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The demise of branch banking – Technology, consolidation, bank fragility ☆

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ABSTRACT

We study bank branching dynamics across 3,143 US counties and 26 years. During the last decade, banks closed their branches at an unprecedented rate. At its peak in 2009, there were 90,783 branches. By 2020, this number has fallen by 12 percent. While technological factors correlate with these branching dynamics, bank fragility and consolidation are also strongly associated with changes in the number of branches (and their openings and closures). Interestingly, technological capabilities to service customers, such as online banking, seem less tightly linked to de-branching than technological capabilities to process internal information. Our analysis shows that large banks rely on internal technology to shed branches, while small banks close branches when they are vulnerable or consolidate.

Banks are closing branches. The de-branching of banks is currently one of the most fundamental changes in the industry, affecting all types of banks and branches. For example, the total number of bank branches in the U.S. has declined by more than one percent each year since 2009, when it peaked at 90,783. In other countries, de-branching started much earlier and progressed even further. Therefore, the recent decline in the U.S. may be part of the ongoing downward trend following the structural break of 2009.

Current academic research still treats bank branches as economically relevant, frequently using branch location to measure geographical proximity or involvement in a market (for example see Allen et al., 2023; Blickle, 2022; Contreras et al., 2023; Erel and Liebersohn, 2022; Granja et al., 2022; Levine et al., 2021; Li and Strahan, 2021, among many others). Branches are proxies for lending relationships, information asymmetries, loan portfolio distributions, and/or exposure to deposit flows. Accordingly, it is surprising that academic research has paid little to no attention to the de-branching of banks, although this phenomenon has received considerable media attention (The Economist, 2019; Financial Times, 2018; Reuters, 2017; Forbes, 2016; Wall Street Journal, 2013). If bank branches remain relevant today, it is crucial to understand their dynamics.

In this study, we attempt to fill this gap in the literature. First, we document the secular de-branching of banks, which has never been done before to the best of our knowledge. We then run regressions to assess and compare the potential relevance of the three main factors that have the potential to drive bank de-branching: technology, bank fragility, and consolidation. In this study, we use a US county panel dataset to explain the net change in the number of bank branches with these drivers. We also explain the decision to close and/or open individual branches using bank-county and branch-level data for the U.S.

Our analysis suggests that no factor has the potential to explain the secular de-branching trend single-handedly. Variables that capture technological developments, such as references to technology in 10-K filings, correlate with concurrent county-level de-branching. Technological variables are also associated with branch closures. Surprisingly, internal use of technology (within the bank to collect, process, and store information) correlates more strongly with de-branching than retail use of technology (for bank customers). The latter is associated with a higher likelihood of opening a branch. In this context less prominently discussed, bank factors such as fragility or consolidation are robustly associated with de-branching. Fragility, as measured by NPLs, by acting as a trigger, can explain the timing of individual bank de-branching. However, no secular decline in stability can be linked to de-branching in the long run. Bank consolidation is robustly and significantly correlated with a decline in branches. This is especially true for acquired target banks and areas where the merging banks' branch networks over-

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Table 1
Framework – theory and empirical work on branch location and clustering.

Theory on bank branch location and clustering					
		Deller and Sundaram-Stukel (2012) Rational			Behavioral
Theory		Hauswald and Marques (2003, 2006); Qi, De Haas, Ongena & Straetmans (2021)			
Conceptual/Empirical Work		De Juan (2003); Qi, De Haas, Ongena & Straetmans (2021)	Brown, Guin and Kirschenmann (2015)		Chang, Chaudhuri and Jayaratne (1997)
		Information Sharing	Retail Demand Depositors Borrowers: firms, households	External Economies of Scale	Groupthink, Empire Building
Our Paper		Bank Internal Technology	Retail Demand Technology	Bank Fragility	Bank Consolidation
Variables	International	High-Speed Internet	Internet Banking Use	Non-performing Loans GDP Growth Rate	Consolidation
	US	High Speed Internet		Non-performing Loans GDP Growth Rate	Consolidation Acquisition Target
		Technology References			
		Internal-Side Technology	Retail-Side Technology		M&A w/Branch Network Overlap

lap. Technology-driven de-branching is more relevant for larger banks, whereas the de-branching of smaller banks occurs when fragility increases and/or there are consolidations. Thus, current technological developments related to de-branching may also be relevant for and interact with competition, fragility, and consolidation in the financial sector.

Regarding the economic magnitude, an increase in technology-related references in a bank's 10-Ks from the 10th to the 90th percentile is associated with an increase in the likelihood that a branch is closed by 29% or 0.95 percentage points. There is no correlation with individual branch openings. An equivalent percentile shift in non-performing loans corresponds to a similar 30% increase in the likelihood of branch closure. However, this also corresponds to a 21% reduction in the likelihood of a bank opening a branch within a county. A branch owned by a merged bank is 21% more likely to close (compared to a branch owned by a bank not recently involved in a merger). This number spikes to 215% when the branch networks overlap and over 120% for the acquisition targets. In summary, these results suggest that technological developments offer only a partial explanation for the loss of bank branches. Controlling for technology, bank fragility and consolidation appears to be an important part of the explanation for overall local de-branching and for individual decisions to close and open branches.

As a point of departure, we consider the conceptual framework provided by Deller and Sundaram-Stukel (2012), which we depict in an included table (Table 1). They distinguish between rational and behavioral motives for closing and/or opening bank branches. As rational motives, they consider pressures from technology and/or economies of scale; for example, branch closures following bank empire building tend to be more behavioral. The current discussion in the media points primarily towards the role of technology in general, and especially towards the Internet and online banking, as the main culprits for this transformation.[1] As customers become more technologically astute, their demand for locally available banking services in branches diminishes, making it less profitable for banks to maintain their brick-and-mortar presence (Brown et al., 2016). For example, in Hauswald and Marquez (2003, 2006), individual banks may decide to locate further away if their enhanced information processing abilities allow them to screen borrowers more carefully.[2] Relatedly, banks may also want to reorganize their branch networks to optimize the usage and further development of technological innovations (Knott and Turner, 2019). Bank de-branching could also potentially lead to increased reliance on Internet banking rather than vice versa. It is also conceivable that the emergence of FinTech lenders and related practices in mortgage, consumer, and small business lending more recently (Buchak et al., 2018; Fuster et al., 2019; Balyuk et al., 2020) has fueled the de-branching of banks more than "older" adoption of digital IT systems.

A wholly unrelated explanation is that adverse economic and financial conditions may affect certain regions and banks, making branches too unprofitable or expensive to maintain (Morgan et al., 2016). This might also be a thwarting factor for de-branching if fragile banks have difficulty keeping their depositor base intact and need to maintain their current brick-and-mortar footprint (for example, Iyer et al., 2019).

Finally, implied by work suggesting that bank consolidation plays a key role in explaining branch closures, as mergers and acquisitions allow combined institutions to streamline previously overlapping branch networks (for example, DeLong, 2001; Degryse and Ongena, 2004; Nguyen, 2019). Given the lack of empirical research in this area, the question of whether and how these three basic factors influence branching dynamics in general and de-branching in particular remains unanswered.

Assessing the reasons for de-branching is particularly important given the variety of organizational and business models in the banking sector. From the economic theory perspective, branches are also important. For example, the banks in Stein (2002) can be decentralized, in which case local branches collect and process soft information and lend locally collected deposits to local businesses that maintain strong relationships with them. Alternatively, banks may be centralized. In this case, local branches collect hard information and transmit it to headquarters. Lending may occur in a different location than where deposits are collected on a more transactional basis.[3] While not synonymous, bank size is often found to go hand-in-hand with organizational and business models, with large banks, for example, being more centralized in their organizations and transactional in their business dealings

[1] On September 17, the Financial Times reported that "Handelsbanken, a leading advocate in Europe for the importance of maintaining bank branches, has conceded defeat to the rise of online banking and is to close almost half its branches in Sweden by the end of next year" (Deller and Sundaram-Stukel, 2012, p. 8).

[2] A broader but reasonable interpretation is also that banks then need fewer branches. In Hauswald and Marquez (2003, 2006) the decision to locate on the Salop (1979) circle, is made in the first stage, considering the setting of loan terms in the second stage (see also Bouckaert and Degryse (1995); Dell'Ariccia (2001)).

[3] On soft versus hard information see Liberti and Petersen (2019).

(Berger et al., 2005). Decisions regarding branch closures and openings are driven by different factors in these opposite cases. For a small, decentralized bank, given its reliance on soft information and relationships with customers, technology may play less of a role, whereas for a large, centralized bank with a transactional business model, its internal information processing technology will uniquely shape its geographical market position (Hauswald and Marquez, 2003). On the other hand, a decentralized and small bank that is in distress or is being acquired may be forced to close its less profitable "stand-alone" branches, while online banking demanded by depositors may redirect some of its branch opening decisions.

This study contributes to the literature on branching decisions. Several studies show that the expansion of bank branches across the U.S. in the late 1990s and the early 2000s was driven by episodes of inter- and intra-state banking and bank branching deregulation (Berger et al., 1995; Jayaratne and Strahan, 1998; Johnson and Rice, 2008; Rice and Strahan, 2010; Keil and Müller, 2020). Other studies show how distance, in general, and information sharing between banks may affect branch openings (De Juan, 2003; Qi et al., 2019). Our work adds to these studies by analyzing the more recent dramatic reversal of this trend.

Our study also relates to research on the effects of bank branch presence and closure. Other authors have shown that branches can be a vehicle for competition and diversification in the banking industry (Deng and Elyasiani, 2008; Puri and Rocholl, 2008; Carlson and Mitchener, 2009; Rice and Strahan, 2010; Jiménez et al., 2013; Goetz et al., 2013, 2016), which drives financial integration, access to finance, and the economic performance of local economies (Puri and Rocholl, 2008; Rice and Strahan, 2010; Acharya et al., 2011; Gilje et al., 2016; Celerier and Matray, 2019). In addition to the obvious direct effects of reducing financial sector employment, branch closures reduce lending and credit availability in exposed areas, adversely affecting borrowers, interest rates, and other loan terms (Degryse et al., 2011; Bonfim et al., 2020; Nguyen, 2019). Based on this literature, we consider branches to be economically important. Although we do not attempt to confirm these already documented effects or explain additional impacts of de-branching, we contribute to the literature by examining the factors that may influence recent decisions to close branches.

Our study also contributes to the rapidly growing empirical literature on the impact of technology on the provision of banking services (e.g. Buchak et al., 2018; Fuster et al., 2019). While most work studies the effects of the emergence of new FinTech companies, what is different here is that we focus on the differential impact on bank branch presence of both bank internal processing technology and external online banking technology.

The main caveat is that no natural or randomized controlled trials can be used. Therefore, we can neither detect causal effects, nor rule out possible reverse causality. Therefore, the results should be interpreted with caution. However, as with some macroeconomic analyses, we believe that our setting with a sample covering all branches in the U.S. over an extended period of time is particularly useful in achieving our specific research objective. The lack of comparability associated with different settings is too great a drawback of experimental settings, and we are primarily interested in comparing the relative potentials of different possible drivers in the same setting, in the same sample, and over the same time period. Although our study is exploratory, we seek to compare the potential for causal effects and the relative importance of the three main drivers of de-branching via regression analysis. We address some of these concerns, albeit partially and imperfectly, by using lagged independent variables, a wide range of controls, different fixed effects specifications, and internal instruments in auxiliary regressions.

In the remainder of this paper, we discuss explanations and develop hypotheses (Section 1), describe the data and analysis (2 and 3), and present the results (4) and (5).

