The Impact of ICTs on Banks, Credit, and Savings: An Examination of Brazil[*,†]

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Abstract

How do "Information and Communication Technologies" (ICTs) reshape the banking industry and banking habits? Using panel data containing detailed banking statements for more than 25,000 public and private bank branches distributed among over 3,500 municipalities of Brazil, I show that, following the rollout of the 4G network, 6% of private banks exit the municipalities while their branches shrink on average 11% within five years of the introduction of this technology compared to municipalities that do not have it. By contrast, public banks are not reactive to better mobile connectivity. Credit, savings, and long-term deposits also display different behaviours at the branch level in response to better mobile network in public and private banks. Globally, these results suggest that the internet has been deeply reshaping the banking industry and modifying how credit and savings are distributed to the population with different levels of internet access, with important policy implications for both the industry and consumers.

Keywords: ICT, internet, 4G mobile network, banks, credit, savings, financial inclusion, competition.

JEL Codes: D14, E51, F12, G21, G40, L10, L86, O14.

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1 Introduction

What are the social and economic implications of more internet services on banking? There is a broad view that increased connectivity leads to financial inclusion (Karlan, McConnell, Mullainathan, and Zinman (2016)), smaller transaction costs (Mbiti and Weil (2011)), and smoother consumption patterns (Jack and Suri (2014)). However, other studies highlight that digitization may induce the most vulnerable to pay more for banking services (Jiang, Yu, and Zhang (2022)) and is not a panacea to alleviate credit constraints (Bharadwaj, Jack, and Suri (2019)) or increase the habit of savings (Dubus and Hove (2017)).

This paper proposes to examine what happens to the banking industry and banking habits as Information and Communication Technologies (ICTs) become available in a developing setting. Given the availability of more and better internet, how do the banks' credit and savings portfolios react? Can better internet change the composition and structure of the banking industry by affecting the number of firms (banks) and shops (branches)? And are banking patterns different for public and private banks?

To accomplish this task, I focus on Brazil. The country offers a unique opportunity to examine the impact of better-quality internet on the financial industry for three reasons. First, there has been a gradual pace of rollout of ICTs in a continental-sized country of 215 million people, which contrasts with the often-simultaneous implementation of internet resources in developed countries. Second, this study benefits from the rich granularity of administrative banking data available for more than 25,000 bank branches distributed in over 3,500 of the 5,570 cities of Brazil. Third, given its size and geographic diversity, Brazil offers a unique case study in the international community for its broad and relatively quick adoption of digital banking technologies to fasten payment methods online[1]. To tackle the research questions, I consider the expansion of the fourth generation (4G) of mobile network infrastructure, which is the first wave of mobile broadband technology that allowed users to freely use mobile banking apps from smartphones and tablets. Starting in 2014 up until August 2020, the rollout of 4G services reached 90% of the municipalities in Brazil.

From a methodological standpoint, obtaining a causal relationship between internet access and banking outcomes is challenging. An ideal experiment would randomly assign municipalities to access new technologies over time and, thus, create exogenous variation in the assignment of treatment and control groups. In the absence of a controlled randomized trial, however, one is forced to turn to nonexperimental methods that, under certain regularity conditions, identify and estimate causal effects. A major concern is that the municipalities that were offered

[1] Digital and online banking are used as synonyms in the text.

internet could be different from the municipalities that were not and that these differences may be correlated to the outcome variables of interest. A common method of controlling for time-invariant unobserved heterogeneity is the use of panel data to estimate differences-in differences models (DiD). I thus turn to a DiD approach, which compares the change in outcomes in the treatment group, i.e., municipalities with 4G network, before and after the intervention, to the change in the outcomes of the untreated group.

I show that, as the 4G network becomes available, private and public banks have different response behaviours. On average, municipalities with access to this technology lose about 6% of private banks (firms), closing 11% of all branches (shops). By contrast, public banks are not responsive to more internet resources, except for a very slight increase in the number of public branches up to two years post-4G network implementation. This sharply distinct outcome for public and private banks is consistent with the fact that public banks do not pursue profits as their main goal, but are primarily the executioners of public policies in Brazil.

The strong decrease in the number of physical branches or shops is accompanied by a decrease of up to 14% in total credit, 24% in savings deposits, and 81% in long-term deposits across private bank branches, and an even more significant decline for credit and savings deposits in public banks – 35% and 46% respectively. The main inference of these results is that citizens of municipalities that gain access to mobile broadband internet expand their banking options beyond their local branches as new products and services become available through the internet. This assumption is consistent with past work from academia and international organisms that have shown that internet connectivity reduces the cost of searching for preferred products and the barriers to moving funds between them (Goldfarb and Tucker (2019); Jiang, Yu, and Zhang (2022); Philippon (2019); Bank (2022)).

The rich granularity of the data in a continental-sized country allows the study of the heterogeneity of the impact of the 4G mobile network, which helps to shed light on some of the mechanisms at play. First, I show that the 4G mobile network impacts more the urban, big, and rich than the rural, small, and poor municipalities. This result suggests that not only the availability of the internet is important to spark changes in the banking industry, but also the quality of the network (IICA (2020)). The second mechanism is related to the behaviour of the industry. By clearly following distinct paths in opening and closing banks and branches as the internet progresses, it becomes clear that more connectivity has been reshaping how public and private banks reorganize themselves, with the predominant channel likely different in both cases. While private branches might be closing because the internet amplifies the banking options to the population, public banks and branches are not responsive to increasing mobile network availability. Third, the fall of credit and savings products at the branch level in response to better internet quality may signalize that consumers are increasingly taking advantage of online banking services offered by different players, from fintechs to traditional banks offering digital channels. Finally, the fact that all results are deeper in big centres suggests a potential channel for the deepening of inequality, as those individuals without the same internet resources may lag behind on the variety of banking options available to them (BIS (2018); Jiang, Yu, and Zhang (2022); Prasad (2021)).

There may be other mechanisms at play as well. For example, even though one can estimate the impact of ICTs on the credit granted at the bank branch level, it is not possible to separate what is due to customers increasing their credit options from the outcomes generated by the externalities associated with the ICT on the credit market. Identifying the causal effect of each channel would require one instrument per channel (Chodorow-Reich (2014); Joaquim, Doornik, and Ornelas (2019)), which is out of the scope of this paper.

I document the absence of pre-trends: the future availability of mobile networks has no effect on credit, savings, and the percentage differences in the number of bank branches, but the effect of the 4G expansion is significant. These results are observed following an event study design and are robust to the inclusion of municipality-bank fixed effects (as in Jiang, Yu, and Zhang (2022)) without affecting the magnitude of the estimates or the statistical significance of the coefficients. In addition, I show the robustness of the results through the implementation of a placebo, the new methodology of DiD for staggered designs (Sun and Abraham (2020)), and a test for spatial correlation between markets that could be contaminating the results (Conley and Molinari (2007)). Finally, I adopt an instrumental variable identification strategy based on geographical barriers that help predict the progress of the 4G network rollout, a design that is relatively well established in the literature (Guriev, Melnikov, and Zhuravskaya (2021); Manacorda and Tesei (2020)). In particular, the incidence of lightning strikes is used to instrument the speed of the mobile network adoption. All results are confirmed in this alternative econometric approach.

This paper is related to several strands of the literature. First, this work is connected to how the use of internet resources can change the banking industry itself (Cisternas Vera (2017); Jiang, Yu, and Zhang (2022)). By showing different paths for private and public banks in the decision to open and close new banks (firms) and branches (shops) at the municipality level in response to better internet services, this work makes a novel contribution to the understanding of the dynamic of the private and public banks when more technology is available (Singh and Arora (2011); Srivastav and Mittal (2016)).

Second, this work is related to financial development through digital finance. Past studies have demonstrated that having access to internet resources to make financial transactions may lead to smaller transaction costs (Mbiti and Weil (2011)) and to the expansion of credit (Bharadwaj, Jack, and Suri (2019)), although not necessarily to higher savings (Dubus and Hove (2017)). This paper contributes to this literature by examining the effect of higher internet availability on the structure and portfolio of the banking industry by using high-frequency data at the bank branch level for the full territory of Brazil.

Third, this paper also connects to the literature that studies the behavioural aspects related to accessing digital products and services. Previous research (Lule, Omwansa, and Mwololo (2011)) has discussed how credibility and ease of use are among the main factors that influence the adoption of the internet to perform financial services online. By observing different patterns in the volume of credit and savings once the internet becomes available in the municipality, one can infer that consumers are changing how they perform financial transactions and how they interact with their banks.

Fourth, the research joins previous work analyzing the impact of bank concentration (e.g. fewer banks available) on credit (Joaquim, Doornik, and Ornelas (2019); Nguyen (2019)). This work adds to the literature by showing the impact of the internet rollout on bank branch availability, as services have been increasingly migrating to digital platforms. As local branches are expected to close as the internet becomes more available, the remaining branches will likely obtain a higher market share, with the potential to increase fees and worsen conditions for local consumers (Jiang, Yu, and Zhang (2022)).

The remaining of this article is organized as follows. Section 2 presents the conceptual framework. Section 3 introduces the setting. Section 4 discusses the data and the empirical strategy. Section 5 shows the average effect of 4G expansion on credit and savings for Brazil and discusses the validity of the identification assumptions. Section 6 develops several robustness checks to validate the main results. Section 7 offers comparative analyses. Section 8 explores the policy implications of mobile broadband internet expansion through the banking channel. Section 9 concludes. All appendix material is found after the References Section.

2 Conceptual Framework

2.1 Cost Theory, Banking, and the Internet

This work is related to how internet access has the potential to revolutionize banking services with significantly lower costs to individuals and firms. My leading hypothesis is that the implementation of the 4G network can be claimed to be responsible for transformations that have been observed in the banking industry, particularly the trend towards the closure of physical stores. In addition, it is expected that better internet connectivity leads to the opening of new opportunities for credit and savings products with more financial intermediaries available online. However, this change might not be homogeneous throughout financial products and municipalities ("markets").

To frame the research questions, I use cost theory applied to the internet and the banking industry. Technology has been reshaping the financial ecosystem and the future of banks at an increasing speed. The internet, in particular, is widely recognised as a distribution channel for the banking industry, including traditional banks and new players that have been discovering its effectiveness compared with other channels (Barbesino, Camerani, and Gaudino (2005)). Different types of information technologies can help reduce information asymmetry and imperfect information in markets, which in turn helps with tasks related to search and coordination, leading to increased market efficiency (Beuermann (2015); Chong and Yanez (2020)).

Seminal models of the impact of lower costs on the economy are proposed by Stigler (1961) and Varian (1980), but the substantial reduction in costs boosted by the internet was developed much later (Borenstein and Saloner (2001); Brynjolfsson, Hu, and Smith (2010);Goldfarb and Tucker (2019); Shapiro and Varian (1998)). In the next paragraphs, I briefly explain what these decreased costs are for the banking industry.

The first type of cost that is reduced with the internet is search costs or the costs of looking for information. The role of geographical distance changes as the individual does not need to travel to a brick and mortar bank to get informed about a loan or savings product, thus significantly reducing "search costs" through online resources (Chong and Yanez (2020); Han and Noh (1999)). At the same time, the bank does not need to provide the same physical infrastructure to offer information, thus enabling much more centralized operations digitally (Acemoglu, Aghion, Lelarge, Van Reenen, and Zilibotti (2007); Bloom, Garicano, Sadun, and Van Reenen (2014)) thus reducing infrastructure costs.

Lower search costs may also increase the prevalence of platform-based businesses such as fintechs, which are considered competitors of traditional banks (BIS (2022)). Past work has estimated that digitalization could cut banks' operational costs by 30 percent to 50 percent mainly due to fewer branches and employees, while revenues are estimated to also decline for all banks by 10 percent to 30 percent due to enhanced competition and transparency (Citi (2019)). For consumers, even though search costs will likely be decreased, price dispersion may remain high in online environments (Barber and Odean (2001); Brynjolfsson, Hu, and Smith (2010)).

The second type of cost that is likely to decrease with the introduction of internet access is related to replication, in the sense that goods made of atoms and bits are non-rival, i.e., they can be consumed by one person without reducing the amount or quality available to others. To a certain extent, products and services offered by financial institutions were already non-rival before the current revolution in digital banking. Still, exclusively online transactions will also decrease paperwork, even though there will be higher costs related to Information Technologies (IT) (Liu (2021); Temenos (2015)). Money invested in IT, however, has the potential to be money well spent. For example, Silva, Souza, and Guerra (2021) show that bank branches in Brazil that invested more in IT before the Covid-19 outbreak suffered less from the adverse effects of the pandemic and ended up leveraging their positions in terms of market power compared to other bank branches that have not done the same investments.

The third type of cost that is reduced with digitization is that of transportation since information is now stored in bits. One interesting question in banking is whether this lower cost will lead to the "death of distance" – in other words, does it matter if the bank has headquarters in the individual's neighborhood or a far away municipality? Lendle, Olarreaga, Schropp, and Vezina (2016) show that, for exclusively online services, distance matters substantially less. However, in places where there is a physical presence of the business, online services may be smaller (Dinlersoz and Pereira (2007); Loginova (2009)). This might be because bank preferences are local (Cisternas Vera (2017); Nguyen (2019)).

