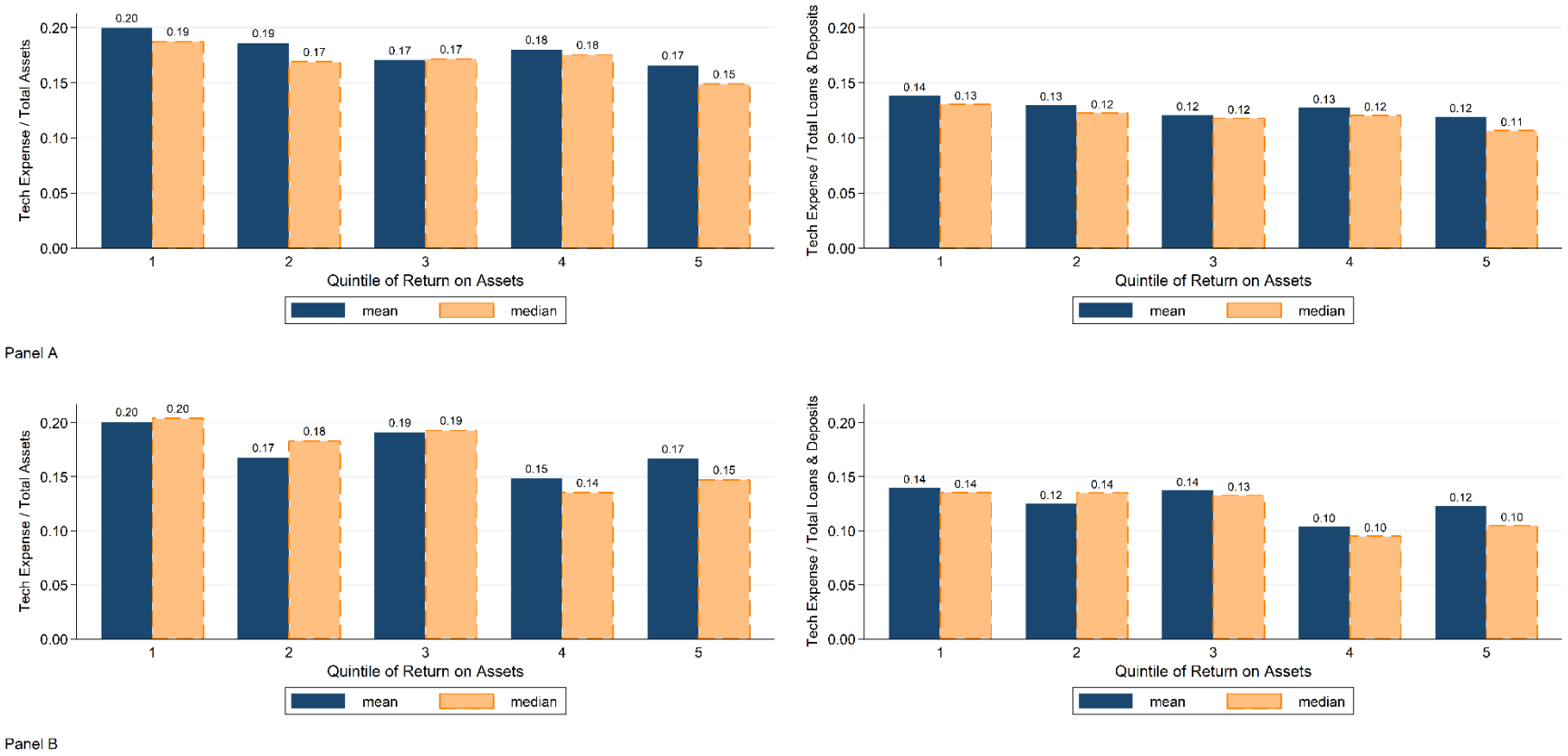

Figure 4. Technology Investment Sorted by Performance

This figure illustrates the means and the medians of technology investment measures (Tech Expense/Total Assets, and Tech Expense/Loans & Deposits) based on the quintiles of their averages of Return on Assets over our sample period. In Panel A, the sample includes banks that have at least five yearly observations of Return on Assets and technology investment measures. In Panel B, the sample includes banks that have all of the consecutive yearly observations of Return on Assets and technology investment measures. All of the variables are defined in Table A1 in the appendix. Since we include the lagged variables in our regressions, we exclude firms with fewer than two consecutive years of technology expense and total assets information. The variables have been winsorized at the 1% and 99% tails of the distributions to avoid the influence of extreme observations.