1. Hypotheses development

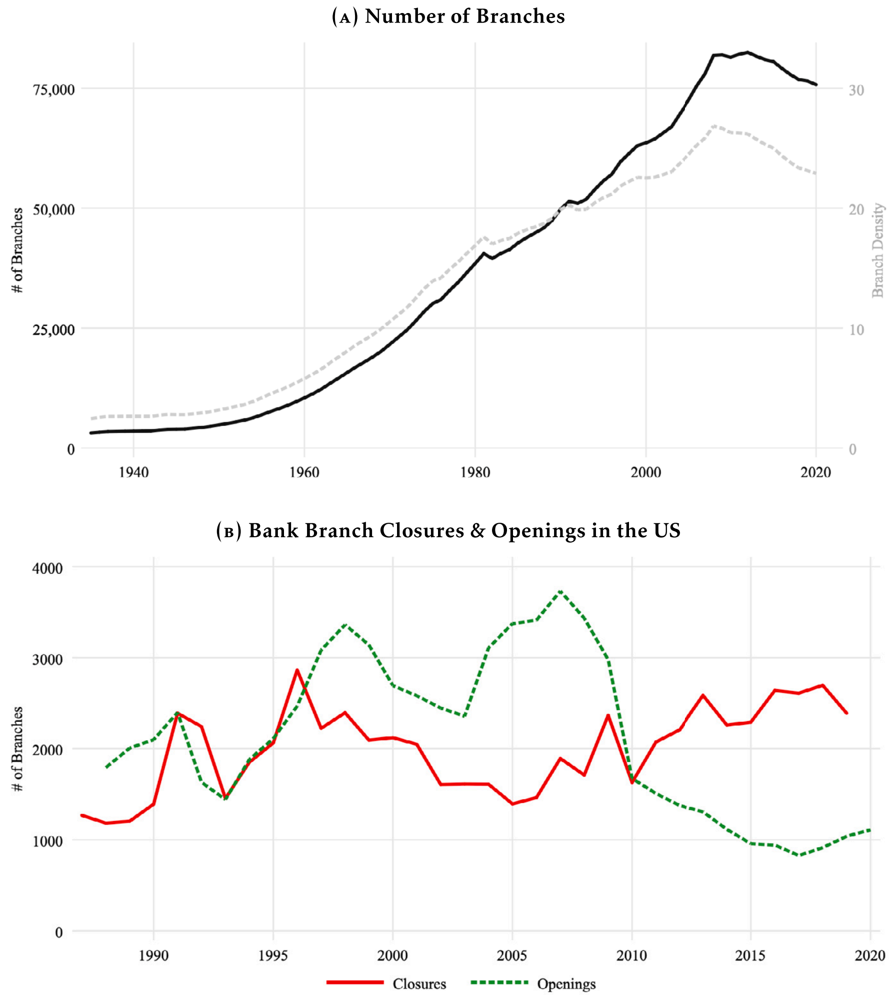
The most frequently discussed explanation for the de-branching of banks is **technology** (Berger, 2003). Since the late 1990s, academic work has focused primarily on internal applications such as emerging IT and scoring systems. Theoretically, these systems formalize and automate lending to households and small companies, diminishing the value of geographical proximity and local branch presence (Kroszner and Strahan, 1999; Berger and DeYoung, 2001; Petersen and Rajan, 2002; Berger and DeYoung, 2006). However, the explanation for the de-branching of banks most often discussed in the media has a very different, technology-based nuance, namely the rise of online and mobile banking. These retail banking services are being used by an increasing number of technologically savvy customers for whom bank branches have become largely redundant, at least when it comes to day-to-day financial needs (Cisternas-Vera et al., 2016). Traditional banks have increasingly adopted newer financial technologies, whereas new non-bank FinTech lenders have emerged and gained a significant market share in mortgage lending, other consumer-related areas, and small business lending (Buchak et al., 2018; Fuster et al., 2019; Balyuk et al., 2020). It may be that the more recent shift towards FinTech lending, instead of the introduction of IT, fueled the de-branching of banks. In the big picture, Internet connections and references to technology in banks' 10-K filings have grown secularly in the U.S. since 2009 and 1994, respectively (see Fig. A.4 in the Appendix). The corresponding hypotheses are that the most important factor in de-branching is the general use of technology or the specific implementation of either (a) internal technology under the hood, (b) trade-related technology, (c) general customer access to technology, (d) own implementation of technological innovations, or (e) the more recent emergence of FinTech credit.

One advantage of our analysis and text mining of 10-Ks is that we can gain information about both the use of technology in banking in terms of internal applications as well as retail banking. We can also differentiate between "new" technologies used by FinTechs over a more recent period and "older" technologies that emerged already in the 90s. At the county level, we have data on access to high-speed Internet, which is a more general proxy for access to technology (which is also likely to be available for banks). At the bank level, we have references to technology in the 10-Ks used in our baseline estimates.

As another potential driver, Traversa and Vuillemey (2019) have found that exogenous net-worth shocks are associated with bank downsizing. Bank **fragility** spiking during and in the aftermath of the financial crisis might have been a potential driver of de-branching in the US, coinciding with the starting point of de-branching (see Fig. A.5 in the Appendix and Fig. 1). Bank fragility and weak local economic conditions will drive branch closures when management closes the least profitable branches to cut costs. However, the academic literature has rarely assessed this possible driver of bank branch closures.

However, several authors point to another possible alternative explanation for branch networks **consolidation** after mergers and acquisitions (M&As), especially in areas with branch network overlap (DeYoung et al., 1999; Degryse and Ongena, 2004; DeYoung et al., 2009; Nguyen, 2019). With the 2008 financial crisis, such mergers increased in frequency, and there was already a secular long-term trend of consolidation in the banking industry (Fig. A.6 in the Appendix illustrates this). Investors have long suspected that branch network overlaps and subsequent branch closures are avenues for creating shareholder value. DeLong (2001) reports that in the U.S., only the combined cumulative abnormal returns of acquirer and target stocks of geographically focused bank M&As (possibly with branch overlap) are positive around the public announcement of the bank merger.[4] The corresponding hy-

[4] Our M&A target indicator circumvents the feature of our regular M&A variable that many branches are coded as being involved in M&A whenever a large bank acquires a smaller one.



In Panel A, the solid black line (dashed gray line) represents the number bank branches (the corresponding branch density per 100,000 inhabitants). Data comes from FDIC "Historical Bank Data" and excludes savings and uninsured commercial banks. In Panel B, the red solid (light green short dashed) line represents the number of bank branches closed (opened) in a year. Opening is defined as the first time appearance of a bank branch location in the data since 1987.

Fig. 1. Bank branches in the US.

potheses are that either a) bank fragility or b) bank consolidation is the most important factor in the de-branching of banks.

Note that our hypotheses are *not* mutually exclusive. However, they represent alternative explanations, and it is possible that a single individual or a combination of different factors has explanatory power for the de-branching of the banks.

2. Data

We analyze county, branch, and bank district level data from the U.S. The bank county panel that we access (to analyze decisions to open new branches) includes all counties in the states where a bank has at least one branch.

Summary of Deposit data files from 1987–1993 and 1994–2020 come from two different Federal Deposit Insurance Corporation (FDIC) websites. This is our source of information on the branch and bank characteristics. We access all bank branches appearing in their files between 1987 and 2020 (data availability for other variables prevents us from studying any year before 1994 in the regressions). The unique branch location identifier variable used for the branch panel in this study (UNINUMBR) tracks branches and their locations during ownership changes. We analyze all branches in the FDIC Summary of Deposit data, including thrift and savings institutions. Branch closure is defined as the termination of the UNINUMBR series. We exclude observations for which identifiers are missing (in some years for savings and loan institutions). We chose not to include credit unions in the analysis because many firms operate only a headquarters with no branches and only partial National Credit Union Administration data are available.

Call Reports data come from the Federal Reserve Bank of Chicago, for years before 2011 and from original raw files available at the FFIEC. This is the most important source of banks' accounting data. Since Summary of Deposits data are available only on June 30 every year, we use Call Reports from the second quarter of each year to align both datasets. Profit and loss accounting data represent the sum of the second quarter of each year plus the preceding three quarters. Some banks report under the RCFD (foreign and domestic operations) series, and others under the RCON (domestic operations) series. These are identical for banks without foreign operations. We use the RCON series where it is available and the RCFD series in a small number of cases in which this RCON variable is missing. Non-performing loans are the sum of nonaccrual loans (item 1403) and loans past due 90 days or more that still accrue (item 1407). Before 2016, FFIEC files do not include this aggregate. It needs to be computed from its components as described in "Schedule RC-N" of reporting forms 041 for institutions with only domestic and 031 for institutions with domestic and foreign operations (computations do differ).

Our source for information on bank mergers is the Transformations Table in the Federal Reserve Bank's National Information Center's Financial Statements for Bank Holding Companies. County data are from the Geographical Comparison Tables of the U.S. Census and the Re-

Table 2
County-level descriptive statistics (explaining %-changes).

Variable	N	Years	Countries	10th Perc.	Median	90th Perc.	Mean	SD
Net Change in Branch #s	58,478	26	2,744	-.059	0	.059	.001	.06
Net Change in Branch Density	58,471	26	2,743	-.059	-.002	.05	-.003	.056
Technology References	58,478	26	2,744	2.152	6.038	13.079	6.976	4.451
High-Speed Internet Access	25,553	11	2,554	20	40	50	35.647	8.732
Retail-Side Technology	58,478	26	2,744	0	1.935	3.69	1.923	1.566
Internal-Side Technology	58,478	26	2,744	0	1.193	3.11	1.492	1.317
Old Technology	58,478	26	2,744	1.541	4.973	8.678	5.214	3.121
FinTech/New Technology	58,478	26	2,744	0	0	.308	.096	.219
Non-performing Loans	58,478	26	2,744	.004	.01	.031	.014	.013
VA Growth	58,471	26	2,743	0	.041	.082	.041	.037
M&A	58,478	26	2,744	0	.273	.6	.299	.226
Branch Density	58,478	26	2,744	22	36	64	41	19
Population Density	58,478	26	2,744	11	61	406	185	379
GDP per Capita	58,478	26	2,744	20	30	46	32	11
County HHI	58,478	26	2,744	.122	.224	.456	.263	.151
Out-of-state Bank Market Share	58,478	26	2,744	0	.172	.626	.244	.25
IBBEA Deregulation	58,478	26	2,744	0	1	1	.813	.39

This table contains summary statistics for county-level regressions. Observations are the ones used in regression 1 in Table 5. See Tables A.1–A.2 for the details on the definition of variables.

gional Economic Accounts of the Bureau of Economic Analysis. For county-level high-speed residential Internet connections, we use an index from the Federal Communications Commission, ranging from 0 (zero-connected households) and 1 (less than 20%) to 5 (more than 80%).

A noteworthy contribution is the **novel dataset** we created for US bank-level measures of exposure to and awareness of technology. Its source is the full body of natural written language contained in 10-K filings for all US banks available since 1994, which is the earliest year in which machine-readable filings can be obtained via the US Securities and Exchange Commission's (SEC) online system EDGAR. After scraping and parsing, we counted the frequency of words or phrases of interest and weighted them by the total number of sentences to obtain bank-level measures for the relevance of technology (robust to filing size). This approach produces the variables of interest for our baseline regressions in Table 5, for which we count technology-related references. We further relied on this approach for regressions where we differentiate between internally used under-the-hood technology and retail-related technology in Table 7 or between FinTech or "new" technologies such as machine learning and between "old" but still digital technologies, such as general information technology (Appendix Table 6). We fuzzy-matched these text-mined variables to banks in our FDIC data sample using an algorithm largely identical to that used in Beck and Keil (2021) and hand-checked the results. Additional details on the main categories of terms are provided in the Appendix.

To provide a comprehensive picture, all variables used in this study are expressed as dummies, logarithms, or winsorized at the 1st and 99th percentiles. We use one-year lags for all the independent variables. Summary statistics are in Tables 2, 3, and 4. See Table A.2 in the Appendix for a description of all variables.

3. Analysis

In our first analysis, we rely on a US county panel estimating equation:

$$\begin{aligned}\%\Delta\text{Branches}_{c,y} =& \beta_1 \text{Tech}_{c,y-1} + \beta_2 \text{NPL}_{c,y-1} + \beta_3 \text{M\&A}_{c,y-1} \\ &+ \gamma \boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}.\end{aligned} \quad (1)$$

The subscripts c and y indicate counties and years, respectively. The dependent variable is the percentage of net change in the number of branches in a county (alternatively, we use the percentage change in branch density in the Appendix). We allow the clustering of error terms $\epsilon_{c,y}$ at the county level, on which our independent variables of interest are defined. Our regressions with the highest fixed effects dimensionality absorb the time-invariant county (η_c) and general year-specific effects (δ_y). We include time-variant lagged county controls in $\boldsymbol{X}_{c,y-1}$.