The fourth type of cost that has significantly changed for the banking industry is that related to marketing, since the virtual world enables personalization and the creation of one-to-one markets, leading to renewed interest in established economic models with asymmetric information and differentiated products such as price discrimination, auctions, and advertising models (Dewan and Seidmann (2001)). One particular innovation in Brazil that is expected to significantly decrease marketing costs is the recently approved "Open Banking" , or open financial system, which allows customers of a particular bank to share their information with other banks on a platform managed by the Central Bank. The new platform promises to foster competition among banks and create a better experience for customers, given that banks can tailor products to their needs (BCB (2021b)). Even though marketing costs may be reduced, it is worth mentioning that the new era of online marketing strategies has made privacy a key issue in the banking industry, which can revert at least part of the costs saved with the internet (Davis (1993);Dewan and Seidmann (2001); Han and Noh (1999)).

The fifth type of cost is related to trust and reputation. The rise of online reputation systems (e.g., credit history platforms) has facilitated trust and created new markets, although digital platforms are more vulnerable to fraud and discrimination. The cost of trust is non-despisable in digital banking (Bank (2020)) – the physical separation of the bank branch and the customer, and that of the customer and the financial advisor, added to the overall environment of perceived insecurity of the internet – all these elements provide unique challenges for banks to find ways in which to initiate and develop e-business relationships (Stewart (2002); Warrington, Abgrab, and Caldwell (2000)). However, for traditional banks, this cost is smaller compared to that incurred by the new entrants, since they are usually well-established brands. Another challenge related to trust is that of cyber-risk (BIS (2022), even if a full-scale digital finance can significantly reduce the circulation of bad or 'fake' money (Rogoff (2015)).

The cost of loyalty is another relevant dimension (Dinlersoz and Pereira (2007)). Past surveys conducted by the banking software company Temenos show that customer loyalty is the top source of concern for bank seniors, which may indicate that bank relationships are not so permanent as to not allow changes (Temenos (2015); Temenos (2019)). As technology improves, verification or tracking of the individual may continue to become easier (Goldfarb and Tucker (2019)). From the point of view of customers, this type of cost is also relevant because they need to know about the integrity of their banks. With the increase of information on the internet, this cost tends to decrease.

The different types of costs for banks and individuals in response to internet access are mapped in Figure 1, with the expected outcomes of the research shown on the right of each diagram. In this paper, I observe the impact of the 4G network on credit and savings deposits registered at bank branches. The scheme presented below is a guide on the interpretation of the outcomes presented and analysed in Section 5.

(a) Traditional Banks *(b) Individuals and Firms*

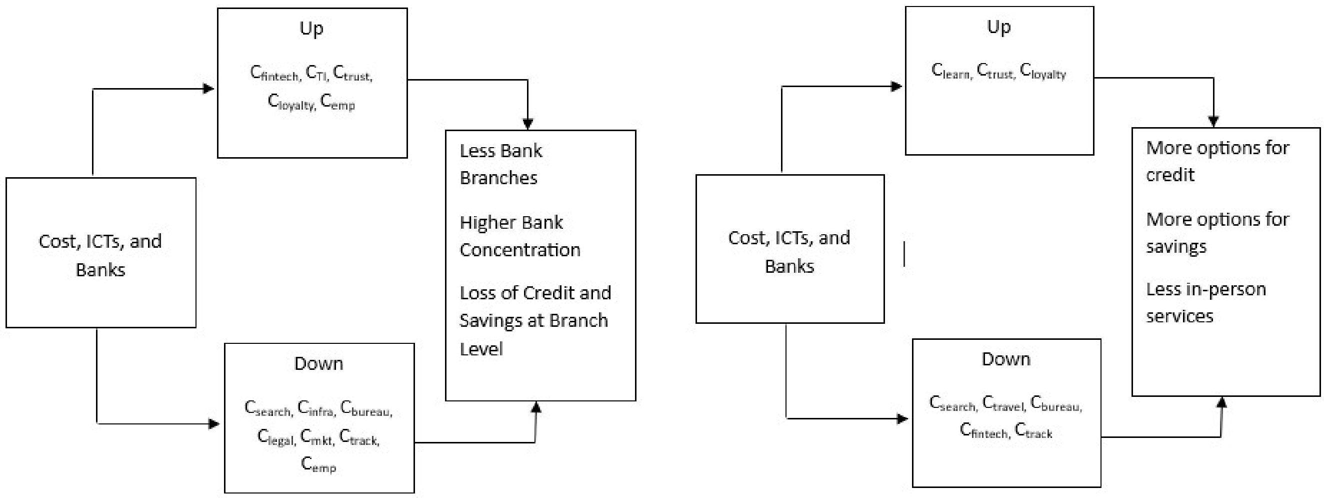


Figure 1: Cost Theory Applied to Internet Access and Banks

Source: Author

2.2 Digital Banking, Credit and Savings

What are the implications of the expansion of bank digitisation for individuals? Optimists argue that mobile banking can lead to financial inclusion (Barajas, Thorsten, and Belhaj (2020)), increased resilience to shocks (Suri and Jack (2016); Patnam and Yao (2020)), and reduced travel distances to receive government transfers Mbiti and Weil (2011). Pessimists, by contrast, argue that the closure of physical branches and the dependency of credit scored algorithms could result not only in impersonal relationships but in the perpetuation of market imperfections on credit access (Bharadwaj, Jack, and Suri (2019)), and that more digitalization will not necessarily mean that people will save more (Dubus and Hove (2017); Mbiti and Weil (2011)). In addition, the closure of physical bank branches may lead to less predisposition to save (Galdo (2021); Shrestha and Nursamsu (2020)), to impersonal relationships that worsen credit access (Berger, Miller, Petersen, Rajan, and Stein (2005)), and to the remaining branches that stay gaining market power among non-digital customers that rely on branches, which implies that non-digital customers pay higher prices for branch services and risk being financially excluded (Jiang, Yu, and Zhang (2022)).

More broadly, the path toward digitalization is not linear nor likely going to benefit all individuals at the same time. In his book, Esward Prasad discusses how digitalization will likely leave many people behind. In his words, the recent and looming changes to money and finance have significant implications for income and wealth inequality. These changes could make it easier for even indigent households to gain entry into the financial system, bring an array of products and services within their reach, and thereby democratize finance. But it is equally possible that the benefits of innovations in financial technologies will be captured largely by the wealthy as a result of disparities in financial literacy and digital access (Prasad (2021), p. 21).

In the same direction, other scholars have ben pointing out that the digitization of financial services may not benefit all communities the same. Philippon (2019) defends that although the innovation brought by technology-based business models can foster innovation, provide new gateways for entrepreneurship, and democratize access to financial services, there are privacy, regulatory and law-enforcement challenges that may increase certain types of discrimination.

Likewise, uneducated communities and low-skilled individuals who might not have the basic financial literacy to use and understand digital finance may not benefit as much from digital banking (Ozili (2018)). In addition, past literature has already shown that it is individuals with high income and higher educational levels tend to benefit more from greater financial inclusion (Demirguc-Kunt and Klapper (2013)).

Another demographic group that might not benefit from digital services availability is the rural population, which has a significantly lower quality of internet access. A 2020 study published by the Inter-American System for agriculture (IICA (2020)) showed that the Rural Connectivity Index in Brazil was only 46.9%.

The Bank of International Settlements summarizes well the complexity of bank digitization. Regardless of the level of development, common elements of concern among jurisdictions include geographic barriers related to vast territories and remote locations, economic and market structure issues including limited competition, lack of profitability when serving excluded groups, characteristics of vulnerability such as barriers by age, gender, income, lack of financial literacy, and low trust in existing financial services (BIS (2018); BIS (2022)). On a more local level, the civil society in Brazil argues that the closure of bank branches leads to ripple effects on local businesses, which are weakened without having the money circulating within the municipality. Those who withdraw their pensions, family allowances and their salaries in another city may consume there and the unbanked municipality ends up with a weakened trade, which by itself may increase unemployment levels (UPB (2020)). This concern is corroborated by new evidence that shows the opposite movement for Brazil, i.e., the opening of bank branches in 2004 led to a boost of the labour market, especially for high-skilled workers (Fonseca and Matrey (2021)).

3 The Setting

3.1 General Features of the Banking Industry

The empirical setting of this paper is Brazil, the largest economy in South America (USD 1,839 billion in 2019) and the sixth-most populous country in the world (estimated 215 million people in 2022). The current banking structure of Brazil is based on the specialization of financial institutions, which can be public or private corporations whose principal or secondary business is the collection, brokerage, or investment of financial resources belonging to themselves or third parties, in domestic or foreign currency, and the custody of assets belonging to third parties (CMN (1964)). Private and public banks are equally spread throughout the territory and have similar regulatory and supervisory frameworks. However, from the municipalities that have only one bank branch, in about 68% of the cases public banks are the only ones present. This is intimately related to the fact that public banks have the added responsibility of being the direct executioners of certain public policies in the country.

There are two main public banks in Brazil. The first is "Banco do Brasil", responsible for financing the national agribusiness, agricultural exports, and small and medium-sized companies. The second is “Caixa Econômica Federal”, which acts on behalf of the state in the implementation of social policies such as unemployment insurance, benefits from social programs, financing of popular housing, and basic public sanitation in states and municipalities (Araujo and Cintra (2011)). About 30% of all clients are from public banks (BCB (2021c)).

Brazil stands out as a country whose banking industry has passed by a striking transformation compared to the average of any other income-grouped economy. Figure 4 in the Appendix reveals the evolution of bank concentration over time compared to other countries. The sector is highly concentrated, with about 80% of total assets belonging to three private and two public “multi-service” banks, i.e., entities that can offer a large number of financial services – commercial, investment, credit, and finance related.

Another feature is the relative size of the banking system. The five largest Brazilian banks alone currently have resources equivalent to the entire Brazilian economy. Boosted by the increase in credit to meet the greater demand during the coronavirus pandemic, the volume of total assets of financial institutions surpassed the Gross Domestic Product (GDP) in the country in March 2020 (InfoMoney (2020)). Brazilian banks are also well-known for their high profitability – four of the ten most profitable banks in the world are in the country (Economatica, 2022).

Finally, Brazil is an interesting case to examine because firms are highly dependent on the banking industry to obtain loans (around 60% of the external finance), which is still above the average of Latin America (51%), the most bank-dependable region for the alleviation of credit constraint in the world (World Bank (2022)).

As of July of 2022, there were 8,627 private and 8,709 public branches spread throughout 3,145 out of the 5,570 municipalities of Brazil. These numbers are down from 12,933 private and 9,991 public bank branches in January 2014, which used to cover 3,669 (65%) of municipalities (BCB (2021c)). In addition, closing branches (“exiters”) outnumber the new branches (“entrants”) in the last ten years (panel A of Appendix Figure 5), with a growing number of municipalities that became unassisted with bank branches in the same period (panel B of Appendix Figure 5).

Of the municipalities that were covered by banks in July of 2022, 1,775 municipalities counted on only one branch. Of these municipalities with only one branch, 1,207 of them were served by public banks. Panels C and D of Appendix Figure 5 shows that both public and private banks compete for municipalities with equivalent sizes of population and GDP, although public banks have a slightly higher presence in smaller municipalities.

3.2 The Evolution of Digital Banking

Digital transactions are possible through two means: internet banking (operations done on the banks' websites, usually on desktops and notebooks) and mobile banking (operations done in applications of the banks on cellphones and tablets). A broader term defined in the literature is "online banking", which refers to "several types of banking activities through which bank customers can request information and carry out most retail banking services such as balance reporting, inter-account transfers, bill payment, etc., via a telecommunication network without leaving their homes" (Stewart, 2002 p. 6).

There is no specific regulation for "digital banking" in Brazil, as digitization permeates the whole financial system (BCB (2020)). Some banks have repositioned themselves to have customers exclusively online, so there is usually one or a few branches available for these banks. Figure 6 in the Appendix plots the savings deposits and long-term deposits for traditional versus digital banks. When comparing both, a few highlights stand out. The first is the proportion of the volume transacted in traditional versus digital banks, of up to 600 to 1 (savings deposits). The second aspect is that the speed of the growth for the financial products – as measured by the inclinations in the curves – is higher for digital banks than for traditional banks, which indicates that digital banks have been gaining market share. The third component is that while savings deposits do not seem to be the focus of digital banks (given their very small proportion), the relative space occupied for long-term deposits is much higher, about 30 to 1. Long-term deposits are more sophisticated financial products than savings deposits and require a minimum commitment that does not exist for savings deposits, which implies that digital banks are being enjoyed by higher income individuals who can afford these higher income commitments.

Panel A of Figure 7 in the Appendix offer a glimpse of the relative volume of transactions performed in traditional versus digital channels. The left panel illustrates the evolution of transactions through internet banking (i.e., through the financial institutions' websites) and mobile banking (i.e., through their mobile platforms) for all banks of Brazil. While "internet banking" has been relatively steady throughout the years (blue bars), mobile banking has grown exponentially since its inception, in 2011. The same can be observed on the right panel, which shows the number of transactions aimed at credit taking through online platforms.

Distinguishing internet banking and mobile banking is relevant in this research for two reasons. First, they offer different degrees of flexibility, which allows for the potential to reach people of different socio-economic backgrounds. Internet banking usually depends on more expensive and heavier equipment such as laptops and desktops, but mobile banking can be done on any smartphone and anywhere with an internet connection. While desktops and notebooks gravitate around 20% of households (tablets even less), cellphones availability has been increasing over the years and has reached 95% of the households in the country in 2021 (Cetic (2021)). The second reason why the distinction between mobile banking and internet banking is relevant is that these channels were initiated in different timelines: while the first online financial transactions were possible through internet banking starting in the year of 1995 (Diniz, 2006), mobile banking did not start until much later, in 2011 (Febraban (2021)).