Appendix

Table A1. Definition of Variables

Variable	Abb.	Definition
Technology and Communication Expense	Technology Expense or Tech Expense	Expenses paid for communications, data processing. and technology including computers, software, information systems, and telecommunications, as defined by S&P Global Market Intelligence (SNL Financial). (SNL keyfield: 132659, tech_comm_exp).
Technology Expense to Total Assets	Tech Expense/Total Assets	Technology and communication expense (SNL keyfield: 132659, tech_comm_exp) scaled by the book value of assets (Compustat: at).
Technology Expense to Loans and Deposits	Tech Expense/Loans & Deposits	Technology and communication expense (SNL keyfield: 132659, tech_comm_exp) scaled by the sum of total loans (Compustat: lntal) and total deposits (Compustat: dptc).
Return on Assets	ROA	Earnings before extraordinary items (Compustat: ib) plus depreciation and amortization (Compustat: dp) divided by the book value of assets (Compustat: at).
Return on Equity	ROE	Earnings before extraordinary items (Compustat: ib) plus depreciation and amortization (Compustat: dp) divided by the book value of equity (Compustat: ceq+txdb). Txdb is set to zero if missing.
Profit Margin	Profit Margin	Earnings before extraordinary items (Compustat: ib) plus depreciation and amortization (Compustat: dp) divided by the sum of interest income (Compustat: niint) and noninterest income (Compustat: tnii).
Asset Turnover	Asset Turnover	The sum of interest income (Compustat: niint) and noninterest income (Compustat: tnii) divided by the book value of assets (Compustat: at).
Market-to-Book Equity Ratio	Market-to-Book	The ratio of the market value of the bank measured as share prices as of the fiscal year-end (Compustat: prcc_f) times common shares outstanding (Compustat: csho) to its book value of equity (Compustat: ceq+txdb). Txdb is set to zero if missing.
Firm Value *Q*	*Q*	The ratio of the market value of the bank measured as share prices as of the fiscal year-end (Compustat: prcc_f) times common shares outstanding (Compustat: csho) plus total assets (Compustat: at) minus the book value of equity (Compustat: ceq+txdb) to its total assets (Compustat: at). Txdb is set to zero if missing.
Market Capitalization	MktCap (Size)	Share prices as of the fiscal year-end (Compustat: prcc_f) times common shares outstanding (Compustat: csho).
Leverage	Leverage	The ratio of total assets (Compustat: at) to the book value of equity (Compustat: ceq+txdb). Txdb is set to zero if missing.
Total Loans/Total Assets	Loans/Assets	The ratio of the banks' total loans (Compustat: lntal) to total assets (Compustat: at).
Total Deposits/Total Assets	Deposits/Assets	The ratio of the banks' total deposits (Compustat: dptc) to total assets (Compustat: at).
Total Deposits/Total Liability	Deposits/Liability	The ratio of the banks' total deposits (Compustat: dptc) to total liabilities (Compustat: lt).
Gross Total Assets	GTA	The sum of total assets (Compustat: at) and provision for loan losses (Compustat: pclc). pclc is set to zero if missing.
Small Banks	Small Banks	Banks whose time-series average GTA are up to $1 billion in 2017 dollars.
Large Banks	Large Banks	Banks whose time-series average GTA exceed $1 billion in 2017 dollars.
Too-big-to-fail banks	TBTF Banks	Banks whose time-series average GTA exceed $50 billion in 2017 dollars.

Table A2. Discussion on Technology and Communication Expense

The technology and communication expense includes expenses paid for communications, such as telephone and fax usage charges, internet data plans, and mobile phone and internet plans, data processing and technology including computers, wire services, modems, routers, and switches, as well as software purchases and subscriptions to cloud-based services. The variable is primarily constructed based on U.S. GAAP Standard FAS No. 86. Some typical examples are as follows:

Bank	Ticker	Technology Expense ($000)	Decomposition		Documents (Sources)
Citigroup	C	$6,581,000	Technology/communication	$6,581,000	12/31/2015 10-K
Bank of America	BAC	$3,938,000	Telecommunications	$823,000	12/31/2015 10-K
			Data processing	$3,115,000	12/31/2015 10-K
First Citizens BancShares, Inc.	FCNCA	$114,896	Tech & Communications Expense	$114,896	Bank Regulatory Filings
			Telecommunications	$14,406	12/31/2015 10-K
Community First Bancorp, Inc.	CMFP	$399	Data processing	$162,616	12/31/2015 10-K
			Telephone	$59,150	12/31/2015 10-K
			Internet banking	$87,643	12/31/2015 10-K
			ATM expenses	$89,771	12/31/2015 10-K
Guaranty Federal Bancshares, Inc.	GFED	$1,171	Data processing	$790,928	12/31/2015 10-K
			Telephone	$141,674	12/31/2015 10-K
			ATM expense	$238,744	12/31/2015 10-K
Home BancShares, Inc.	HOMB	$17,857	Data processing expense	$10,774	12/31/2015 10-K
			Electronic banking expense	$5,166	12/31/2015 10-K
			Telephone	$1,917	12/31/2015 10-K
Pandora Bancshares, Inc.	PDRB	$736	Tech & Communications Expense	$736	Bank Regulatory Filings
			Data Processing	$505	12/31/2015 10-K
Webster Financial Corporation	WBS	$34,639	Tech & Communications Expense	$34,639	Bank Regulatory Filings
First Farmers Financial Corporation	FFMR	$2,303	Tech & Communications Expense	$2,303	Bank Regulatory Filings