In the second analysis, we explain branch closure using the following equation:

$$\begin{aligned}\text{Closure}_{i,y} =& \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} \\ &+ \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \gamma_4 \boldsymbol{Z}_{i,y-1} \\ &+ \theta_c + \eta_b + \delta_y + \epsilon_{i,y}.\end{aligned} \quad (2)$$

Subscripts i, b, c, and y indicate branch, bank, county, and year levels, respectively. The dependent variable is a branch closure dummy that equals one if a branch disappears (zero otherwise). We cluster the error terms $\epsilon_{i,y}$ at the bank level, where we define the independent variables of interest. Our regressions with the highest fixed effects dimensionality absorb time-invariant bank-, county-, and general year-specific effects (η_b, θ_c, and δ_y). The time-variant lagged county, bank, bank-county, and branch controls are included in $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$.

We analyze branch openings in a bank-county-year panel, estimating the following equation:

$$\begin{aligned}\text{Opening}_{b,c,y} =& \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} \\ &+ \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}.\end{aligned} \quad (3)$$

This is the most granular structure for analyzing bank entry. The dependent variable is a dummy variable that equals one if the bank opened at least one branch in the county in a given year (and zero otherwise). The panel includes all bank-counties in states where a bank has at least one branch. There are no control variables at the branch level. All the subscripts, other control variables, and fixed effects are equivalent to Equation (2).

A fundamental concern may be that some of our results are due to regulatory differences: The expansionary dynamics created by the deregulation of interstate branching may have acted as a restraining factor and expired in the late 2000s. Accordingly, we address this concern by controlling for deregulation following the Interstate Bank Branching Efficiency Act, using a dummy variable if a state lifts at least one restriction, as in (Koetter et al., 2012; Chava et al., 2013; D'Acunto et al., 2018; Keil and Müller, 2020). All the control variables are listed in Tables A.1–A.2.

While we cannot eliminate endogeneity concerns, we at least partially and imperfectly address them with lagged independent variables, a very broad set of lagged control variables in our micro-level regressions, three different fixed effect specifications, and internal instru-

Table 3
Branch-level descriptive statistics (explaining closures).

Variable	N	Years	Branches	10th Perc.	Median	90th Perc.	Mean	SD
Branch Closure	691,717	26	84,494	0	0	0	.033	.178
Technology References	691,717	26	84,494	2.49	6.59	15.29	7.73	5.08
High-Speed Internet Access	467,572	11	67,159	30	40	50	42.59	7.08
Retail-Side Technology	691,717	26	84,494	0	1.93	3.87	2.16	1.77
Internal-Side Technology	691,717	26	84,494	0	1.27	3.67	1.59	1.61
Old Technology	691,717	26	84,494	1.9	4.8	9.4	5.4	3.46
FinTech/New Technology	691,717	26	84,494	0	0	.5	.161	.366
Non-performing Loans	691,717	26	84,494	.004	.012	.046	.019	.019
VA Growth	691,710	26	84,493	.009	.043	.077	.043	.029
M&A	691,717	26	84,494	0	0	1	.393	.488
Acquisition Target	691,717	26	84,494	0	0	0	.057	.231
M&A with Overlap	691,717	26	84,494	0	0	0	.014	.115
Branch Density	691,717	26	84,494	19.09	30.7	45.56	31.93	11.45
Population Density	691,717	26	84,494	54	461	2,617	1,306	3,105
GDP per Capita	691,717	26	84,494	25.74	41.77	65.13	44.16	15.9
County HHI	691,717	26	84,494	.093	.148	.301	.179	.101
Out-of-state Bank Market Share	691,717	26	84,494	.028	.457	.807	.438	.278
IBBEA Deregulation	691,717	26	84,494	1	1	1	.929	.258
Real Asset	691,717	26	84,494	906	23,190	1,772,655	433,747	719,953
Deposits/Assets	691,717	26	84,494	.61	.756	.851	.739	.103
Fee Income/Total Income	691,717	26	84,494	.048	.112	.206	.122	.065
C&I Loans/Assets	691,717	26	84,494	.139	.307	.454	.303	.124
Branches	691,717	26	84,494	15	237	5,603	1,593	2,181
Diversification HHI	691,717	26	84,494	.036	.113	.573	.21	.239
Savings Bank	691,717	26	84,494	0	0	0	.042	.2
Out-of-state Bank	691,717	26	84,494	0	0	1	.486	.5
Bank's Market Share in County	691,717	26	84,494	.012	.102	.307	.137	.128
Bank-County's Share in Bank	691,717	26	84,494	.001	.027	.602	.153	.262
Real Deposits	691,717	26	84,494	8,506	43,081	140,290	66,839	81,700
Branch-Headquarter Distance	691,717	26	84,494	6.73	134.11	1,450.88	399.69	593.67
Full Service Non-Brick & Mortar	691,717	26	84,494	0	0	0	.055	.228
Limited Service	691,717	26	84,494	0	0	0	.037	.188
De Novo Branch	691,717	26	84,494	0	0	1	.358	.479
Branch Age	691,717	26	84,494	2	9	24	12.31	15.1

This table contains summary statistics for branch-level regressions. Observations are the ones used in regression 1 in Table 5. See Tables A.1–A.2 for the details on the definition of variables. Total assets and deposits are expressed in millions of USD.

Table 4
Bank-county-level descriptive statistics (explaining openings).

Variable	N	Years	Bank-Counties	10th Perc.	Median	90th Perc.	Mean	SD
Branch Opening	1,559,597	26	256,023	0	0	0	.003	.052
Technology References	1,559,597	26	256,023	1.82	6.17	15.67	7.66	5.89
High-Speed Internet Access	812,060	11	139,992	20	40	50	35.51	8.79
Retail-Side Technology	1,559,597	26	256,023	0	1.79	4.72	2.28	2.41
Internal-Side Technology	1,559,597	26	256,023	0	1.19	3.75	1.74	2.23
Old Technology	1,559,597	26	256,023	1.21	4.79	11.17	5.88	4.94
FinTech/New Technology	1,559,597	26	256,023	0	0	.371	.112	.335
Non-performing Loans	1,559,597	26	256,023	.002	.009	.035	.015	.017
VA Growth	1,559,428	26	255,997	-.002	.039	.079	.039	.038
M&A	1,559,597	26	256,023	0	0	1	.261	.439
Branch Density	1,559,597	26	256,023	21.1	36.41	65.39	40.95	20.54
Population Density	1,559,597	26	256,023	13	62	441	195	402
GDP per Capita	1,559,597	26	256,023	20.77	31.63	46.85	33.1	10.65
County HHI	1,559,597	26	256,023	.122	.235	.514	.286	.181
Out-of-state Bank Market Share	1,559,597	26	256,023	0	.152	.613	.231	.25
IBBEA Deregulation	1,559,597	26	256,023	0	1	1	.889	.314
Real Asset	1,559,597	26	256,023	298	1,476	98,045	83,826	335,158
Deposits/Assets	1,559,597	26	256,023	.675	.801	.879	.782	.097
Fee Income/Total Income	1,559,597	26	256,023	.036	.096	.206	.111	.071
C&I Loans/Assets	1,559,597	26	256,023	.102	.212	.407	.24	.132
Branches	1,559,597	26	256,023	5	21	491	346	1,086
Diversification HHI	1,559,597	26	256,023	.056	.356	.989	.418	.314
Savings Bank	1,559,597	26	256,023	0	0	0	.04	.196
Out-of-state Bank	1,559,597	26	256,023	0	0	1	.352	.478
Bank's Market Share in County	1,559,597	26	256,023	0	0	0	.011	.052
Bank-County's Share in Bank	1,559,597	26	256,023	0	0	0	.009	.068

This table contains summary statistics for bank-county-level branch opening regressions. Observations are the ones used in regression 4 in Table 5. See Tables A.1–A.2 for the details on the definition of variables. Total assets and deposits are expressed in millions of USD.

Table 5
De-branching in the US.

Dependent Variable: Unit of Analysis:	Net % Change in Branch # Country-Year			Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-US County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Technology References	-0.003	-0.082***	0.007	0.074***	0.102***	0.030	0.001	-0.003	0.000
	(0.782)	(0.000)	(0.546)	(0.004)	(0.000)	(0.243)	(0.465)	(0.121)	(0.938)
Non-performing Loans	-0.363***	-0.302***	-0.207***	0.253**	-0.000	0.233**	-0.021**	-0.025***	-0.019***
	(0.000)	(0.000)	(0.001)	(0.036)	(0.998)	(0.048)	(0.012)	(0.000)	(0.007)
Merger/Acquisition	-0.013***	-0.001	-0.008***	0.009***	0.006***	0.007***	0.001***	0.001***	0.001***
	(0.000)	(0.767)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)
Controls									
County	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank				Yes	Yes	Yes	Yes	Yes	Yes
Bank-County				Yes	Yes	Yes	Yes	Yes	Yes
Branch				Yes	Yes	Yes			
Fixed Effects									
County		Yes	Yes		Yes	Yes		Yes	Yes
Bank					Yes	Yes		Yes	Yes
Year	Yes		Yes	Yes		Yes	Yes		Yes
Observations	58,506	58,453	58,453	685,794	685,547	685,547	1,559,597	1,559,595	1,559,595

Regressions 1–3 explain percentage-net-changes in a county's number of branches in a county-year panel via equation

$$\%\Delta\text{Branches}_{c,y} = \beta_1 \text{Tech}_{c,y-1} + \beta_2 \text{NPL}_{c,y-1} + \beta_3 \text{M\&A}_{c,y-1} + \gamma \boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}$$

Regressions 4–6 explain closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \gamma_4 \boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

Regressions 7–9 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Fixed effects in these equations correspond to Columns 3, 6, and 9. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by state (bank) in Columns 1–3 (4–9). ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

ments in auxiliary regressions where we instrument the lagged independent variables of interest with their prior values.

4. Results

Before discussing the regression results, we provide some descriptive insights. Panel A of Fig. 1 illustrates that the number of branches of insured commercial banks in the U.S. has grown steadily since 1929. This trend accelerated in the 1990s because interstate branching restrictions were lifted following the passage of the Riegle-Neal Interstate Branching and Banking Efficiency Act in 1994 (Berger et al., 1995; Jayaratne and Strahan, 1998; Johnson and Rice, 2008; Rice and Strahan, 2010; Keil and Müller, 2020). This expansionary trend broke out in 2009 in terms of absolute numbers and branch densities. Since then, the decline has been more severe than ever. Insured commercial banks have lost a net 6,755 branches compared to the peak of 82,461 branches in 2012, and there have been fewer branches in each successive year. When uninsured banks and savings institutions are added, the loss increases to 11,158 branches compared with the 2009 peak of 90,783 branches.[5]

To complement our micro-level regression analyses, we distinguish the two potential drivers behind the net decline in the number of branches by distinguishing between closures and openings (see panel B in Fig. 1). While closures declined slightly between 1995 and 2005, they began to increase slowly but steadily. Interestingly, however, most "action" comes from a dramatic decline in branch openings since 2009, reaching a historically low rate in 2011 and remaining depressed ever since.

As a supplement to our county-level regressions, we illustrate in Fig. 2 that there is substantial geographical variation in how fast branches decline in the U.S. De-branching is driven by around 60 percent of counties. Since 2009, about 40 percent of all counties have lost more than 15 percent of their branches. Coastal regions were generally more affected than the central U.S. Unexpectedly, however, 36% of all US counties did not see any decline. The number of branches increases in approximately 10 percent of counties. In Texas, for example, 82% of counties saw no decline and 37% experienced growth in the number of branches.

In the Appendix, we provide more details by plotting all 2009 branches that were either sustained, closed, or opened by 2019 (Fig. A.3) and plotting timelines for the number of branches by state (Fig. A.2). The latter shows that all states have experienced losses since 2009, and timelines look remarkably similar to the national aggregate trend.

4.1. Technology, fragility, and consolidation

In this section, we present our baseline regression results by comparing technology, bank fragility, and consolidation as independent

[5] In Fig. A.1 in the Appendix we illustrate that all major types of branches are contracting. Even trends in mobile and seasonal branch numbers and limited-service drive-through branches point downwards.