3.3 The Role of Fintechs

The word 'fintech' relies on the concepts of data capture and analysis and how to use them to either improve existing services or create new ones (Gupta and Tham (2019)). Likewise, the Financial Stability Board (FSB) defines the concept broadly in the sense that fintechs are "financial innovations, enabled by technologies that may result in new business models, applications, processes or products with tangible assets in markets, in financial institutions and the provision of financial services" (FSB (2022)). In this work, I use 'fintech' to refer to companies whose initial and primary businesses are to deliver financial services using newer technologies, and they can have either no or very few bank branches (Jiang, Yu, and Zhang (2022)). Fintech firms are often smaller scale and funded by venture capital. They can acquire a banking license and turn themselves into a bank or choose to cooperate with incumbent banks. Some of the fintech firms may also be acquired by banks (Liu (2021)).

The authorization for opening, maintaining and closing deposit accounts exclusively through digital channels without the need for representation or presence of physical infrastructure was an important step in the direction of more digitization, a feature that was enhanced by the authorization of "credit fintechs" in Brazil in 2018 , since these are specialized firms that work exclusively in online environments and are not subject to the same regulation of traditional banking by the Central Bank of Brazil. Another nuance is that, while payment institutions also known as "fintechs" cannot grant credit directly, it is not uncommon for them to act as a digital platform to offer other products such as financial investments and operations of credit, made available by other partner banks that may even belong to the conglomerate to which the payment institution itself belongs (BCB (2021c)).[2]

Fintechs have been growing at an exponential speed in Brazil. In December 2021, there were 1,446 financial technology startups, a 90% growth compared to the previous year. However, they still have a relatively small market share (9% of credit – R$ 4 trillion in 2020 for fintechs, compared to R$ 44 trillion for the whole market in the same year) (Statista and Statista (2022)). The volume of credit per fintech is not detailed in the Estban database, so the analysis of fintechs is not part of the scope of this work.

[2]Law BR 12,865/2013.

4 Data and the Empirical Strategy

This analysis makes use of a rich set of variables coming from four different data sources: (i) administrative data from the Central Bank of Brazil countaining the physical location, balance sheets and number of banks and branches of each bank by municipality; (ii) whether a municipality is covered by the 4G network (datasets from both Teleco and Anatel); (iii) frequency of lightning strikes, to be used as an instrument to explain the evolution of the 4G network, provided by the WWLLN (Lay, Rodger, Holzworth, and Dowden (2005)) [3]; (iv) real outcomes (GDP, population, literacy rate, share of rural population) from the Brazilian Statistics and Geography Institute (IBGE), to be used in the heterogeneity analysis. In this section, I discuss the main characteristics of the variables and the datasets. Details on the variable construction and additional considerations can be found in the Appendix Table 9.

4.1 Banking

The data on banking variables comes from Estban, the monthly banking statements by bank branch made available by the Central Bank of Brazil, and covers the period between July 2012 and December of 2022, i.e., one and a half years before the initial rollout of the 4G network and the latest data available. In terms of the industry arrangement, one observes the number of banks and branches, which can be paralleled to the concepts of firms and shops in economics BCB (2022). A bank or firm enters a municipality when at least one shop is open in that market, and exits a municipality when its last branch or shop closes. A branch or shop may close in the municipality, but other shops belonging to the same bank or firm may still be present.

I also observe total credit, savings deposits, and long-term deposits per bank branch in time.[4]

[3] World-Wide Lightning Location

[4] The values observed for each variable are the "balance" deposited in each type of account, which can be broken down into the following equation:

$D_t = (1 + i_{t-1}) * D_{t-1} + L_t - P_t$

where D_t is the total debt held by individuals and firms in time t, i_{t-1} is the agreed interest rate of the accumulated debt, L_t are the new loans, and P_t are the payment of installments from individuals and firms at period t.

Table 1: Descriptive Statistics

	Mean	Median	St. Dev.
Public Banks			
Credit - Total	117.75M	45.50M	591.98M
Savings Deposits	36.96M	17.99M	80.07M
Long-Term Dep.	36.14M	3.67M	546.50M
Banks	1.54	1.00	2.02
Branches	2.76	2.00	14.10
Private Banks			
Credit - Total	106.74M	6.82M	3,130M
Savings Deposits	18.72M	9.49M	115.08M
Long-Term Dep.	42.76M	8.90M	472.80M
Banks	1.31	1.00	2.01
Branches	3.34	1.00	34.02

Notes: bank variables are in reais (Brazilian currency) and were calculated across municipality-months. Values are deflated by the Consumer Price Index (IPCA). Source: Central Bank of Brazil.

Table 1 shows the descriptive statistics separated by private and public banks across the full dataset 2012-2022. For credit, while the mean ticket is similar in both cases for total credit, there are important differences in terms of the median value (higher in public banks) and the standard deviation (higher in private banks). With respect to deposits, savings deposits are on average twice as large for public banks, while this difference is not observed for long-term deposits. For private banks, there is an average of 1.31 banks (firms) and 3.34 branches (shops) per municipality, while public banks have an average of 1.54 banks and 2.76 branches. While these numbers are similar, the dispersion is much higher for private banks.

I consider a municipality in Brazil to be the benchmark definition of a local banking market. Treated cities (i.e., municipalities that have access to the 4G network) have limited economic integration due to the extreme spatial dispersion of cities in Brazil given the country's continental size. In that sense, they can be plausibly considered a collection of small independent economies, which allows the interpretation of the estimates as "local general equilibrium effects" (Fonseca and Matrey (2021); Joaquim, Doornik, and Ornelas (2019)). This assumption is also consistent with the literature in the United States that shows that banking markets are highly localized (Cisternas Vera (2017); Garmaise and Moskowitz (2004); Granja, Leuz, and Rajan (2019); Nguyen (2019)).

From the banking data, the location of the branches is observed but not the location of borrowers. In addition, the banking operations done by individuals and firms are not disaggregated by channel, i.e., whether the operations were done through a digital means such as banking apps or the physical branch. That being said, it is plausible to assume that the differences observed in credit and savings before and after the internet rollout is due to the increased bank digitalization, given that Brazil has seen a dramatic increase in the number of digital financial transactions performed through cellphones and tablets. To illustrate it, from 2015 to 2020, there has been an increase of 173% in the use of these platforms for banking operations, with digital transactions reaching 67% of all banking activity in the year 2020 (BCB (2021c)) and 7 out of 10 bank operations in 2021 (Febraban (2022)). Panel B of Appendix Figure 7 also helps to corroborate the close relationship between the evolution of the 4G network and the credit operations taken online, as both move in the same upward direction.

4.1.1 Treatment Variables

Because the interest is to estimate the effect of mobile broadband internet availability on credit and saving, I exploit spatial and time variation in the 4G expansion. The 4G technology was the first generation of mobile networks that allowed users to actively browse the web on their phones, making financial transactions more accessible through bank apps regardless of the type of contract with the telecom carrier, pre- or post-paid. Up until 2013, about 80% of all contracts were still pre-paid (Anatel (2020)).

From the point of view of the identification strategy, it is relevant to note that the expansion of the 4G network was facilitated by the infrastructure already in place for the previous generation (3G network), which was rolled out by a complex set of regulations that requested telecom companies to serve both poor and rich regions simultaneously[5] [6]. For example, a company that won an auction to serve São Paulo (a richer region) also had to acquire and serve the Northeast (a poorer region).

Another feature of the treatment is that the mobile broadband rollout obeyed a six-step expansion rule, from the largest to the smallest cities, which resulted in a quick expansion from 8.4% of the municipalities covered at the end of 2015 to 88% at the end of 2019, as illustrated in Figure 2 below. This is equivalent to more than 4,651 municipalities connected to this mobile internet technology in a five-year interval. In terms of population, this expansion meant that, in this period, approximately 185 million people gained access to broadband 4G mobile internet coverage. By contrast, in August of 2020, the latest month available for this technology, 12%

[5] Edital 002/2007.

[6] Part of the equipment is used in the transmission of both standards (3G/4G), given that the signal arrives to the telecom operators through optic fibers originated from big backbones. From there, the signal is taken to towers through routers and high-performance switches. It is only at this last stage that the two standards, 3G and 4G network, differentiate between each other (Hamman (2013)).

(652 municipalities) were still not covered by 4G.

Interestingly enough, the rise in access to 4G technology was accompanied by a stable access to internet connectivity. As shown in Appendix Panel B of Table 2, except for the percentage of households with mobile internet use, the other indicators – the percentage of households with internet use, broadband subscriptions and mobile subscriptions – remained either stable or even decreased over time (Cetic (2021)). The reasons for this apparent contradiction are threefold. The first two help to explain the contraction of mobile subscriptions. First, telecom carriers reduced their interconnection rates, which encouraged people to reduce the number of chips (i.e., subscriptions). Second, this period coincides with free messaging services. The third explanation applies to both mobile and fixed broadband: the expansion of the 4G network coincides with years of negative or very slow economic growth in Brazil.

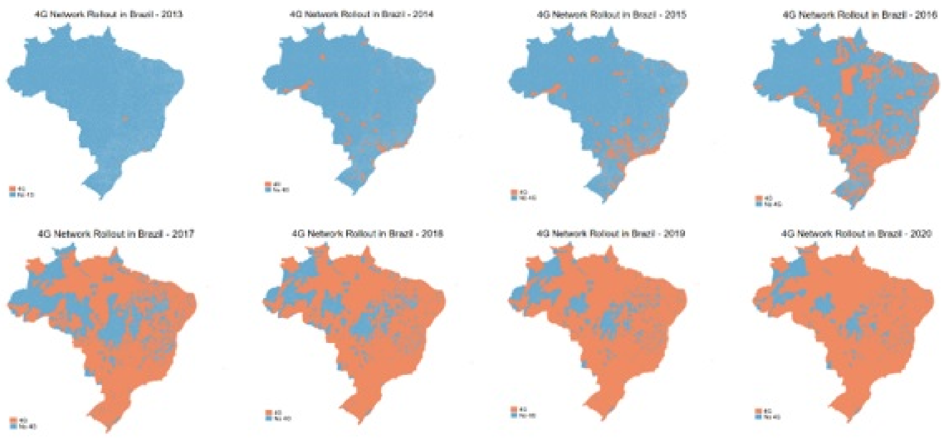


Figure 2: The Rollout of the 4G Network between 2013 and 2020

Source: Teleco (2021). Maps plot the municipalities (in orange) that had 4G network coverage (at least one telecom carrier) in December of each year (except for 2020, since the last month of the dataset is August).

The data on whether a municipality was connected to 4G internet by month and year comes from Teleco, a telecommunications consultancy firm in Brazil. For this analysis, I consider that a municipality has 4G internet at the half-year t whenever 4G started operating by June of t (first semester) or December of t (second semester). The dataset was built from the information they collect directly from telecom carriers and includes, for each municipality, the month and year of the first 4G internet connection.

As a robustness check, I also use the concept of the National Telecom Regulator (Anatel) to test the impact of the 4G network on the banking variables (see Section 6). The regulator considers that the municipality was covered by this technology in the month that the signal was measured for the first time.

4.1.2 Control Variables

Besides the banking-related control covariates such as number of banks and branches at the baseline period, I use the following demographic variables as controls: population, GDP, literacy rate, population density, and share of the rural population. The data on population and GDP are from 2012, which corresponds to two years before the initial year of the rollout of the 4G mobile networks and are provided by the Brazilian Institute of Geography and Statistics (IBGE). The other demographic data are from the Census of 2010. Panel C of Appendix Table 2 brings the descriptive statistics for the control variables and Appendix Table 9 brings a dictionary of the control variablesthat are used in this work.

4.2 Main Empirical Approach

The objective of this paper is to identify the causal effects of 4G mobile network on financial outcomes. Specifically, the interest is to compare outcomes for treated municipalities (i.e., with 4G) with outcomes in the counterfactual group (no 4G), before and after the technology rollout. A municipality is considered treated if it has at least one telecom carrier offering the service each month. The identifying assumption of the estimates is that of parallel trends: absent the 4G technology, treatment and control municipalities would show the same change over time conditional on the municipality's characteristics. Although this assumption is not directly testable, I provide evidence of its validity by examining changes in the outcomes for the treated and untreated groups before and after exposure to the 4G network.

Since the causal effect of the 4G availability on finance cannot be estimated through a random experiment, the goal is to estimate causal effects through a statistical framework. A simple means comparison between treated and untreated units does not help us to achieve causality because of the potential correlation between the independent variables and other variables that are correlated with the outcomes of interest, which render selection into the "treatment group" non-random. Instead, assignment to the treatment group will likely have been a function of some other factor and, more importantly, that other factor will be correlated with a higher or lower level of the outcome of interest before the treatment variable is even assigned. For example, richer urban areas may have the privilege of having internet first. In this case, the correlation between internet availability and credit would be confounded with the wealth effect. This makes it more or less likely to erroneously attribute a causal effect to the treatment variable when comparing the difference between treatment and control groups after assignment (Manardo (2011)).

In principle, many of the types of unobservable characteristics that may confound identification are those that vary across municipalities but are fixed over time. A common method of controlling for time-invariant unobserved heterogeneity is to use panel data and estimate differences-in-differences models (DiD) controlling for time and municipality fixed effects. Therefore, without the benefit of a controlled randomized trial, I turn to a DiD approach, which compares the change in outcomes in the treatment group before and after the intervention to the change in outcomes in the control group. By comparing changes, I control for observed and unobserved time-invariant municipality characteristics that might be correlated with the internet rollout decision as well as with the outcomes of interest. The change in the control group is an estimate of the true counterfactual, that is, what would have happened to the treatment group if there had been no intervention. In other words, the change in outcomes in treatment areas controls for fixed characteristics and the change in outcomes in the control areas controls for time-varying factors that are common to both control and treatment areas (Galiani, Gertler, and Schargrodsky (2005)). Formally, the DiD model can be specified as a two-way fixed-effect linear regression model:

$$y_{m,t} = \alpha_m + \lambda_t + \beta_t X_{m,t} + \Sigma_\tau \delta_\tau Internet_{m,t-\tau} + \varepsilon_{m,t} \tag{1}$$

where $y_{m,t}$ is an output of interest in municipality m at month t; α_m is a fixed effect unique to municipality m that removes time-invariant heterogeneity across cities, and λ_t is the effect common to all municipalities in period t; $X_{m,t}$ is a vector of bank and municipality control variables; and $Internet_{m,t-\tau}$ is a dummy variable that is equal to 1 if the municipality m is exposed to the 4G technology in month $t-\tau$. I use τ values ranging from -18 to 60, that is, one year and a half before the beginning of the internet rollout up to 5 years later. The coefficient δ is the differences-in-differences estimate of the average effect of internet availability on the outcomes of interest.

The error $\varepsilon_{m,t}$ is a municipality time-varying error and is assumed to be distributed independently of all α_m and λ_t . The errors $\varepsilon_{m,t}$ might be correlated across time and space. For example, economic potential factors could induce time-series correlation at the municipality level. Error correlation could also be present in the cross-section dimension of the panel. The economic progress of one municipality could affect neighboring municipalities. Moreover, telecom carriers may decide to provide internet in multiple cities that are close to each other at the same time. To avoid potential biases in the estimation of the standard errors, I allow for a more stringent assumption about the variance-covariance structure by computing the standard errors clustered at the micro-region level (510 clusters in the sample) instead of the municipality (treatment) level.

I also address the challenges raised by the recent DiD literature that highlights the caveats associated with the estimation of fixed-effects models with the staggered rollout of the treatment over time (e.g. Goodman-Bacon (2018)) and Callaway and Sant'Anna (2019)). Goodman-Bacon (2018) show that the coefficient for the treatment effects is a weighted average of all possible two-by-two DiD estimators in the data. As such, the use of the earlier treated as an effective control group for the later treated would be problematic because changes in the outcomes for the earlier treated units may reflect changes in the treatment effects over time. In this sense, the estimates for the treatment coefficient could be smaller in absolute values than the true treatment effects in dynamic treatment effects.[7] Section 6 shows that the results of the main specification are robust to the more stringent approach of the new literature.

One challenge of this research is that although the DiD fixed effects approach controls for time-constant omitted variables, the estimates are susceptible to attenuation bias from measurement errors. For example, credit at the branch level may artificially be declared to be zero for accounting purposes for certain banks and the balance be transferred to the headquarters of that bank, which tends to be persistent throughout time. Measurement errors can also change from month to month (a bank may decide to change policies from maintaining to not maintaining credit at zero on the financial statements). Furthermore, while the value in credit may be misreported or miscoded for only a few bank branches in any single month, the observed month-to-month changes in credit may be considered mostly noise, and persistent problems or the lack of within-variation may lead to smaller fixed-effects estimates (Angrist and Pischke (2009)). To alleviate this challenge, the bank statements are condensed on intervals of half-year periods.

Finally, although DiD can be used to estimate the effects of time-varying independent variables in the presence of time-constant omitted variables, this methodology does not help solve the problem of time-varying omitted variables that may be correlated to the explanatory variables (Wooldridge (2020)). To mitigate this concern, I turn to a second identification strategy – the 2SLS/IV approach, as developed in Section 6.

5 Results: 4G Network and Banking

This section presents evidence of the impact of the 4G mobile network on banks and branches separately by private and public banks, followed by the impacts on credit, savings, and long-

[7]Sun and Abraham (2020) provide a unified framework for average treatment effects in DiD setups with multiple periods, variation in treatment timing, and when the parallel trends assumption holds potentially only after conditioning on observed covariates, thus avoiding the traps in the interpretation of DiD for multiple periods as pointed out by previous work (Athey & Imbens, 2018; de Chaisemartin & D'Haultfœuille, 2020; Sun & Abraham, 2020).

term deposits. All results here are obtained through the main specification, that is, the dynamic DiD approach.

5.1 Main Outcomes

5.1.1 Banks

The first variable we explore is the number of banks or 'firms' per municipality over time. A firm is considered to exit the local market when their last branch closes in the municipality. Panels A and B of Figure 3 show an event study design using TWFE for multiple time periods for the number of private and public banks per municipality pre and post internet rollout.[8] It plots the coefficients of the internet (4G network) captured by the δ_τ's estimated from Equation (1) with the number of banks in municipality m at the half-year t as the dependent variable. Following the rollout of the 4G network, there is a small expansion of banks in the first three semesters post-technology, but after that banks exit municipalities by up to 6% at the end of five years. By contrast, no movement is observed for public banks.

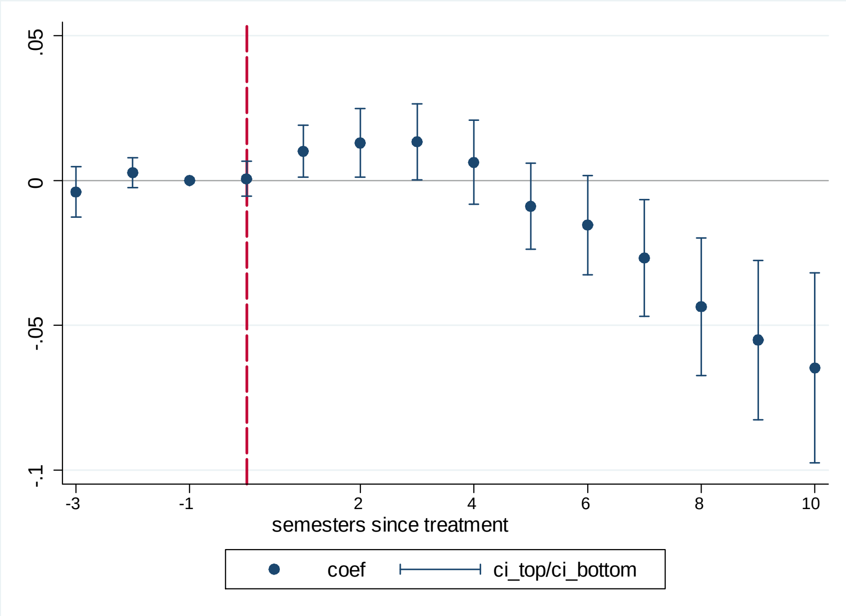
These graphs are important because they show that: (i) treatment municipalities are not systematically different from controls before the rollout, which shows that the parallel trends assumption is plausible; (ii) the impact of mobile network on banking is indeed large; (iii) there is a clearly distinct behaviour between private and public banks in response to the 4G network, with private banks exiting municipalities in response to more technologies while public banks do not display any reaction. Together, these results support the current literature of the impact of digitization on banking: more internet resources lead to the shrinking of their physical presence, and this movement is being led by the private sector.

5.1.2 Branches

Using the same approach as the previous section, Panels A and B of Appendix Figure 9 show the number of private and public branches ('shops') pre and post internet rollout. Following the start of the 4G network, private branches systematically fall by up to 11% in five years. This result is also consistent with the methodology of Sun and Abraham (2020) and displayed graphically at Appendix Figure 11 and in Table 3. With respect to public banks, there seems to be a slight increase in the number of branches, but by the end of three semesters after the 4G is implemented this movement stops. This outcome suggests that another channel might be at play: the potential expansion of investments in local markets sparked by the internet.

[8] The term "dynamic differences-in-differences" is used as a synonym of the staggered TWFE in this text.

(a) Private Banks



(b) Public Banks

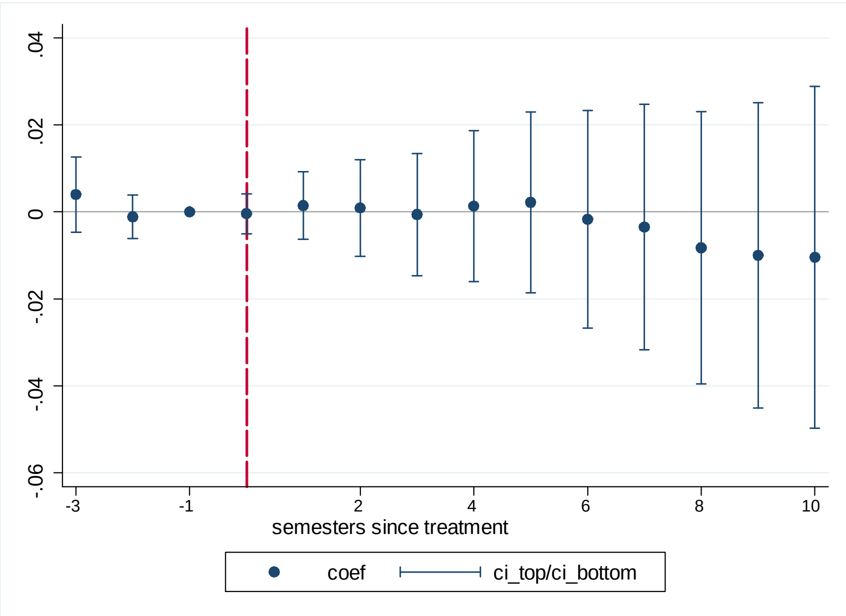


Figure 3: Number of Banks per Municipality

$\delta_{\mathcal{T}}$'s estimated from Equation (1) with the number of private and public banks in municipality m at the half-year t as the dependent variable using dynamic differences-differences. The regression outcome is from the branch-municipality balance sheets (ESTBAN). Standard errors are clustered at the municipality level. Bars show 95% confidence intervals. Values are normalized at $\delta_{-1} = 0$. Treatment municipalities are those that started to count on at least one telecom carrier to offer 4G network. Vertical lines represent the number of semesters that passed since the initial rollout of the internet technology.

5.1.3 Credit

Total credit at private branches has fallen in the period of the implementation of the 4G network, by about 14% in five years. Credit at public banks is more reactive to the internet –

up to 35% in five years. Panels C and D of Figure 9 and Table 4 detail the coefficients over time. Total credit can be further granulated by earmarked and non-earmarked credit in the bank statements, with earmarked credit targeted to the agricultural and real estate sectors. Earmarked credit accounts for roughly 30% of all loans and is funded and allocated through government programs. The government uses both private and public banks to allocate this type of loan, although about 75% of the volume of credit to housing market and to agriculture is distributed through public banks. The regressions for these two these variables show that both of these concessions are also sensitive to the 4G network, but only for public banks [9].

5.1.4 Deposits

Understanding the path of savings accounts as well as deposits is relevant to the analysis of how financial services are being used, as they are basic services offered by banks that guarantee the safe and convenient storage and movement of resources (BCB (2021a)).

Savings deposits can be considered a Giffen good because they are the worst alternative for savings in Brazil, in the sense that the yield is below inflation depending on the basic interest rate of the economy. Contrary to other forms of investment, there is no minimum amount to be retained in the bank, so usually, this product is the "first entrance" to saving in banks. With more internet, customers from both private and public banks drive away from savings deposits in traditional banks. Panels A and B of Appendix Figure 10 show that savings deposits falls both at private and public banks, a suggestion that customers are looking for more complex savings alternatives as new options are open with more internet resources. The decrease in the volume of savings deposits is more pronounced for public banks (-46% at the end of five years) than for private banks (-24%), which is consistent with the path of private branches (strong decrease) and public branches (mild increase) with respect to the internet.

Long-term deposits, which are comprised of more sophisticated savings products with varying portfolios of private and public bonds, escape private branches with more internet resources by up to 81% in five years, although the same is not observed for public banks (Panels C and D of Appendix Figure 10 and Table 4). This is easy to interpret given that although the profile of customers of private and public banks may be similar on average (Almeida (2022)), private banks hold about 70% of long term deposits. In addition, private banks may be preferable for high-income individuals and firms (Mariano (2015)).

Three pieces of evidence help corroborate the results that were obtained for savings and long-term deposits in this work. The first is the skyrocketing increase in the volume of term deposits through mobile banking, from 76 to 147 million reais between 2020 and 2021, a 93%

[9] Graphs and tables available upon request.

increase in the period (Febraban (2022))[10]. The second comes from two recent surveys that show that term deposits from traditional banks have lost relative ground for similar products in digital banks (Falla (2022)). Third, there has been a detachment between term deposits and savings deposits in the months following the pandemic of Covid-19, with the first rapidly gaining ground while the last decreased (BCB (2022)).

5.2 Event Study and the New Literature on DiD

Recent studies show that, in the presence of heterogeneous treatment effects, the coefficients on the leads and lags of the treatment variable in an event study might place negative weights on the average treatment effects for certain groups and periods (e.g., see Goodman-Bacon (2018); Callaway and Sant'Anna (2019); de Chaisemartin and D'HaultfÅŞuille (2020); Sun and Abraham (2020)). To address this concern, I follow the alternative regression-based model that is more robust to treatment effects than the classical dynamic treatment effects (TWFE) by using the shares of cohorts as weights, guaranteeing that the estimates are weighted averages of the underlying effects (as in Sun and Abraham (2020)). In particular, this method proposes an estimator that uses last-to-be-treated units as the comparison group rather than the not-yet-treated of the classical TWFE.