Table 6
Internet access vs technology references.

Dependent Variable: Unit of Analysis:	Net % Change in Branch # Country-Year			Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-US County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Technology References	-0.019*	-0.136***	-0.040*	0.102***	0.162***	0.091**	0.002	-0.000	0.001
	(0.081)	(0.000)	(0.069)	(0.001)	(0.000)	(0.029)	(0.212)	(0.887)	(0.802)
High Speed Internet Access	-0.000	-0.002*	0.002**	-0.000	0.002**	0.000	-0.000***	-0.000	-0.000
	(0.871)	(0.061)	(0.049)	(0.662)	(0.026)	(0.662)	(0.005)	(0.233)	(0.449)
Controls									
NPL & M&A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank				Yes	Yes	Yes	Yes	Yes	Yes
Bank-County				Yes	Yes	Yes	Yes	Yes	Yes
Branch				Yes	Yes	Yes			
Fixed Effects									
County		Yes	Yes		Yes	Yes		Yes	Yes
Bank					Yes	Yes		Yes	Yes
Year	Yes		Yes	Yes		Yes	Yes		Yes
Observations	25,570	25,532	25,532	462,490	462,436	462,436	812,060	812,059	812,059

Regressions 1–3 explain percentage-net-changes in a county's number of branches in a county-year panel via equation

$$\%\Delta\text{Branches}_{c,y} = \beta_1\text{Tech1}_{c,y-1} + \beta_2\text{Tech2}_{c,y-1} + \beta_3\text{NPL}_{c,y-1} + \beta_4\text{M\&A}_{c,y-1} + \gamma\boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}$$

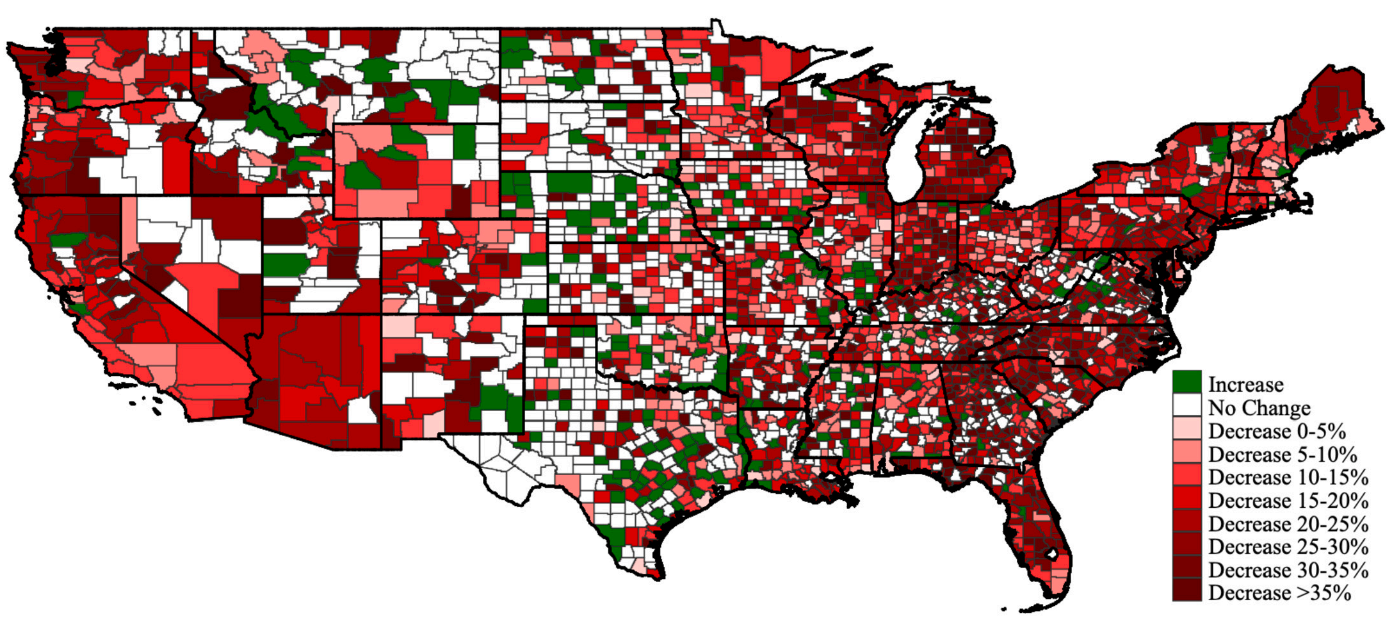
Regressions 4–6 explain closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1\text{Tech1}_{b,y-1} + \beta_2\text{Tech2}_{b,y-1} + \beta_3\text{NPL}_{b,y-1} + \beta_4\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \gamma_4\boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

Regressions 7–9 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1\text{Tech1}_{b,y-1} + \beta_2\text{Tech2}_{b,y-1} + \beta_3\text{NPL}_{b,y-1} + \beta_4\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Fixed effects in these equations correspond to Columns 3, 6, and 9. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by state (bank) in Columns 1–3 (4–9). ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.



This figure plots the percentage change in the number of bank branches by county in the U.S. from 2009 to 2020.

Fig. 2. Changes in the number of bank branches since 2009, by US county.

Table 7
Retail vs internal technology references.

Dependent Variable: Unit of Analysis:	Net % Change in Branch # Country-Year			Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-US County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Retail-Side Technology	0.068**	0.236***	0.050	-0.012	0.017	0.064	0.005	0.008**	0.003
	(0.016)	(0.000)	(0.203)	(0.829)	(0.762)	(0.271)	(0.387)	(0.037)	(0.562)
Internal-Side Technology	-0.019	-0.123***	0.061	0.207***	0.123	-0.054	-0.007	-0.011***	-0.007
	(0.660)	(0.009)	(0.121)	(0.004)	(0.106)	(0.500)	(0.106)	(0.006)	(0.113)
Controls									
NPL & M&A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank				Yes	Yes	Yes	Yes	Yes	Yes
Bank-County				Yes	Yes	Yes	Yes	Yes	Yes
Branch				Yes	Yes	Yes			
Fixed Effects									
County		Yes	Yes		Yes	Yes		Yes	Yes
Bank					Yes	Yes		Yes	Yes
Year	Yes		Yes	Yes		Yes	Yes		Yes
Observations	58,506	58,453	58,453	685,794	685,547	685,547	1,559,597	1,559,596	1,559,596

Regressions 1–3 explain percentage-net-changes in a county's number of branches in a county-year panel via equation

$$\%\Delta \text{Branches}_{c,y} = \beta_1 \text{Tech1}_{c,y-1} + \beta_2 \text{Tech2}_{c,y-1} + \beta_3 \text{NPL}_{c,y-1} + \beta_4 \text{M\&A}_{c,y-1} + \gamma \boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}$$

Regressions 4–6 explain closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1 \text{Tech1}_{b,y-1} + \beta_2 \text{Tech2}_{b,y-1} + \beta_3 \text{NPL}_{b,y-1} + \beta_4 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \gamma_4 \boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

Regressions 7–9 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1 \text{Tech1}_{b,y-1} + \beta_2 \text{Tech2}_{b,y-1} + \beta_3 \text{NPL}_{b,y-1} + \beta_4 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Fixed effects in these equations correspond to Columns 3, 6, and 9. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by state (bank) in Columns 1–3 (4–9). ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

variables of interest.[6] These variables are defined at the bank level. In the county regressions, we compute the corresponding branch-number-weighted county average. To the dependent variables at the top of the table we add a description indicating the panel used. In the bottom section of the table we describe control groups and fixed effects. The saturation and completeness of specifications increase from the first to the third model. The results are presented in Table 5. Columns 1–3 explain the net annual percentage change in the number of bank branches in a county (in a county-year panel). Columns 4–6 explain the dummy which equals one if a branch disappears and zero if it does not (in a branch-year panel). Columns 7–9 explain the dummy that equals one if the bank opened at least one new branch in the county in that year (in a branch-county-year panel). Micro-level regressions allow for the inclusion of more controls and fixed effects.

Although the regression specifications we use are intended to represent the impact of the independent variable on bank de-branching *ceteris paribus* at various levels, we cannot exclude the possibility that de-branching may contemporaneously impact technology, thereby creating an endogeneity bias in the estimates. While we think that this is less likely to occur, for example, for our measure of high-speed Internet access for individual bank outcomes, we cannot exclude the possibility that both variables can be affected by a common factor that we do not adequately control for, despite the comprehensive sets of fixed effects, covariates, and lags for the independent variables. It may also be that de-branching increases reliance on Internet banking rather than vice versa. In any case, we want to be clear in that we cannot claim that for all independent and dependent variables and all units of analysis, the estimated regressions allow for convincing causal interpretations. Therefore, our findings should be interpreted with caution.[7]

References to technology in banks' 10-K filings are statistically significant in only one of the three county-level regressions (Columns 1–3, Table 5). There is an insignificant positive coefficient in our specification with the highest fixed-effects dimensionality. The technology-related coefficients are all scaled by 100 for readability. The estimated coefficient in model 2, which includes county fixed effects, means that an increase in average technology preferences from the 10th to the 90th percentile corresponds to a decrease in the percentage of net change in the number of branches in a county of just under 0.9 percentage points (pp). The sample mean is +0.1 percentage points. Interestingly, this effect seems to be related to the closure rather than the opening of branches. Technology References are positive in all estimates of regression branch closures and statistically highly significant in two out of

[6] When we focus on one factor in a regression (for example, technology) we always control for two of these remaining factors also when their estimated coefficients are not reported in the table.

[7] A downside of most experimental settings for our analysis would be that any representative comparability between factors as different as what we analyze would be limited. Given our interest in comparing economic magnitudes of coefficients of very different variables, the broad and long-term nature of the phenomena we are interested in studying also seems to make it particularly challenging to find common instruments that are both not weak and complying with the exclusion restriction.

Table 8
Branch network overlap and acquisition targets in M&As.

Dependent Variable: Unit of Analysis:	Branch Closure 1/0 Branch-Year					
	(1)	(2)	(3)	(4)	(5)	(6)
M&A	0.006***	0.005**	0.005***	0.002	0.002	0.002
	(0.001)	(0.015)	(0.007)	(0.285)	(0.327)	(0.212)
M&A with Overlap	0.077***	0.067***	0.066***			
	(0.000)	(0.000)	(0.000)			
Acquisition Target				0.047***	0.040***	0.040***
				(0.000)	(0.000)	(0.000)
Controls						
Tech & NPL	Yes	Yes	Yes	Yes	Yes	Yes
County	Yes	Yes	Yes	Yes	Yes	Yes
Bank	Yes	Yes	Yes	Yes	Yes	Yes
Bank-County	Yes	Yes	Yes	Yes	Yes	Yes
Branch	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects						
County		Yes	Yes		Yes	Yes
Bank		Yes	Yes		Yes	Yes
Year	Yes		Yes	Yes		Yes
Observations	685,794	685,547	685,547	685,794	685,547	685,547

Columns 1–6 contain estimated coefficients from regressions explaining closures of a branch in a given year in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \beta_4 \text{Overlap}_{b,y} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \gamma_4 \boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

$\text{Overlap}_{b,y}$ is replaced by Acquisition $\text{Target}_{b,y}$ in Equations (4)–(6). i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. County, bank, bank-county, and branch fixed effects correspond to Columns 3 and 6. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by bank. ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

three specifications. However, the significance disappears when county, bank, and year fixed effects are added together. The lower of the two significant coefficients explaining branch closures (columns 4 and 5) implies that an increase in Technology References from the 10th to the 90th percentile (in the branch level dataset) corresponds to a 0.95 pp increase in the likelihood that a branch is closed. This is 29% of the sample mean. In contrast, there appears to be no statistically significant explanatory power of Technology References over branch openings, as all estimates are statistically insignificant and the signs of the coefficients change. This suggests an asymmetric effect, where technology can be used as a tool to close less attractive locations and reduce the branch network.

Compared to Technology References, the nonperforming loan ratio, which captures the health of the bank, is more consistently associated with de-branching across all units of analysis. It explains both closure and opening. Eight of the nine estimated coefficients are significant. The coefficient in specification 3 implies that an increase in average NPLs from the 10th to the 90th percentile corresponds to a decline in the percentage net change in the number of branches in a county by 0.55–.98 pp (statistical significance is high in all county estimates). Although the lower end of this range is smaller than the corresponding magnitudes of the Technology References, the robustness and statistical significance is higher. The same percentile increase in NPLs (in the branch and bank-county-year level datasets respectively) is associated with at least a 0.98 pp higher likelihood of branch closure (30% of the sample mean) and a 0.6 pp lower likelihood of opening. The latter represents 21% of the sample's mean probability of 0.003 percent.

M&As correlate conditionally with de-branching, both significantly and robustly. Moving from the 10th to the 90th percentile at the county level means that either 0% or 60% of branches are affected by an acquisition. This corresponds to a decline in the annual percentage change in the number of branches of 0.5–0.8 pp. The average likelihood that a branch is closed increases by at least 0.6 pp (18%) when the owner is involved in a merger or acquisition. Interestingly, there is an asymmetry in which branch-opening decisions are *positively* associated with consolidation. This may be because both M&A activity and the opening of entirely new branches reflect a bank being generally on an expansionary path.

We find very similar results when we use the net percentage change in branch density instead of the branch number at the county level (Table A.4), or when we instrument each independent variable of interest with its own lagged value in individual regressions in Table A.5 in the Appendix, separately treating technology, NPLs, or M&A as endogenous in individual equations. Only M&As, explaining net changes at the county level or branch closures, lose significance, which is unsurprising if acquisitions are rare. In Appendix Table A.6, we explore whether there was a structural break around the Global Financial Crisis by analyzing subsamples before 2007 and after 2009. The results are similar. However, technology appears to have become more important after the crisis and to work on the margins of branch closures. NPLs and M&As are relevant for de-branching throughout but appear to work more consistently on the margin of branch openings. Following many recent applied studies, we use linear probability models for reasons related to both operation and interpretation.[8] However, for robustness, we employ binary dependent variable models for the less saturated specification in Table A.7 in the Appendix. While there are some expected differences in magnitude, the results remain similar.

To summarize our main findings from the baseline regressions, we find evidence that technology is associated with the loss of bank

[8] For example, we saturate with many fixed effects making it hard to effectuate estimations and employ interactions in regressions below which are difficult to interpret in a binary variable model.

Table 9
County VA growth vs bank NPLs.

Dependent Variable: Unit of Analysis:	Net % Change in Branch # Country-Year			Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VA Growth	0.056***	0.055***	-0.022***	-0.042**	-0.040**	0.005	0.004***	0.007***	0.001
	(0.000)	(0.000)	(0.009)	(0.044)	(0.021)	(0.774)	(0.007)	(0.000)	(0.418)
Non-performing Loans	-0.350***	-0.276***	-0.209***	0.250**	-0.009	0.233**	-0.021**	-0.023***	-0.019***
	(0.000)	(0.000)	(0.001)	(0.039)	(0.921)	(0.048)	(0.013)	(0.001)	(0.008)
Controls									
Tech & M&A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank				Yes	Yes	Yes	Yes	Yes	Yes
Bank-County				Yes	Yes	Yes	Yes	Yes	Yes
Branch				Yes	Yes	Yes			
Fixed Effects									
County		Yes	Yes		Yes	Yes		Yes	Yes
Bank					Yes	Yes		Yes	Yes
Year	Yes		Yes	Yes		Yes	Yes		Yes
Observations	58,499	58,445	58,445	685,787	685,541	685,541	1,559,428	1,559,426	1,559,426

Regressions 1–3 explain percentage-net-changes in a county's number of branches in a county-year panel via equation

$$\%\Delta\text{Branches}_{c,y} = \beta_1\text{Tech}_{c,y-1} + \beta_2\text{Growth}_{c,y-1} + \beta_3\text{NPL}_{c,y-1} + \beta_4\text{M\&A}_{c,y-1} + \gamma \boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}$$

Regressions 4–6 explain closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1\text{Tech}_{b,y-1} + \beta_2\text{Growth}_{c,y-1} + \beta_3\text{NPL}_{b,y-1} + \beta_4\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \gamma_4\boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

Regressions 7–9 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1\text{Tech}_{b,y-1} + \beta_2\text{Growth}_{c,y-1} + \beta_3\text{NPL}_{b,y-1} + \beta_4\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Fixed effects in these equations correspond to Columns 3, 6, and 9. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by state (bank) in Columns 1–3 (4–9). ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

branches. However, NPLs and M&As correlate even more robustly with de-branching.

4.2. Different aspects of technology

In the previous section, we found a positive association between measures of technology and variables related to the de-branching of banks. In this section, we explore hypotheses related to the more differentiated views of technology in financial intermediation that we presented in Section 1.

First, we compare high-speed Internet access as a measure of the population's general access to technology with Technology References in the 10-Ks as a measure of technology relevancy for banks (see Table 6). The subsample is considerably smaller owing to limited data availability. Internet access is not clearly related to the percentage net change in the number of branches in a county. Interestingly, Technology References become considerably more significant in all county-level regressions when high-speed Internet access is included and the sample is smaller. The results for branch closure decisions are equivalent. Bank-level Technology References are more robustly associated with branch closures than general high-speed Internet access. However, the effect is not symmetric: bank-level factors are uncorrelated with a bank's decision to open a branch in a county, while high-speed Internet access has a negative effect on our dummy for branch opening (significant in one of three regressions). This suggests that branches are opened in counties where general access to technology, including access to online banking is more problematic.

In our second set of regressions differentiating technological aspects, we compare retail-related technology references in 10-Ks with terms/stems like "online banking", "user interface", or "contactless payment" to internal under-the-hood banking technology with letter sequences like "information technolog", "algorithm", or "cloud computing". The results in Table 7 illustrate that the most popular explanation that de-branching is primarily related to online banking is not supported by the data. If anything, the estimates suggest a positive relationship between retail technology and the change in the number of branches at the county level. The same is true for the probability of opening a branch. Two out of three coefficient signs of Retail-Side Technology references are as expected in the regressions explaining branch closures. However, they are all insignificant. In contrast, the relative frequency of terms referring to internal under-the-hood technology applications is correlates more consistently with de-branching. However, two of the nine coefficients have unexpected signs (the coefficients in these two cases are not significant statistically). There is a clear tendency that internal use of technology is associated with a negative rate of change in the number of branches in the counties, a higher branch closure likelihood of closing branches, and a lower likelihood of opening branches.

In a third set of auxiliary regressions in Table A.3 in the Appendix, we differentiate between "newer" and "older" digital technologies. Terms in the former category relate to more recently emerged banking models (such as "FinTech", "smartphone", "machine learning") or to technology that has already been available for a while (term stems such as "direct bank", "desktop", or "information processing"). Our findings show that both term groups are weakly but consistently positively associated with branch-closure decisions. Only FinTech/New Technology

Table 10
Bank size heterogeneity.

Dependent Variable: Unit of Analysis:	Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)
County Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bank Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bank-County Controls	Yes	Yes	Yes	Yes	Yes	Yes
Branch Controls	Yes	Yes	Yes	Yes	Yes	Yes
County Fixed Effects		Yes	Yes		Yes	Yes
Bank Fixed Effects		Yes	Yes		Yes	Yes
Year Fixed Effects	Yes		Yes	Yes		Yes
Panel A: Technology References in 10-Ks						
NPL & M&A Controls	Yes	Yes	Yes	Yes	Yes	Yes
Tech Ref × Tot Assets	0.047***	0.049***	0.041***	-0.003***	-0.003*	-0.002
	(0.000)	(0.000)	(0.000)	(0.009)	(0.055)	(0.136)
Technology References	-0.694***	-0.683***	-0.625***	0.046***	0.036*	0.031
	(0.000)	(0.000)	(0.000)	(0.005)	(0.060)	(0.114)
Total Assets	0.004	-0.018	-0.027**	0.001***	0.001	0.001**
	(0.420)	(0.145)	(0.031)	(0.001)	(0.174)	(0.031)
R^2	0.02	0.05	0.05	0.03	0.04	0.04
Observations	685,794	685,547	685,547	1,559,597	1,559,595	1,559,595
Panel B: Non-Performing Loans						
Tech & M&A Controls	Yes	Yes	Yes	Yes	Yes	Yes
NPLs × Tot Assets	-0.125***	-0.114***	-0.114***	-0.004	0.003	0.001
	(0.000)	(0.001)	(0.000)	(0.588)	(0.631)	(0.938)
Non-performing Loans	2.457***	2.027***	2.266***	0.034	-0.071	-0.026
	(0.000)	(0.001)	(0.000)	(0.718)	(0.433)	(0.771)
Total Assets	0.010**	-0.012	-0.023*	0.001***	0.000	0.001*
	(0.030)	(0.350)	(0.091)	(0.004)	(0.492)	(0.071)
R^2	0.02	0.05	0.05	0.03	0.04	0.04
Observations	685,794	685,547	685,547	1,559,597	1,559,595	1,559,595
Panel C: Consolidation						
Tech & NPL Controls	Yes	Yes	Yes	Yes	Yes	Yes
M/A × Tot Assets	-0.004***	-0.003***	-0.003***	0.000	0.000*	0.000
	(0.000)	(0.000)	(0.000)	(0.195)	(0.096)	(0.137)
Merger/Acquisition	0.087***	0.058***	0.058***	-0.002	-0.003	-0.002
	(0.000)	(0.000)	(0.000)	(0.319)	(0.159)	(0.227)
Total Assets	0.009*	-0.010	-0.022*	0.000***	0.000	0.001*
	(0.089)	(0.434)	(0.094)	(0.008)	(0.591)	(0.087)
R^2	0.02	0.05	0.05	0.03	0.04	0.04
Observations	685,794	685,547	685,547	1,559,597	1,559,595	1,559,595

Columns 1–3 contain estimated coefficients from regressions explaining closures of a branch in a given year in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \gamma_4 \boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

and Regressions 4–6 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}$$

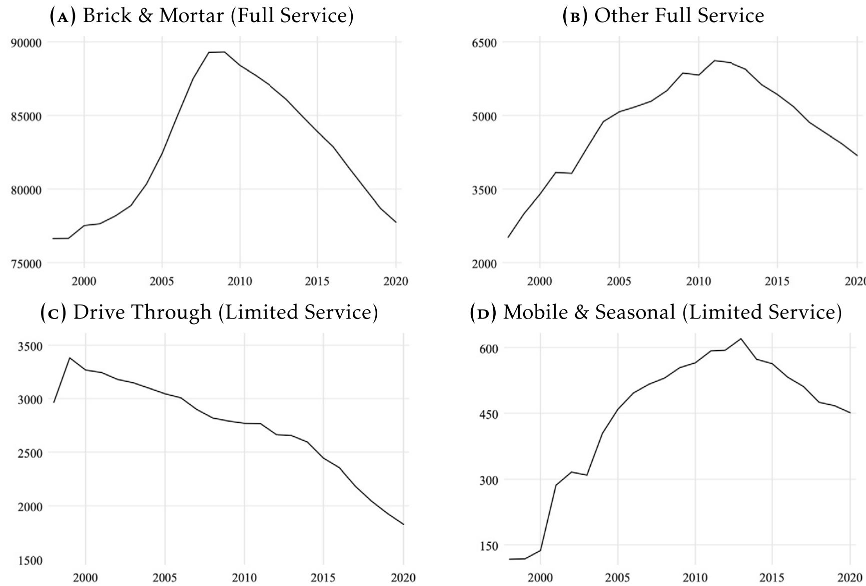
Both regressions also contain the logarithm of total assets and its interaction with one of the three independent variables of interest. i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. County, bank, bank-county, and branch fixed effects correspond to Columns 3 and 6. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by bank. ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

appears to be associated with de-branching in our county-level regressions, while Old Technology points into the opposite direction. Again, no significant outcomes were observed for branch opening.

4.3. Additional and alternative variables

Rather than bank-level factors, adverse economic and financial conditions may affect certain regions and banks, rendering branches unprofitable or expensive to maintain (Morgan et al., 2016). In Table 9, we follow exactly the same line as in the baseline in Table 5, except for adding the growth rate in the value added to NPLs. Economic growth almost invariably slows de-branching. A one standard deviation increase in growth implies an increase in the net change in county branch numbers by approximately 0.46 pp. However, the coefficient sign in one regression switches. County-level VA Growth is also mostly negatively associated with branch closure and positively with branch opening. At each level, all the coefficient signs are as expected. Five of the six micro-level regressions are statistically.