The results of the TWFE dynamic differences-in-differences (odd columns) are contrasted to the more stringent estimates of Sun and Abraham (2020) (even columns) for private banks and branches in Appendix Table 7. The results are confirmed in general, with most cases consisting of smaller coefficients with the stricter literature.

For public banking, although the number of banks seems to be increasing at a statistical significance using Sun & Abraham, the coefficients are very close to zero[11]. For branches, the internet seems to increase the number of shops in the first years post-4G rollout using the more stringent specification, but at the end of five years they are also negative and statistically significant. This implies that the increase in the number of public branches with the internet obtained with the dynamic DiD must be interpreted with caution. As with private banks, the volume of credit, savings deposits, and long-term deposits are confirmed, although at smaller coefficients. As a graphical example, I compare the dynamic treatment effects and the estimators proposed by Sun and Abraham for the fall of private branches in Appendix Figure 11. The parallel trends assumption holds well in both cases and the coefficients are similar.

[10] Local currency. In December of 2021: 1 US$ = R$ 5.5713 (BCB, 2021).

[11] The contrast of variables for public banks is available upon request.

6 Robustness Checks

In this section, I present evidence that suggests that, under the assumptions made in the DiD approach, the variation of the 4G network in Brazil is plausibly exogenous. I also corroborate this evidence by performing an instrumental variable analysis by using lightning strikes as a geographical barrier to the 4G network as an exogenous source of variation in the speed of the implementation of the 4G network.

6.1 Placebo: test advancing treatment of 4G network by 7 years

To further probe the plausibility of the identification assumption, I conduct a falsification test and estimate a placebo DiD with a similar specification but advancing treatment in five years, that is, with treatment starting in January of 2009. The variables of interest – banks, branches, credit, savings, and short- and long-term deposits – do not have a distinguishable path for treated and untreated municipalities[12]. This is true for both the pre- and post-events, as the coefficients have high confidence intervals at non-statistically significant levels. This parallel trend of the variables in another time period increases the confidence in the identification assumption. In other words, in the absence of the 4G network, the group of affected and unaffected municipalities by the treatment would have continued on approximately parallel trends in the post-treatment period.

6.2 Using Municipality-Bank Fixed Effects and Micro-Region Year Fixed Effects

The main results displayed in Tables 3 and 4 are robust to two alternative specifications. The first one implements municipality-bank fixed effects instead of municipality fixed effects, to account for time-invariant characteristics of banks' decisions (Jiang, Yu, and Zhang (2022)). The second specification changes the correction of the standard errors by implementing a two-way clusterization at the level of municipalities (to account for correlation over time) and at the level of micro-regions in each year (to account for within-micro-region-year correlation) (Guriev, Melnikov, and Zhuravskaya (2021)) [13].

6.3 Alternative Definition for 4G Network

Contrary to the main dataset used in this research, which was made available by a telecom private company that collected the information directly from the telecom carriers, the National

[12] Graphs and tables available upon request.
[13] Available upon request.

Telecom Regulator (Anatel) officially recognizes that a municipality is covered by the 4G network when the signal was physically measured in loco. By that criterion, the 4G network only became available starting in September 2014. By July 2021 (the latest available date), there were 5,329 municipalities covered with this mobile technology (95.6% of the total cities). Using this alternative definition, I run new regressions following the main specification (equation 1). The results are qualitatively similar under this alternative definition of treatment[14].

6.4 Lightning Strikes as an Instrumental Variable

To single out the exogenous source of variation in the speed of regional 4G expansion, I adopt an instrumental variables approach that explores the mean frequency of lightning strikes per area of municipality using the World-Wide Lightning Location Network (WWLLN) dataset. The WWLLN provides the exact coordinates and time of all cloud-to-ground lightning strikes across the world which, in contrast to in-cloud lightning, is much more relevant in affecting the mobile infrastructure (Guriev, Melnikov, and Zhuravskaya (2021)).

The identification assumption behind the IV approach demands two conditions. The first is the exclusion restriction, which is not directly testable but by inference we can plausibly conclude that the instrument affects y_{mt} only through its effect on internet expansion. In the context of this paper, the exclusion restriction is likely valid because the decision to close branches or provide credit is unlikely to be driven by weather conditions (except in extreme climatic cases).

The second condition is the "relevance restriction", i.e., the incidence of the instrumental variables must be meaningful in explaining the speed of access to the internet (Angrist and Pischke (2009)). This condition is testable and is shown both graphically and numerically. Graphically, panel B of Appendix Figure 12 illustrate the relationship between the speed of the 4G mobile network adoption and lightning strikes. To capture the potential to explain the rollout of the internet connectivity, a dummy equal to 1 was associated with the IV above the national average. Numerically, the F-statistic of the excluded instrument is 10.57, which satisfies the usual 'rule of thumb' associated with the exclusion restriction. Given these results, it is possible to conclude that the chosen IV not only moves the 4G network in the predicted direction, but the concern of "weak instrumentation" does not seem to be relevant in this case.

The problem of selection bias is minimized in the IV approach by finding a variable (or instrument) that is correlated with the treatment ("availability of the 4G network") but not correlated with unobserved characteristics affecting the outcomes. This instrument is used to predict the timing of the internet connectivity (Khandker, Koolwal, and Samad (2009)).

[14] Idem note 11.

The ground for the identification of the mobile network evolution relies on the strategy of identifying natural and exogenous spatial barriers that explain why certain regions inside a country get connected before others. In this work, I explore the incidence of lightning strikes, which hinder the rollout of telecommunication technologies because the power surges associated with them will increase the costs of providing service and maintaining the telecommunications infrastructure. The frequency of lightning strikes has been shown to affect the diffusion of digital technologies due to an increase in the expected costs associated with voltage spikes and dips (e.g., Andersen, Bentzen, Dalgaard, and Selaya (2009)). The equipment needed for mobile phone infrastructure, including the mobile broadband network infrastructure, is particularly sensitive to electrical surges caused by lightning strikes, which can lead both to immediate damage and quicker depreciation of equipment over time (Martin (2016); Zedham and Day (2014)). Power surge protection can partially alleviate the problem, but it is expensive, not always effective, and less readily available in developing countries.

The data from the World Wide Lightning Location Network contains the exact coordinates and time of all detected cloud-to-ground lightning strikes for the entire globe. I calculate the average number of strikes of the respective polygon of the municipalities between 2014 and 2020 and consider that a municipality has a high frequency of lightning strikes if it is above the national median.

This methodological approach is particularly suitable to study the case of Brazil because the country is a world leader in lightning strikes, with an average of 77.8 million electrical discharges every year. This is explained by both the location and size of the country's area – Brazil is the largest tropical country on the planet, and the tropics have the most storm-susceptible climate (Junior and Pinto (2021)).

As both the endogenous regressor (availability of 4G) and the exogenous source of variation are at the municipality level, I estimate the following first-stage equation at the municipal-monthly level:

$$Mobile_{m,t} = \vartheta z_m + \beta_t X_{m,t} + \delta_\tau trend + \varepsilon_{m,t} \tag{2}$$

where $Mobile_{m,t}$ is a dummy variable that is equal to 1 when the telecom carrier starts to operate at the municipality, z_m is a dummy variable representing the high frequency of lightning strikes, $X_{m,t}$ is a vector of control variables, and $trend$ is a linear time trend to reflect the evolution of the 4G network over time. The vector of control variables aims to reflect the sociodemographic and economic features that help to explain access to the internet and contains the literacy rate, the share of the rural population, and the GDP of the baseline year

(2012).

Assuming that a valid instrument z_m for the 4G mobile rollout is chosen, and following Wooldridge (2002) and Adams, Almeida, and Ferreira (2009), a consistent estimate of the coefficient for the 4G network δ_τ is obtained by the following procedure:

1. Estimate a binary response model (e.g. probit) of δ_τ on z_m plus relevant controls. This model is adopted given the binary nature of the dependent variable (1 when the first telecom carrier starts to offer the service in the municipality).

2. Compute the fitted probabilities (δ_τ), reconstructing the initial date of the rollout by rounding up the fitted probabilities to the first integer and re-estimating the new dates (as in Belyadi and Haghighat (2021)), now informed with the exogenous instruments and covariates.

3. Estimate $y_{m,t}$ by the IV-adjusted dates and the same structure of the DiD, to capture the coefficients over time, with the following specification:

$$y_{m,t} = \alpha_m + \lambda_t + \beta_t X_{m,t} + \Sigma_\tau \delta_\tau \widehat{Internet}_{m,t-\tau} + \varepsilon_{m,t} \tag{3}$$

where $\widehat{Internet}_{m,t-\tau}$ is a dummy variable that is equal to 1 if the municipality m is exposed to the technology in the new estimated date using the instrumental variable.

This procedure is different from the traditional method of running an OLS regression of the outcome variable on the predicted value of the independent (endogenous) variable and controls. This is justified by the fact that the 2SLS has a number of shortcomings with binary endogenous variables. First, predicted values in linear probability models are not bound within the unit interval. This can contribute to heteroscedasticity in single equation models and lead to "awkward" interpretations of conditional probabilities (Wooldridge 2002, p. 455). In addition, as Moffitt, R (2001) and Wooldridge (2002) point out, neglecting to control for non-linearity in the first stage of the linear probability model can lead to inconsistent estimates in the second stage. By contrast, Chiburis, Das, and Lokshin (2012) find that probit models tend to perform better than 2SLS when there are continuous covariates and treatment probability is close to 0 or 1. Both conditions are satisfied here. Moreover, as pointed out by Wooldridge (2002, p. 623), the usual test statistics and IV standard errors obtained through the application of probit in the first stage are still asymptotically valid.

The results of the IV regressions are displayed on Appendix Table 8. The coefficients are either confirmed or have a slightly lower coefficient by using the 2SLS/IV approach.

7 Evidence on the Mechanism: Distributional Impact

The internet has the potential to revolutionize banking services with significantly lower costs to individuals and firms, acting as a distribution channel for the banking industry (Barbesino, Camerani, and Gaudino (2005)). Different types of ICTs can help reduce information asymmetry and imperfect information in markets, which in turn helps with tasks related to search and coordination, leading to increased market efficiency (Beuermann (2015); Chong and Yanez (2020)) and lower tracking costs (Goldfarb and Tucker (2019)) while creating the challenge of the so-called e-business relationships (Stewart, 2002; Warrington et al., 2000), including on how to build trust (Bank (2020)) and loyalty (Dinlersoz and Pereira (2007)). From the point of view of the industry, the arrival of new players such as fintechs generates even more pressure to increase efficiency and reduce costs (BIS (2022)).

Appendix Table 5 and Table 6 show the impact of 4G network on banks, branches, credit and long-term deposits segmented by high and low GDP, population, and literacy rate (equal to 1 if above national median) and by the urban and rural classification for municipalities (IBGE (2017)). In general, municipalities that are rich, big, urban, and have relatively more literate populations are the ones that display the stronger impacts on the rearrangement of the industry and a rippling effect on credit and deposits. However, some exceptions apply. There is some evidence that while private banks are closing on richer municipalities, they might be opening in poorer ones (column 1of Table 5). A similar opposite movement was observed for public banks in high- versus low-literacy rates (column 2 of Table 5). There is also a modest evidence that total credit at private branches are increasing in relatively poor municipalities in response to the internet resources while this is not observed in rich markets (column 1 of Table 6). The most likely explanation for these contrasting results is the occurrence of a rechanneling of resources to branches where online services might not be as available.

8 Policy Implications

Several issues related to public policy emerge from this paper. The first refers to the distinct behaviours of public and private banks in response to more internet resources. While it is common knowledge that the private sector has more flexibility and agility in adapting to new technologies than governmental institutions (Gatautis, Medziausiene, Tarute, and Vaiciukynaite (2015); Li (2005)), this is the first paper that shows the unique patterns of private and public banks in response to ICTs in a developing setting. That fact that public banks are not sensitive to mobile networks while private banks tend to exit the markets as a consequence of more technology reflects their different management decisions. This is even more striking considering that, while private branches have been steeply declining in response to mobile networks, public branches seem to be slightly increasing, at least in the short run. These results show that policymakers must be attentive to the dynamic of the industry itself, particularly given the many changes that are expected to happen with bank digitization in the near future (Temenos (2019)).

The second policy implication relates to the rearrangement of the local economy when bank branches are no longer available. When a branch closes, there may be ripple effects on local businesses, which are weakened without having the money circulating. Those who receive their pensions, family allowances, and their salaries in another city may consume where they receive their resources. The unbanked municipality ends up with a weakened trade, which may increase unemployment levels (UPB (2020)). Even if public banks seem to have been opening branches in response to the internet, their movement of added units is much smaller than the closure of branches happening on the side of private banks.

The third policy implication pertains to the risk of financial exclusion, as the digitization of financial services may not benefit all communities equally. For example, uneducated communities and low-skilled individuals might not have the basic financial literacy knowledge to use and understand digital finance (Ozili (2018)). Past literature has shown that individuals with high income and higher education levels tend to benefit more from greater financial inclusion (Demirguc-Kunt and Klapper (2013)). A recent national survey confirmed that while 90% of the individuals in the upper income bound had done financial transactions through the internet in the previous 12 months, only 25% of minimum wage workers declared to have done so. Likewise, while 79% of individuals with tertiary education declared to have done digital financial transactions, only 12% of the illiterate individuals enjoyed the same habit (Cetic (2021)). In this paper, the regressions that consider the relative importance of literacy rate (Appendix Table 5) show that the banking outcomes for municipalities with higher literacy rates follow a similar pattern of the richer municipalities, a suggestion that the inequality observed in the national qualitative data is also present in the outcomes of this paper. Similarly, rural populations may not benefit the same as they usually have a significantly lower quality of internet access (IICA (2020)). In fact, recent national data showed that, while 45% of adults in urban centres performed digital financial transactions in urban centres, only 21% of the rural population followed the same pattern (Cetic (2021)).