Although we find strong results for bank consolidation in our baseline analysis, it is conceivable that the detected relationships are even stronger when banks are acquired or overlap in their branch networks (for example DeLong, 2001; Degryse and Ongena, 2004; Nguyen, 2019).



These figures plot the total number of bank branches in the U.S. by branch type classification.

Fig. A.1. Number of bank branches by types.

We add corresponding dummies in our branch closure regressions (e.g., defining a variable such as an acquisition target makes little sense when analyzing entry at the bank-county-year level). The results are presented in Table 8. The moderate 0.5 pp increase in closure likelihood after a merger (the M&A coefficient in Column 3) spikes by an additional staggering 6.6 pp or more when networks overlap (Columns 1–3). In total, this represents an increase of 215%. All the coefficients in these three regressions are highly significant. While the branches of acquiring entities are not significantly more likely to be closed, those owned by the acquisition target are at least 4 pp more likely to close the year after the acquisition, which is more than 120% of the average closure likelihood in the entire estimation sample.

4.4. Heterogeneity: the role of bank size

In the preceding sections, we established that the de-branching of banks is not only associated with technology but also with bank fragility and consolidation. In Stein (2002) the type of information that loan officers are incentivized to collect goes hand-in-hand with the degree of bank centralization. Centralized (“large”) banks will collect mostly hard information, and hence improvements in information processing technology will allow these banks to lend across longer distances (Hauswald and Marquez, 2003), obviating the need for local brick-and-mortar presence. On the other hand, small banks that are dealing with soft information may re-position and even open branches to supplement the online banking services provided to customers with “handshake” contact. When in distress or acquired, they close branches. In this section, we explore bank size-related heterogeneity using our most granular branch and bank-county regression specifications, where we interact real total assets with technology references in the 10-Ks, NPLs, and M&As. While we also include individual terms for completeness, the interaction terms are our variables of prime interest.

Regression results are in Table 10. The estimates in columns 1–3 in Panel A show a highly significant positive interaction term between bank size and references to technology, suggesting that technology-driven de-branching is associated with large banks rather than small banks. This could be due to the greater availability of resources for software development and other technological changes with increasing returns to scale. Consistent with the branch closure estimates, most of the interaction terms explaining branch opening decisions in columns 4–6 are significant, implying that large banks that use technology are less likely to open a new branch in a county in a given year. These results suggest that one explanation for the lower significance and robustness of technology in our baseline regressions is that bank size is an important heterogeneity that masks the expected relationship between technology and de-branching in the aggregate.

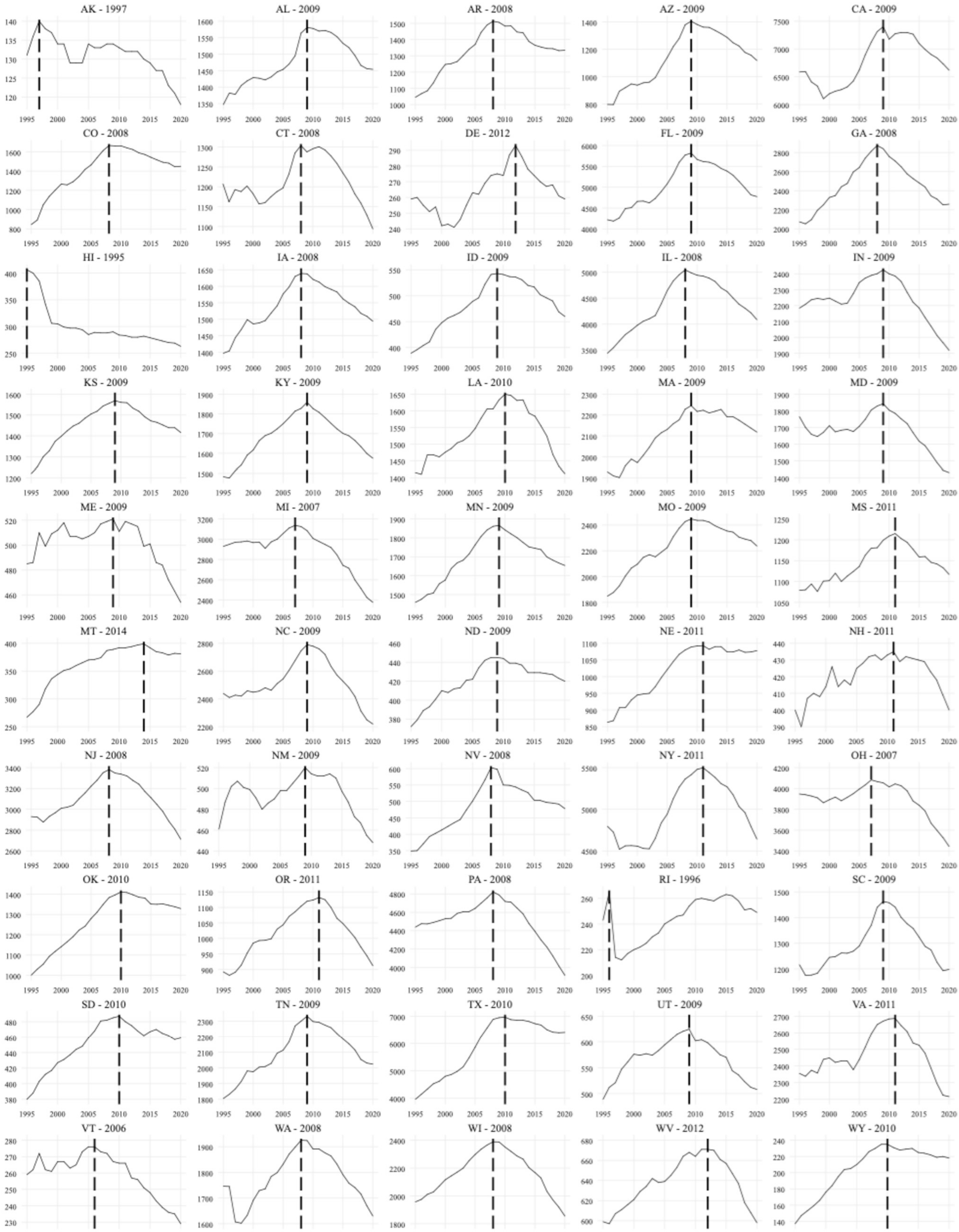
In columns 1–3 of Panel B, we see exactly the opposite of what we find for technology. The negative coefficients on the interaction term suggest that small banks are more likely to close branches when their financial health deteriorates. This could be due to fewer financial resources, lower resilience, or possibly higher funding or operating costs that put more pressure on smaller institutions to streamline their operations. The coefficients in columns 4–6 are not significant, which could be due to smaller banks being less expansionary and making fewer opening decisions.

Analyzing bank consolidation in columns 1–3 of Panel C, we also see that branches of smaller banks seem to be among the losers (the interaction term is consistently negative and highly significant). This is not surprising, as smaller banks are more likely to be acquisition targets and our earlier results show that their branches are more likely to be closed. The interaction term coefficients explaining entry in Columns 4–6 are positive, which might be because larger banks active in M&A generally expand and are more likely to open branches.

5. Conclusion

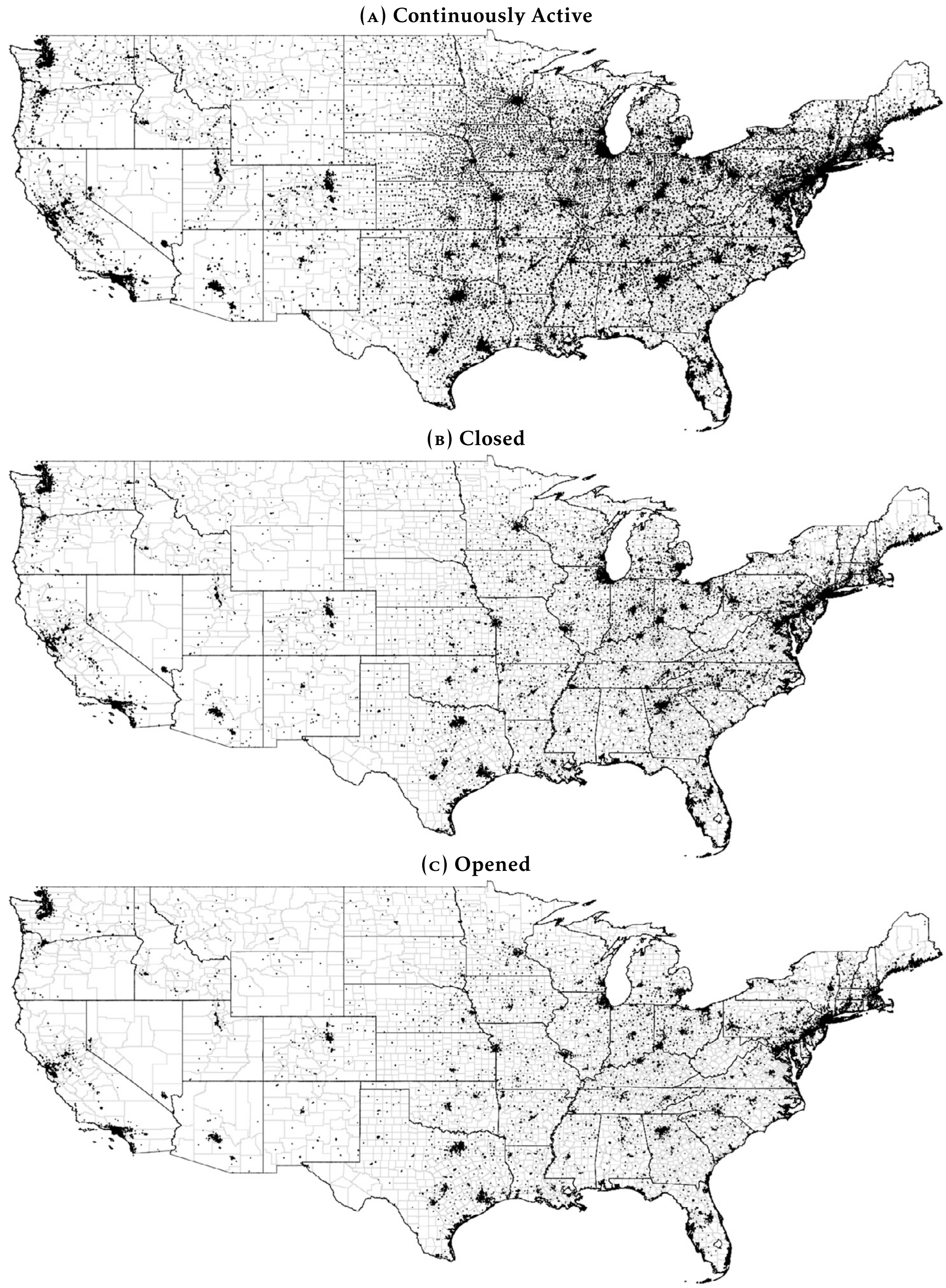
The de-branching of banks represents a mayor secular transformation of the financial sector around the world. Our empirical analysis shows that de-branching corresponds to changes in technology. However, surprisingly, to a lesser extent and with less economic impact than bank consolidation and fragility. Large banks appear to be driving the technology-induced decline of branch banking, while small banks are more likely to close branches as fragility increases or consolidation occurs.

Internal technology appears to be more closely related to de-branching than other more eye-catching and frequently discussed technological factors related to the retail side, such as mobile banking. References to FinTech, but also to “older” technologies used since the 1990s, appear both before and concurrent with de-branching. Branch openings seem to be associated more with local technological factors than bank-level technological factors.



These figures plot the number of bank branches by year for each US state, with indications for peak years.

Fig. A.2. Number of branches by state.



Panel A plots all bank branches that remained active since 2009 until 2020 across contiguous US states. Panel B plots those that were closed until 2020, and Panel C those that were opened up newly since 2009 and remained active in 2020.

Fig. A.3. Bank branches since 2009.