The fourth policy implication is related to the finding that all forms of credit and savings are more impacted in relatively more populated municipalities in Brazil. This outcome suggests that, as the internet disrupts traditional banks, customers from the big centers are taking proportionately more advantage of the new digital banking resources available than those living in smaller municipalities. This outcome suggests the potential for the deepening of inequality through the banking channel, as higher-income and financially literate individuals from big municipalities are taking advantage of digital resources and their better prices and convenience while poorer and uneducated individuals who have an inelastic demand for bank products continue depending on physical branches to meet their financial needs – including to receive resources from social assistance programs, making them pay for the physical branches available (Jiang, Yu, and Zhang (2022)).

The fifth policy implication is that while this paper shows that the 4G network is the first type of internet technology that caused an impact on the banking system, it is certainly not the last. The advent of new technologies such as the forthcoming generation of mobile networks (5G in the case of Brazil, 6G for other countries) promises to provide much faster connectivity, which may deepen the results that are observed in this work. As pointed out by the World Economic Forum when discussing the implementation of the 5G network, digitization must be rolled out across all sectors of the economy for it to work – both public services and the industry (WEF (2021)). To reduce the digital inequality that may be amplified with newer and more expensive technologies, there could be incentives for private stakeholders to make wi-fi service points available in public spaces such as schools and community centres. Another solution would be to strengthen the regulation of the sector to make sure that telecom carriers will provide the services in both economically profitable and marginalized communities, as was done with the implementation of the 3G network in the mid-2000s.

The final policy implication is related to the last, but from the banks perspective. As financial transactions get increasingly internet-dependent, more sophisticated products are also being created. The Brazilian IP scheme that enables users to send or receive payment transfers through banking apps in a few seconds (PIX) has the potential to lower financial costs and increase financial inclusion, but not all individuals can benefit with the same intensity of these services as the degree of connectivity varies within the country. The same can be predicted as happening when the Central Bank Digital Currency becomes a reality. In this sense, the new "technology run" from the banks' side may also deepen the disparity between the rich and the poor.

9 Conclusions

There has been an increasing recognition that Information and Communication Technologies (ICT) are a key component of social and economic development, given their potential to integrate and accelerate innovation and social inclusion. The adoption of these technologies by citizens, governments, and firms is a relevant component to eliminating sources that generate and deepen structural disparities that already exist in Brazil. For the banking industry, in particular, internet resources can create opportunities to expand forms of credit, more sophisticated savings mechanisms, and ease of making financial transactions with the press of a few buttons instead of having to travel to bank branches to obtain these services. In other words, reliable ICTs may lead to increased expansion of access to financial services in places where the population is scant or where the geographic or security conditions are difficult to overcome, in addition to providing the means through which individuals can seek information to help them make better financial decisions. However, this is possible only when there is reliable connectivity.

Promoting access to the internet involves taking care of technical, political, and regulatory aspects to guarantee sustainable transformation. Even though telecom service providers have a key role in expanding networks and developing new business models, Brazil's sociodemographic characteristics make the market much less attractive to the private sector in several municipalities. In particular, public policies targeted at universal access to the internet in the country still face the enormous challenge of reducing the digital divide, particularly for low-income households and those living in rural areas. Moreover, policies must not only expand access but also ensure the continuous improvement of networks. This component is important to ensure that individuals can develop the skills and capabilities to capitalize on the dividends of digital transformation.

To summarize, ICTs are a potential tool to promote development. They can close information gaps and improve the efficiency of banking services, but these technologies also depend on factors related to differences in access. Poor, less educated or individuals living in rural areas will benefit less as they do not have the same access to the infrastructure of the internet and may not be able to afford computers or internet subscriptions. This means that the potential benefits for development originating from ICTs are diminished, as their gains come not only from the number of devices installed but also from the quantity, quality, and effective use of digitized information and communication in the system (ECLAC (2011)).

This paper unveiled another dimension of the importance of eliminating the disparity in internet access: as richer municipalities are those that usually first get access to reliable internet, its spillover effects onto credit and savings might contribute to deepening inequality even further. Besides, as bank branches close and migrate to online platforms, certain segments of the population may be vulnerable to financial exclusion, particularly those who cannot afford to pay for internet subscriptions and good-quality equipment to use online banking services, not to mention illiterate individuals who do not have the knowledge or trust on how digital financial transactions work.

Understanding the impact of earlier technologies to access the internet on financial outcomes is also important to glimpse at the future of the financial industry in general and of the credit and savings market in particular. As improved types of technological progress while the financial industry reacts by providing more services virtually, what can be expected in terms of financial inclusion or exclusion? Are credit conditions improved or worsened? In the words of the economist Esward Prasad (Prasad (2021), p. 21):

The recent and looming changes to money and finance have significant implications for income and wealth inequality. These changes could make it easier for even indigent households to gain entrée into the financial system, bring an array of products and services within their reach, and thereby democratize finance. But it is equally possible that the benefits of innovations in financial technologies will be captured largely by the wealthy as a result of disparities in financial literacy and digital access.

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A Figures

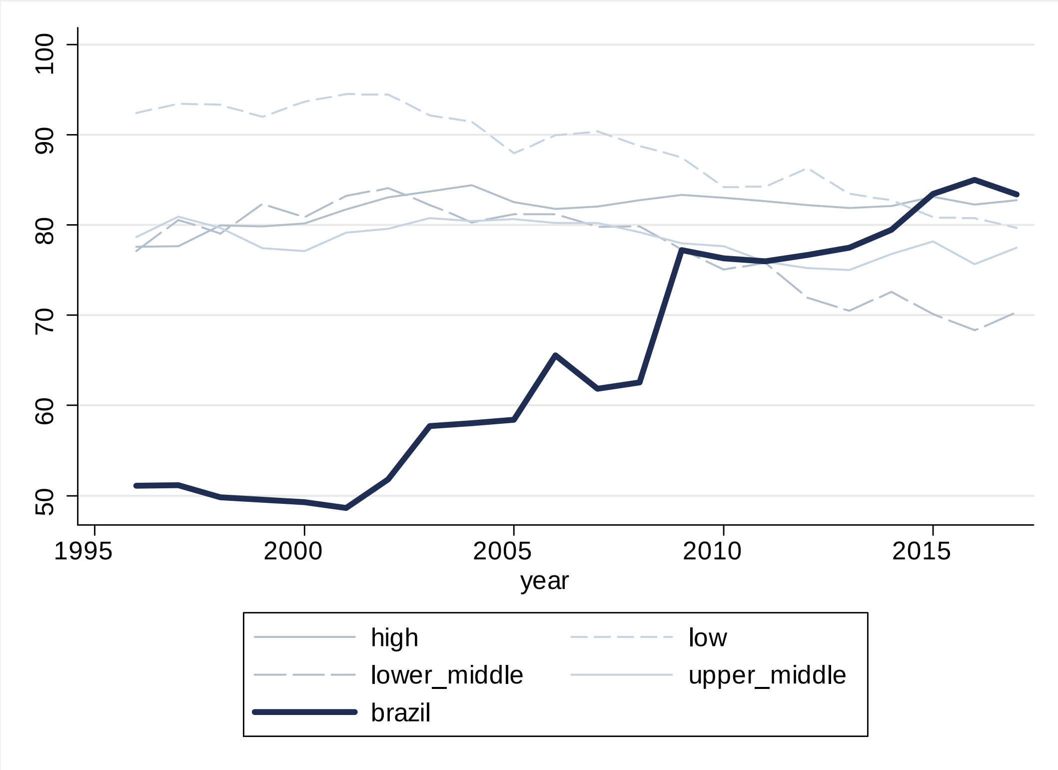
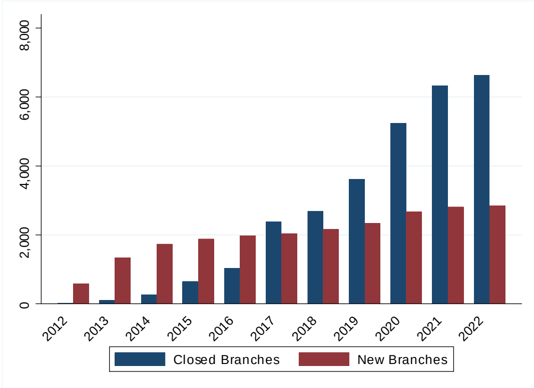


Figure 4: Evolution of Bank Concentration for Brazil and Selected Regions

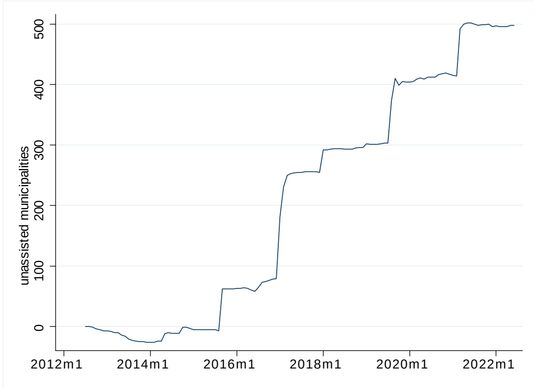
Notes: % Share of 5 Largest Banks. Data from the Global Financial Development Database (World Bank). Brazil is compared in bank concentration (percentage of share of assets of the five largest banks) to the average of high, upper-middle-, and low-income countries.

Panel A: Incoming and Outcoming Branches and Unassisted Municipalities

(a) Branches – incoming and outcoming

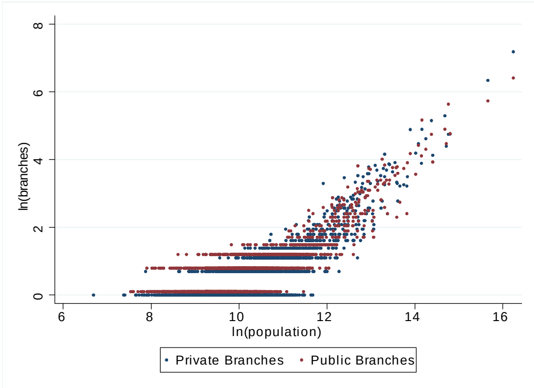


(b) Unassisted Municipalities



Panel B: Presence of Private and Public Banks by the Population and GDP

(c) Branches as a function of the population



(d) Branches as a function of the GDP

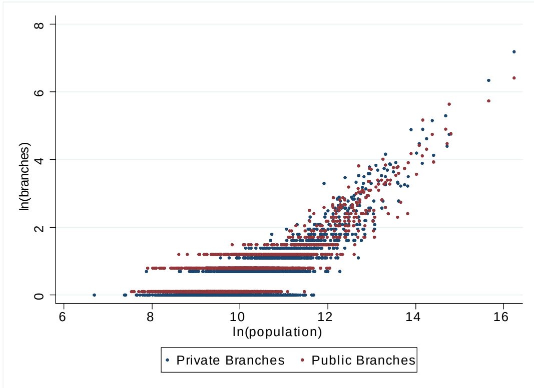
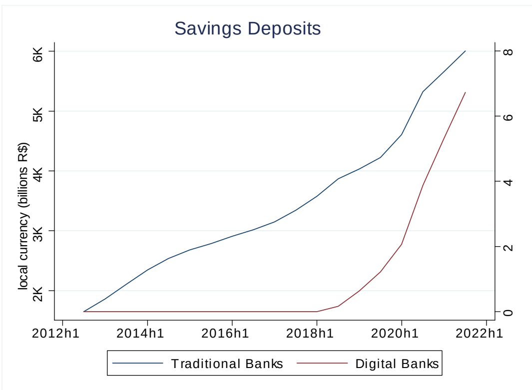


Figure 5: Profile of the Banking Industry

Notes: Panel A: the panel on the left shows the cumulative number of branches that closed (red) and opened (blue) in the period analysed. The panel on the right shows the cumulative number of municipalities that had at least one bank branch and were left without a bank branch between 2012 and 2022. Panel B: the distribution of branches is shown by population and GDP of the baseline year (variables in log).



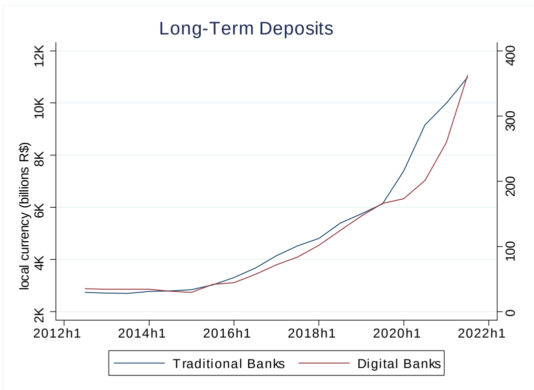


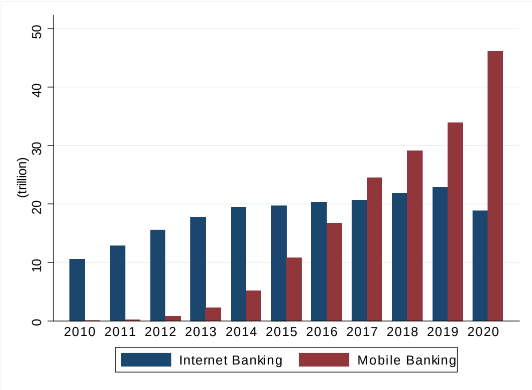
Figure 6: Traditional versus Digital Banking

Note: comparison of savings and long-term deposits held at traditional and digital banks. Digital banks are those that have repositioned themselves to have none or very few branches to offer exclusively online services .

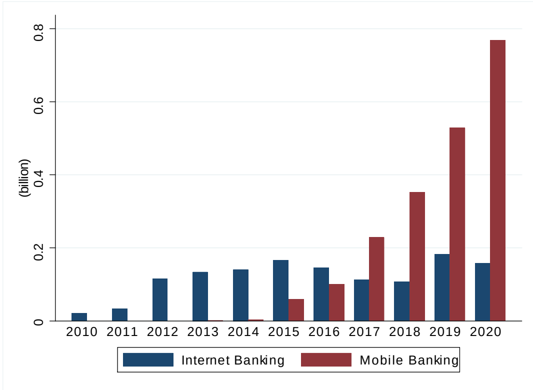
Local currency corrected by the local CPI index (IPCA-BR). Fintechs are not included.

Panel A: Evolution of Digital Transactions

(a) Total Digital Transactions



(b) Credit through Digital Transactions



Panel B: Evolution 4G Network and Credit Operations Through Bank Apps

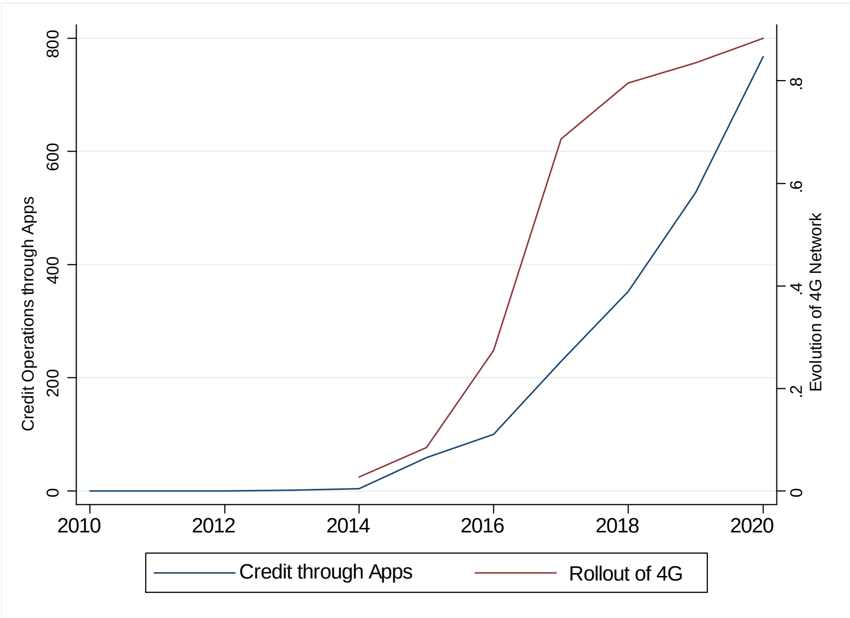


Figure 7: Evolution of Digital Banking

Note: Panel A: Source: BCB (2021b). These are exclusively the number of transactions. The volume transacted in digital channels is not available. Panel B: Source: Febraban (credit) and Teleco (4G Network)

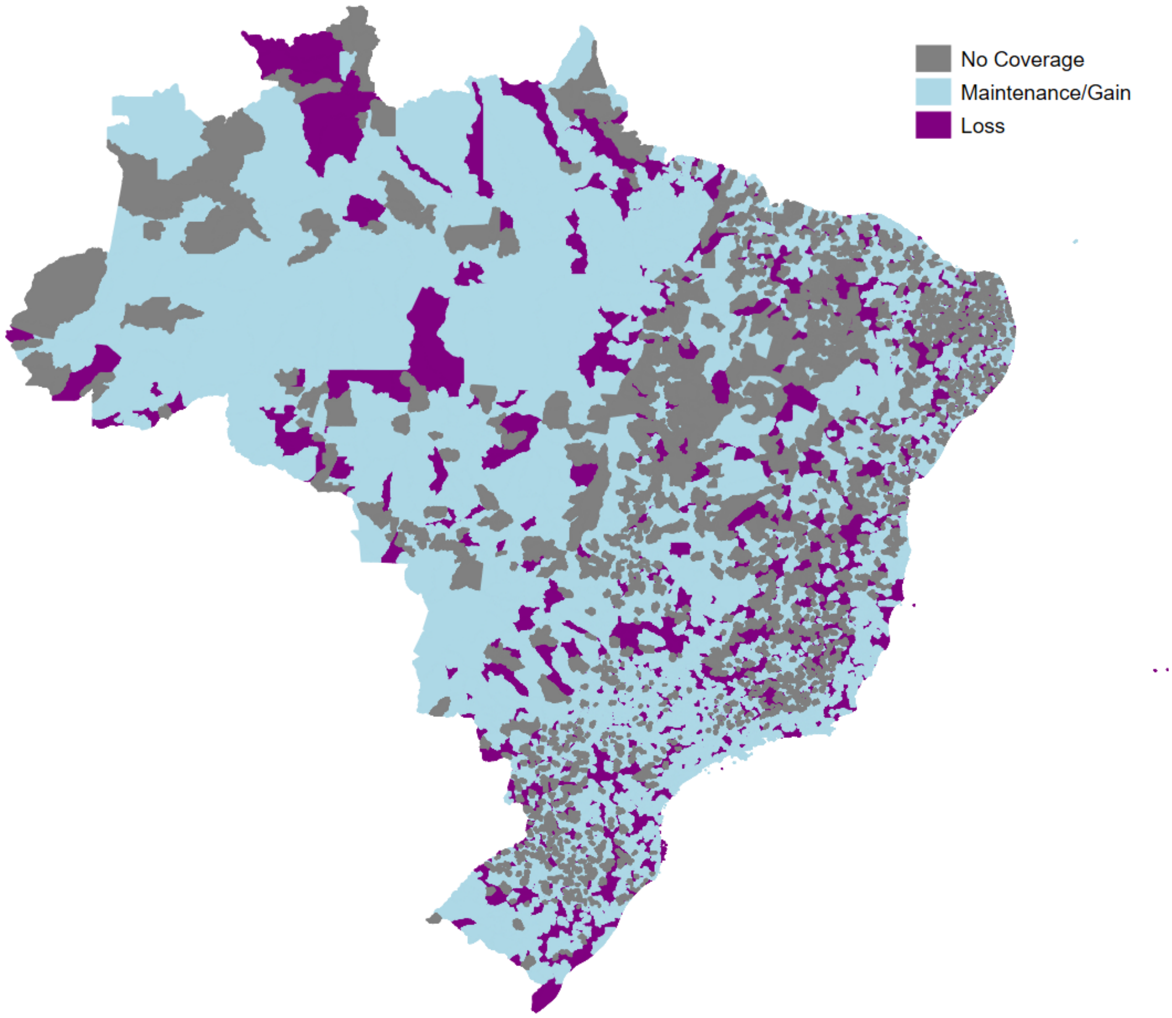


Figure 8: Evolution of Bank Variables in 2014-2021

Representation of cities that lost branches (dark blue), never had coverage (medium blue), and maintained branches (light lavender). Period considered: January of 2014 to December of 2021.

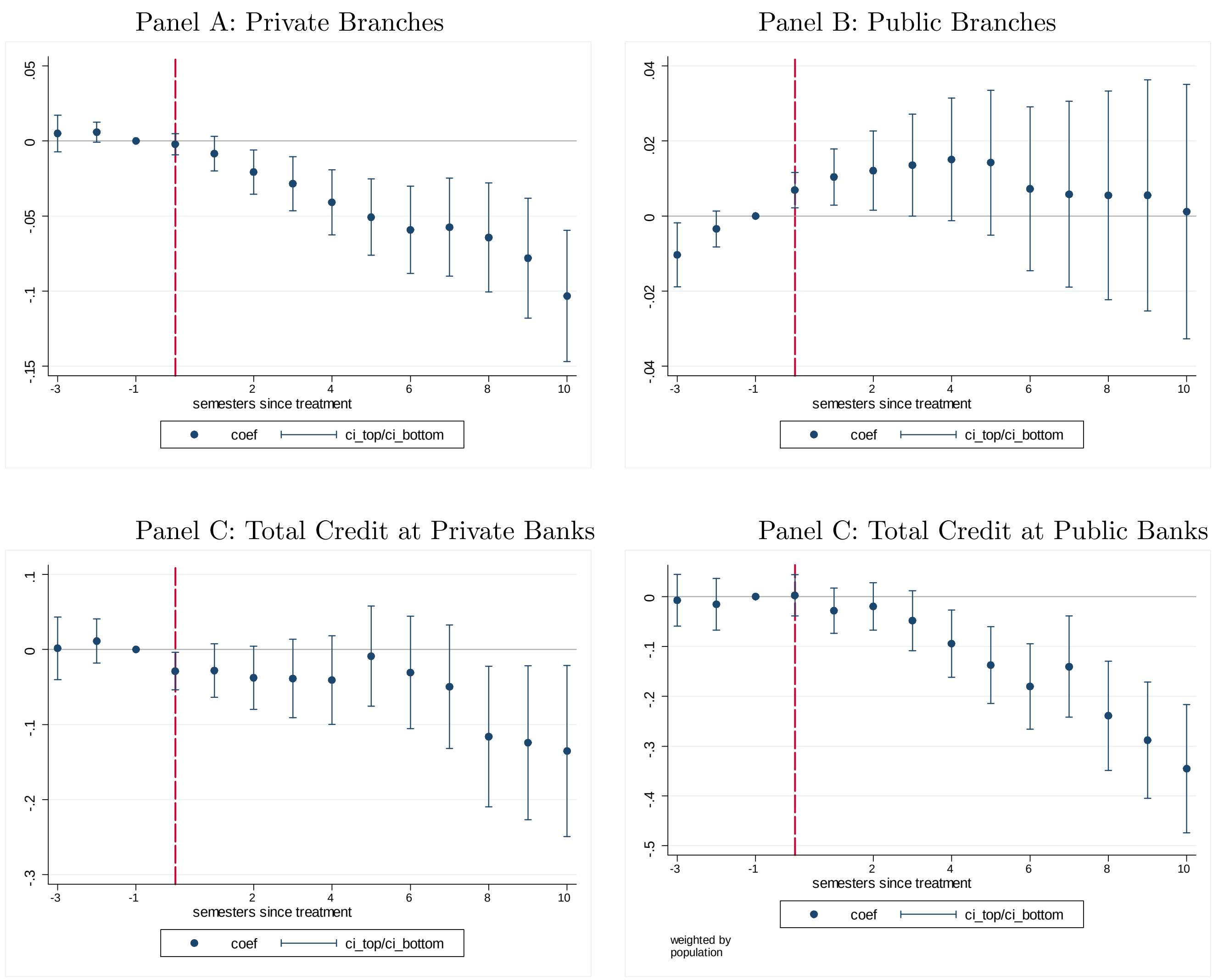


Figure 9: The Effect of 4G Network on Branches and Credit

Note: $\delta_\iota' s$ estimated from Equation (1) with the outcome variables in municipality m at the half-year t as the dependent variable using dynamic differences-differences. The regression outcome is from the branch-municipality balance sheets (ESTBAN). Standard errors are clustered at the microregion level. The regressions are weighted by the population at the baseline level and follow a Poisson distribution (Panels A and B) and a normal distribution (all others). Bars show 95% confidence intervals. Values are normalized at δ'_{-1}=0. Treatment municipalities are those that started to count on at least one telecom carrier to offer 4G network. Vertical lines represent the number of semesters that passed since the initial rollout of the internet technology.