A promising future research agenda could include empirical analyses of the economic impact of de-branching and experiments that allow us to better identify the causal impact of various factors on the decline in the number and importance of bank branches.

CRediT authorship contribution statement

All authors contributed equally to this manuscript.

Data availability

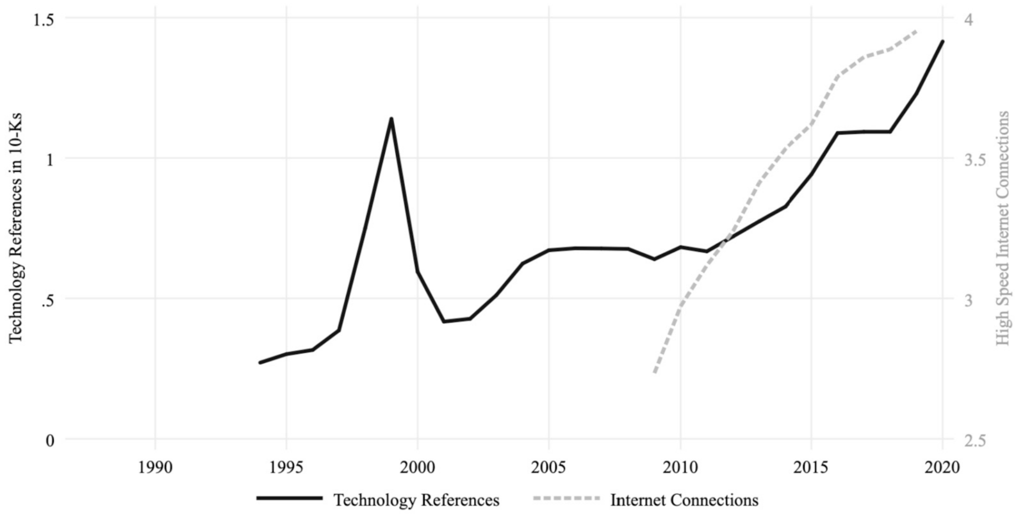
Data will be made available on request.

Appendix A

List of text mined terms

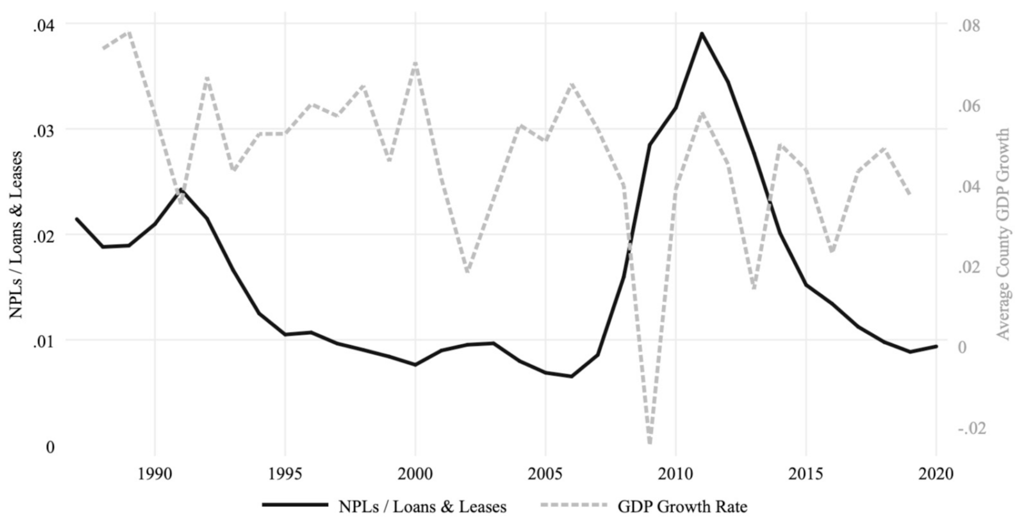
The technology references we use in our text analysis of 10-Ks are terms that are general and related to the Internet, software, hardware, or technology companies active in the FIRE space. We count all terms as follows:

- related to general technology: *'technolog', 'tech', 'it system', 'information processing', 'digital', 'virtual', 'cyber'*
- related to internet: *'internet', 'broadband', 'online', 'world wide web', 'website', 'web site', 'webpage', 'web page', 'web interface', 'user interface', 'homepage', 'home page', 'browser', 'browse', 'browsing', 'wireless', 'email', 'e mail', 'social media', 'malware', 'troyan', 'spam'*



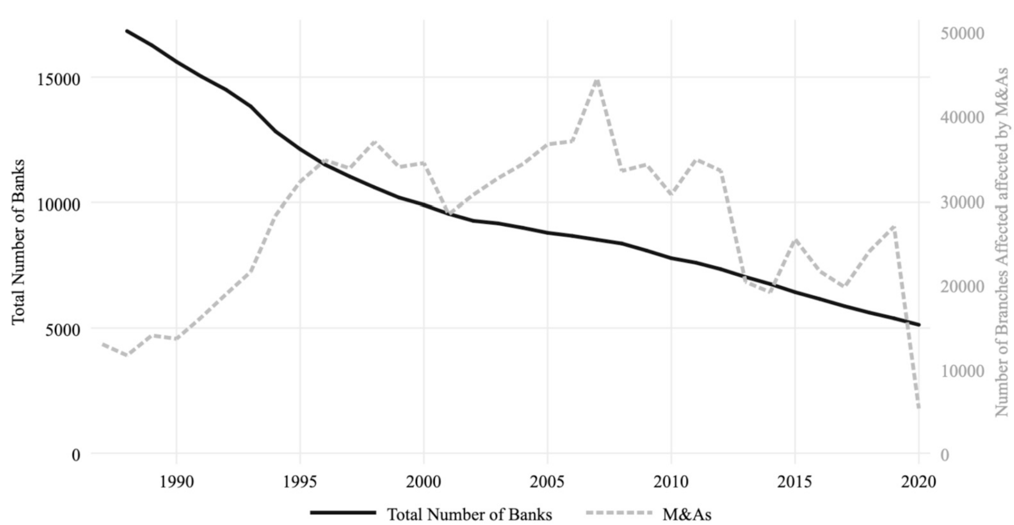
The solid black line in this figure plots the number of technology-related terms per 10 sentences in 10-Ks filed by US banks. The dashed gray line is an index representing the percentage of households with access to high-speed internet connections.

Fig. A.4. General technology references and internet access.



This figure plots the average non-performing loans in percent of total loans and leases for US banks and savings and thrift institutions during the period of analysis.

Fig. A.5. Bank health.



This figure plots the total number of banks and savings and thrift institutions (black solid line) and the number of branches owned by banks involved in mergers and acquisitions (gray dashed line) in the U.S. during the period of analysis.

Fig. A.6. Bank consolidation.

Table A.1
Definitions of main variables of interest.

Variable	Level	Definition (Source)
Branching Measures		
Net Change in Branch #s	county	percentage growth rate in the number of branches (Summary of Deposits)
Branch Closure	branch	dummy indicating the first year in which a branch is missing in a branch-year panel (Summary of Deposits)
Branch Opening	bank-county	dummy indicating that at least one branch is opened in a bank-county-year panel (Summary of Deposits)
Technology Measures		
Technology References	county, bank-county, branch	number of technology-related terms per 100 sentences in 10-Ks filed by US banks (Securities and Exchange Commission, own calculations)
Retail-Side Technology	county, bank-county, branch	number of technology-related terms related to the retail/customer faced side per 100 sentences in 10-Ks filed by US banks (Securities and Exchange Commission, own calculations)
Internal-Side Technology	county, bank-county, branch	number of technology-related terms related to the back office side per 100 sentences in 10-Ks filed by US banks (Securities and Exchange Commission, own calculations)
High-Speed Int. Access	county, bank-county, branch	index (from 0–5) for the percentage of population in a county with high-speed internet access ranging from 0 to 80–100% in 20-percentage-point brackets (Federal Communications Commission)
Bank Fragility Measures		
Non-performing Loans	county	branch market share weighted of NPLs/total loans & leases (Call Reports)
	bank-county, branch	non-performing loans/total loans & leases (Call Reports)
VA Growth	county, bank-county, branch	percentage growth rate in personal income (BEA)
Bank Consolidation Measures		
Merger/Acquisition	county	branch market share weighted dummy indicating if the bank or bank holding company of branches in a county is affected by a merger (FED NIC Transformations Table)
	bank-county, branch	dummy indicating if the bank or bank holding company was affected by a merger (FED NIC Transformations Table)
Acquisition Target	bank-county, branch	dummy indicating if the bank or bank holding company was an acquisition target (FED NIC Transform. Table)
M/A With Network Overlap	bank-county, branch	dummy indicating if the bank or bank holding company was part of such a merger with overlap in the branch's county (FED NIC Transformations Table)
Additional Variables Used in the Appendix		
Change in Branch Density	county	percentage growth rate in the branch density (branch number/population) (Summary of Deposits)
Old Technology	county, bank-county, branch	number of technology-related terms related to "old" digital technology (e.g. general IT) side per 100 sentences in 10-Ks filed by US banks (Securities and Exchange Commission, own calculations)
FinTech/New Technology	county, bank-county, branch	number of technology-related terms related to "new" technologies such as machine learning per 100 sentences in 10-Ks filed by US banks (Securities and Exchange Commission, own calculations)

Table A.2
Definitions of control variables.

Variable	Definition (Source)
County Controls (used in all Regressions)	
Population Density	logarithm of population/square kilometers (BEA and Census)
GDP per Capita	logarithm of per capita GDP in US $ (BEA and Census Indicators)
Branch Density	logarithm of the number of branches/100,000 citizen (BEA)
IBBEA Deregulation	dummy equal to 1 if a state lifted at least one restriction following the Interstate Bank Branching Efficiency Act
Out-of-State Bank Market Share	out-of-state banks' branch deposit market share (Summary of Deposits)
County HHI	Herfindahl-Hirschman Index of branch deposit concentration (Summary of Deposits)
Bank Level Controls (used in Branch and Bank-County Level Regressions)	
Real Assets	logarithm of total assets in real 2020-$ (Summary of Deposits)
Fee Income/Total Income	income from fees/total income (Call Reports)
Deposits/Assets	deposits/assets (Summary of Deposits)
C&I Loans/Assets	value of commercial & industrial loans/assets (Call Reports)
# of Branches	logarithm of the total # of branches (Summary of Deposits)
Diversification HHI	geographical county-branch deposit network diversification HHI (Summary of Deposits)
Savings Bank	dummy variable equal to 1 if the bank is a savings bank or thrift institution (Summary of Deposits)
Bank-County Level Controls (used in Branch and Bank-County Level Regressions)	
Out-of-State Bank	dummy variable identifying if a bank is an out-of-state lender (1) or not (Summary of Deposits)
Bank's Market Share in County	branch deposit market share of bank in a county (Summary of Deposits)
Bank-County's Share in Bank	bank's branch deposits in the county/bank's total deposits (Summary of Deposits)
Presence of Bank in a County	dummy variable identifying if a bank is present in a county (1) or not (Summary of Deposits)
Branch Level Controls (used in Branch Level Regressions)	
Real Deposits	logarithm of branch deposits in real 2020-$ (Summary of Deposits)
Branch-Headquarter Distance	logarithm of the geospatial distance between a branch and the owning bank's headquarter in miles (Summary of Deposits)
Full Service Non-Brick & Mortar	dummy variable equal to 1 for full service non-brick and mortar branches (Summary of Deposits)
Limited Service	dummy variable equal to 1 for limited service branches (Summary of Deposits)
De Novo Branch	dummy variable equal to 1 for branches not acquired by the bank from another institute (Summary of Deposits)
Branch Age	logarithm of the age of a branch (Summary of Deposits)

Table A.3
References to FinTech vs "Older" technology in banking.

Dependent Variable: Unit of Analysis:	Net % Change in Branch # Country-Year			Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-US County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Old Technology	0.013	0.047***	0.025	0.020	0.064**	0.015	0.001	-0.001	0.000
	(0.263)	(0.003)	(0.106)	(0.436)	(0.019)	(0.579)	(0.754)	(0.788)	(0.890)
FinTech/New Technology	-0.122	-2.009***	-0.162	0.663***	0.276	-0.105	0.003	-0.044	-0.015
	(0.523)	(0.000)	(0.327)	(0.008)	(0.330)	(0.764)	(0.943)	(0.120)	(0.579)
Controls									
NPL & M&A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank				Yes	Yes	Yes	Yes	Yes	Yes
Bank-County				Yes	Yes	Yes	Yes	Yes	Yes
Branch				Yes	Yes	Yes			
Fixed Effects									
County		Yes	Yes		Yes	Yes		Yes	Yes
Bank					Yes	Yes		Yes	Yes
Year	Yes		Yes	Yes		Yes	Yes		Yes
Observations	58,506	58,453	58,453	685,794	685,547	685,547	1,559,597	1,559,595	1,559,595

Regressions 1–3 explain percentage-net-changes in a county's number of branches in a county-year panel via equation

$$\%\Delta\text{Branches}_{c,y} = \beta_1\text{Tech1}_{c,y-1} + \beta_2\text{Tech2}_{c,y-1} + \beta_3\text{NPL}_{c,y-1} + \beta_4\text{M\&A}_{c,y-1} + \gamma\boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}$$

Regressions 4–6 explain closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1\text{Tech1}_{b,y-1} + \beta_2\text{Tech2}_{b,y-1} + \beta_3\text{NPL}_{b,y-1} + \beta_4\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \gamma_4\boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

Regressions 7–9 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1\text{Tech1}_{b,y-1} + \beta_2\text{Tech2}_{b,y-1} + \beta_3\text{NPL}_{b,y-1} + \beta_4\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Fixed effects in these equations correspond to Columns 3, 6, and 9. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by state (bank) in Columns 1–3 (4–9). ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

Table A.4
Branch density change instead of branch number change.

Dependent Variable: Unit of Analysis:	Net Change % in Branch Density Country-Year		
	(1)	(2)	(3)
Technology References	-0.006	-0.060***	0.011
	(0.586)	(0.000)	(0.348)
Non-performing Loans	-0.310***	-0.185***	-0.138**
	(0.000)	(0.000)	(0.011)
Merger/Acquisition	-0.015***	-0.001	-0.008***
	(0.000)	(0.562)	(0.000)
NPL & M&A Controls	Yes	Yes	Yes
Country Controls	Yes	Yes	Yes
Country Fixed Effects		Yes	Yes
Year Fixed Effects	Yes		Yes
R^2	0.05	0.13	0.17
Observations	56,104	56,047	56,047

This table contains estimated coefficients from regression

$$\%\Delta\text{Branch Density}_{c,y} = \beta_1\text{Tech}_{c,y-1} + \beta_2\%\Delta\text{NPL}_{c,y-1} + \beta_3\text{M\&A}_{c,y-1} + \gamma\boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}$$

c and y stand for county and year levels. $\boldsymbol{X}_{c,y-1}$ contains county controls. County and year fixed effects correspond to Column 3) explaining percentage-net-changes in a counties' density of branches relative to the population in a county-year panel. Variables including controls are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by county. ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

Table A.5
De-branching in the U.S. – with internal IVs.

Dependent Variable: Unit of Analysis:	Net % Change in Branch # County-Year			Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Technology References	0.002	-0.004	-0.003	0.098***	0.078***	0.074***	0.003	0.001	0.001
	(0.913)	(0.670)	(0.769)	(0.003)	(0.003)	(0.003)	(0.225)	(0.532)	(0.500)
Non-performing Loans	-0.360***	-0.565***	-0.363***	0.141*	0.260**	0.277**	-0.019**	-0.023***	-0.021**
	(0.000)	(0.000)	(0.000)	(0.094)	(0.050)	(0.037)	(0.037)	(0.006)	(0.025)
Merger/Acquisition	-0.011***	-0.013***	-0.013*	0.007***	0.010***	-0.001	0.001***	0.001***	0.002**
	(0.000)	(0.000)	(0.060)	(0.000)	(0.000)	(0.888)	(0.001)	(0.001)	(0.042)
Controls									
County	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank				Yes	Yes	Yes	Yes	Yes	Yes
Bank-County				Yes	Yes	Yes	Yes	Yes	Yes
Branch				Yes	Yes	Yes			
Year Fixed Effects	Yes		Yes	Yes		Yes	Yes		Yes
F-statistic	20.93	25.61	15.26	37.44	44.23	38.95	42.75	54.15	52.41
Kleibergen-Paap F-stat	705.67	3314.46	233.22	1681.92	2475.12	58.18	4730.56	3627.40	104.28
Observations	54,316	58,391	58,499	607,641	625,991	667,587	1,257,742	1,435,565	1,462,215

Regressions 1–3 explain percentage-net-changes in a county's number of branches in a county-year panel via equation

$$\%\Delta\text{Branches}_{c,y} = \beta_1 \text{Tech}_{c,y-1} + \beta_2 \text{NPL}_{c,y-1} + \beta_3 \text{M\&A}_{c,y-1} + \gamma \boldsymbol{X}_{c,y-1} + \eta_c + \delta_y + \epsilon_{c,y}$$

Regressions 4–6 explain closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \gamma_4 \boldsymbol{Z}_{i,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{i,y}$$

Regressions 7–9 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \theta_c + \eta_b + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Fixed effects in these equations correspond to Columns 3, 6, and 9. In each equation we assume on independent variable of interest to be endogenous and instrument this variable by a 1-year lag of its value (in addition to its 1-year lag in the regression). All other independent variables of interest are retained as controls, but omitted from the table for clarity. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by state (bank) in Columns 1–3 (4–9). ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

- related to software: *'software', 'machine learning', 'ai', 'artificial intelligence', 'algorithm', 'computing', 'compute', 'operating system', 'coding', 'programming', 'programmer', 'cloud service', 'cloud comput', 'cloud stor', 'data manage', 'data system', 'database', 'data scien'*
- related to hardware: *'hardware', 'computer', 'smartphone', 'smartwatch', 'tablet', 'laptop', 'desktop', 'server', 'our server', 'web server'*
- related to technology driven business models: *'fintech', 'neobank', 'neo bank', 'web bank', 'home bank', 'directbank', 'direct bank', 'neobroker', 'neo broker', 'directbroker', 'direct broker', 'robo advis', 'roboadvis', 'robot advis', 'robotadvis', 'electronic bank', 'e bank', 'ebank', 'e platform', 'eplatform', 'e service', 'eservice', 'e channel', 'echannel', 'lending automat', 'automated lending', 'credit automat', 'automated credit', 'mortgage automat', 'automated mortgage', 'mobile bank', 'mobile channel', 'mobile service', 'mobile offer', 'mobile payment'*

The two mutually exclusive groups of terms in the auxiliary regression in the main body of our analysis partially overlapped with the broader search algorithm from the baseline regressions. The first contains terms most likely to be associated with the visible, demand-oriented "retail"-side of technology in banking that is often discussed with respect to the replacement of branch services for household customers (such as "online offer", "direct banking", "user interface" (and other similar terms). The second term group targets supply-side, under-the-hood, or internal lending technology, with terms such as "algorithm", "machine learning", "automated lending" (and other similar terms) associated with the use of hard information and digital technology to streamline lending, collect new internet based information, or analyze data with more recent, software based methods.

Further details of our methodologies and code are available upon request. Klaus Doerner assisted us with the web scraping process. However, any existing inconsistencies and errors are the authors' responsibility.

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Table A.6
Was there a structural break in the financial crisis?

Dependent Variable: Unit of Analysis:	Net % Change in Branch # County-Year		Branch Closure 1/0 Branch-Year		Branch Opening 1/0 Bank-County-Year	
Model:	Before 2007	After 2009	Before 2007	After 2009	Before 2007	After 2009
	(1)	(2)	(3)	(4)	(5)	(6)
Technology References	0.010	-0.020*	0.033	0.110***	0.001	0.820
	(0.499)	(0.075)	(0.108)	(0.001)	(0.465)	(0.163)
Non-performing Loans	-0.338***	-0.252***	1.632**	0.075	-0.021**	-13.652***
	(0.003)	(0.000)	(0.018)	(0.468)	(0.012)	(0.003)
Merger/Acquisition	-0.017***	-0.012***	0.023***	0.003	0.001***	0.219***
	(0.000)	(0.000)	(0.000)	(0.113)	(0.000)	(0.000)
Controls						
County	Yes	Yes	Yes	Yes	Yes	Yes
Bank			Yes	Yes	Yes	Yes
Bank-County			Yes	Yes	Yes	Yes
Branch			Yes	Yes		
Fixed Effects						
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	27,610	23,788	170,432	468,229	1,559,597	1,559,597

Regressions 1–2 explain percentage-net-changes in a county's number of branches in a county-year panel via equation

$$\%\Delta\text{Branches}_{c,y} = \beta_1\text{Tech}_{c,y-1} + \beta_2\text{NPL}_{c,y-1} + \beta_3\text{M\&A}_{c,y-1} + \gamma\boldsymbol{X}_{c,y-1} + \delta_y + \epsilon_{c,y}$$

Regressions 3–4 explain closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1\text{Tech}_{b,y-1} + \beta_2\text{NPL}_{b,y-1} + \beta_3\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \gamma_4\boldsymbol{Z}_{i,y-1} + \delta_y + \epsilon_{i,y}$$

Regressions 5–6 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1\text{Tech}_{b,y-1} + \beta_2\text{NPL}_{b,y-1} + \beta_3\text{M\&A}_{b,y-1} + \gamma_1\boldsymbol{W}_{c,y-1} + \gamma_2\boldsymbol{X}_{b,y-1} + \gamma_3\boldsymbol{Y}_{b,c,y-1} + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Variables are described in Tables A.1–A.2 in the Appendix. Standard errors are clustered by state (bank) in Columns 1–2 (3–6). ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

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Table A.7
Logit and probit als alternatives to linear probability.

Dependent Variable: Unit of Analysis:	Branch Closure 1/0 Branch-Year			Branch Opening 1/0 Bank-County-Year		
	(1)	(2)	(3)	(4)	(5)	(6)
Technology References	0.074***	2.302***	1.042***	0.001	0.820	0.290
	(0.004)	(0.001)	(0.001)	(0.465)	(0.163)	(0.199)
Non-performing Loans	0.253**	8.185**	3.217**	-0.021**	-13.652***	-5.215***
	(0.036)	(0.014)	(0.020)	(0.012)	(0.003)	(0.002)
Merger/Acquisition	0.009***	0.271***	0.121***	0.001***	0.219***	0.101***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Model						
Linear Probability	Yes			Yes		
Logit		Yes			Yes	
Probit			Yes			Yes
Controls						
County	Yes	Yes	Yes	Yes	Yes	Yes
Bank	Yes	Yes	Yes	Yes	Yes	Yes
Bank-County	Yes	Yes	Yes	Yes	Yes	Yes
Branch	Yes	Yes	Yes			
Fixed Effects						
Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	685,794	685,794	685,794	1,559,597	1,559,597	1,559,597

Regressions 1–3 closures of a branch in a branch-year panel via equation

$$\text{Closure}_{i,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \gamma_4 \boldsymbol{Z}_{i,y-1} + \delta_y + \epsilon_{i,y}$$

Regressions 4–6 explain openings of a branch in a bank-county-year panel via equation

$$\text{Opening}_{b,c,y} = \beta_1 \text{Tech}_{b,y-1} + \beta_2 \text{NPL}_{b,y-1} + \beta_3 \text{M\&A}_{b,y-1} + \gamma_1 \boldsymbol{W}_{c,y-1} + \gamma_2 \boldsymbol{X}_{b,y-1} + \gamma_3 \boldsymbol{Y}_{b,c,y-1} + \delta_y + \epsilon_{b,c,y}$$

i, b, c, and y indicate branch, bank, county and year levels. $\boldsymbol{W}_{c,y-1}$, $\boldsymbol{X}_{b,y-1}$, $\boldsymbol{Y}_{b,c,y-1}$, and $\boldsymbol{Z}_{i,y-1}$ are lagged county, bank, bank-county, and branch controls. Fixed effects in these equations correspond to Columns 3, 6, and 9. Standard errors are clustered by bank. ***, **, and * indicate statistical significance at 1%, 5%, and 10%. P-values are between parentheses.

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