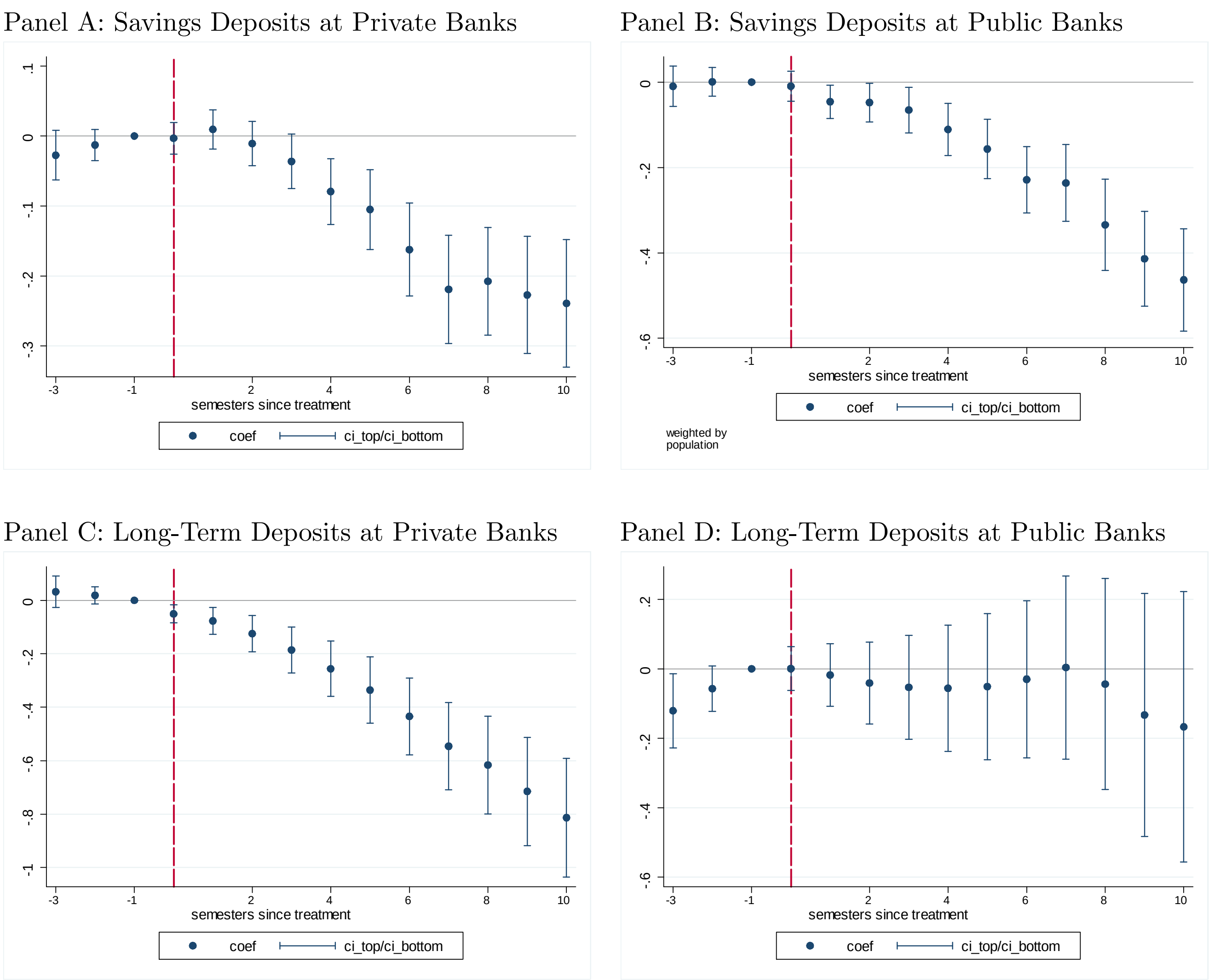


Figure 10: The Effect of 4G Network on Savings and Long-Term Deposits

Note: $\delta'_{\iota}s$ estimated from Equation (1) with the outcome variables in municipality m at the half-year t as the dependent variable using dynamic differences-differences. The regression outcome is from the branch-municipality balance sheets (ESTBAN). Standard errors are clustered at the microregion level. The regressions are weighted by the population at the baseline level and follow a Poisson distribution (Panels A and B) and a normal distribution (all others). Bars show 95% confidence intervals. Values are normalized at δ'_{-1}=0. Treatment municipalities are those that started to count on at least one telecom carrier to offer 4G network. Vertical lines represent the number of semesters that passed since the initial rollout of the internet technology.

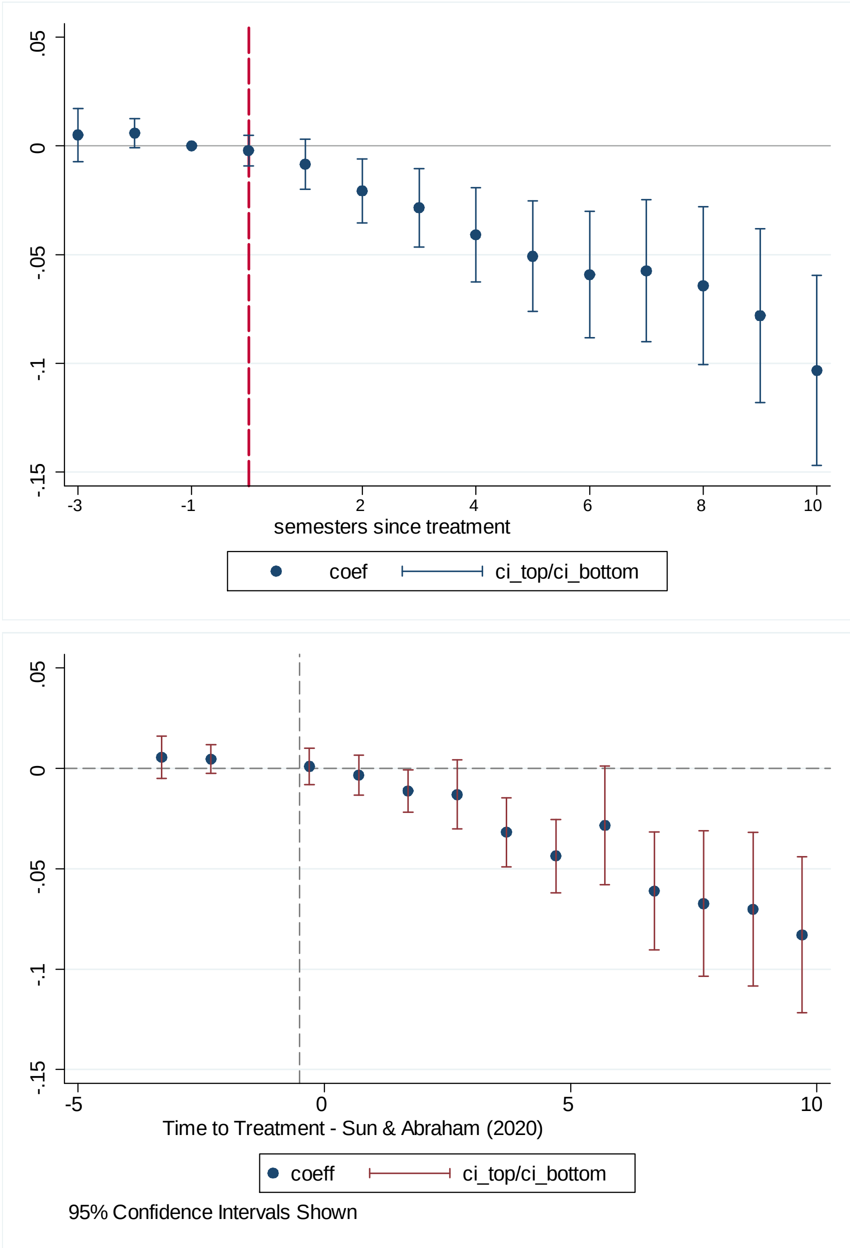
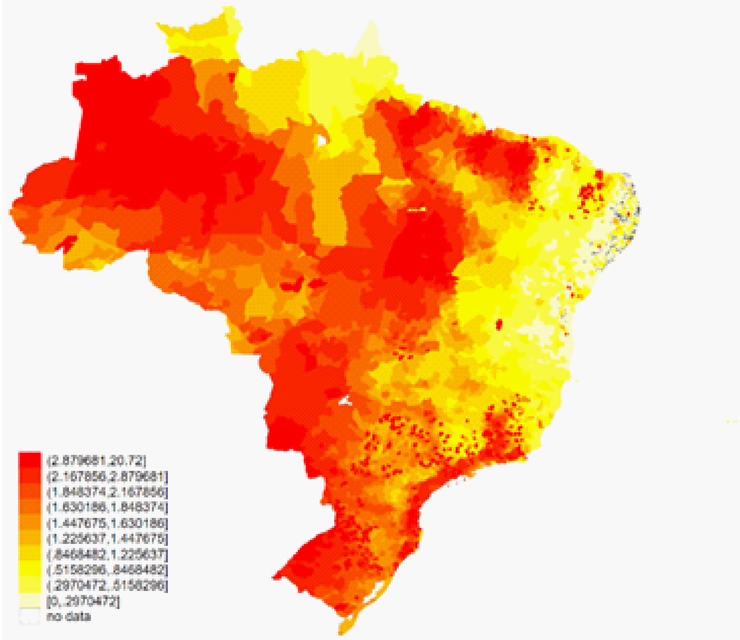


Figure 11: Event Study

Note: Panel A presents an event study in which private bank branches are regressed on a set of semi-year dummies around the event defined as the month upon which the municipalities of Brazil started to count on 4G network coverage. The regressions are run on the full dataset. The results of the underlying regression for private bank branch are presented in Column 1 of Table ??. Regressions are weighted by the population size of the baseline period (2012). Panel B presents the estimates based on the estimator proposed in Sun and Abraham (2020), which ensures that the average treatment effects in each group and period do not have negative weights. Both panels of the figure show that the decrease in the number of bank branches for the private sector occurred after the significant expansion of the 4G network.

Panel A: Distribution of Lightning Strikes in Brazil



Panel B: Delay of the 4G Network Rollout vs. Lightning Strikes

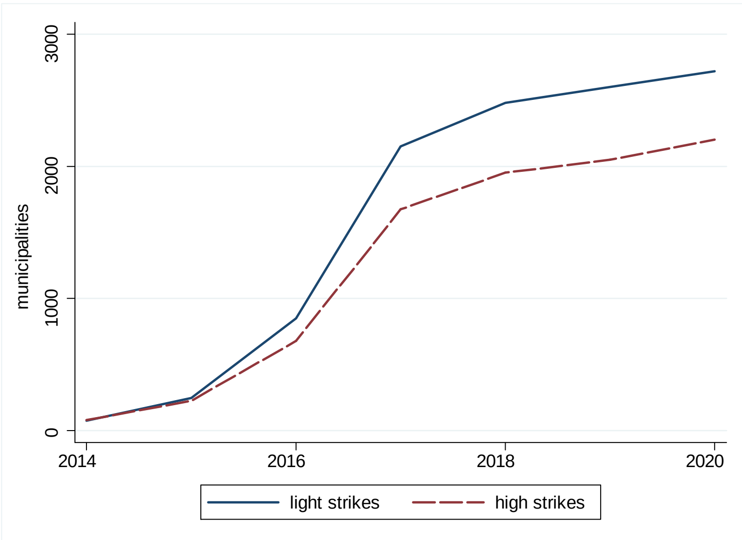


Figure 12: Instrumental Variables and 4G Mobile Network

Note: comparison of non-earmarked credit, savings deposits, and short and long-term deposits held at traditional and digital banks. Digital banks are those that have repositioned themselves to have none or very few branches to offer exclusively online services . Local currency corrected by the local CPI index (IPCA-BR). Fintechs are not included.

B Tables

Table 2: Adoption of 4G Network and Demographic Profile

	Full	<=2016	2017-2018	>=2019
Panel A: Regional Rollout of the 4G Coverage				
% mun. with 4G	0.88	0.27	0.79	0.88
% mun. with 4G, SE	0.89	0.45	0.86	0.89
% mun. with 4G, SO	0.98	0.29	0.93	0.98
% mun. with 4G, CO	0.82	0.18	0.67	0.82
% mun. with 4G, NO	0.84	0.18	0.64	0.84
% mun. with 4G, NE	0.84	0.14	0.71	0.84
Panel B: Internet Adoption				
% households with Internet use	0.61	0.51	0.54	0.61
% households with mobile Internet use	0.22	0.22	0.25	0.25
Fixed broadband subscriptions per 100 people	17.1	13.03	14.91	15.59
Mobile subscriptions per 100 people	97	118	100	97
Panel C: Demographic Profile				
GDP per capita (2012)	15.80	21.88	14.54	11.51
Gini Index (2010)	0.50	0.49	0.50	0.53
Literacy Rate (2010)	0.85	0.90	0.85	0.81
Population (2012)	34,820	90,356	16,174	8,136
% Rural Population (2010)	0.36	0.20	0.39	0.49
Area Municipalities (sq. km^2)	1,525	1,144	1,489	1,899
Number of municipalities	5,570	1,526	2,903	489

Note: descriptive statistics of the treated mun. with 4G network. Column "$\leq$2016" contains the subsample of mun. that gained 4G access between April of 2013 and December of 2016. "2017-2018" is for mun. that gained access to the 4G network between January of 2017 and December of 2018", and "$\geq$2019" is the subsample of municipalities that gained access between January of 2019 and August of 2020, the end of the dataset. Panel A: "% municipalities with 4G" refers to the share of cities with at least one telecom carrier for the 4G access in Brazil across regions (source: Teleco). Panel B: "% households with (mobile) internet use" is the share of households that report using (mobile) Internet (source: TIC Domicilios, Cetic). Broadbrand and mobile internet subscriptions per 100 people (source: World Bank). Panel C: demographic profile of the mun. that started having access to the 4G network in each period range (source: IBGE).

Table 3: Main results - Banks and Branches

Dep. Variable	BanksPr	BanksPu	BranchesPr	BranchesPu
12 months	0.019*	0.000	-0.023***	0.014*
	(0.009)	(0.005)	(0.007)	(0.006)
24 months	0.011	0.003	-0.046***	0.023***
	(0.012)	(0.009)	(0.010)	(0.011)
36 months	-0.010	-0.006	-0.066***	0.008
	(0.009)	(0.013)	(0.013)	(0.014)
48 months	-0.037*	-0.007	-0.074***	-0.000
	(0.019)	(0.015)	(0.016)	(0.017)
60 months	-0.058*	-0.014	-0.111***	-0.007
	(0.034)	(0.020)	(0.019)	(0.021)
Obs.	32,742	32,742	32,742	32,742
Mun x Time FE	y	y	y	y
Controls	y	y	y	y

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Abbreviations are used for private (Pr) and public (Pu) banks. All variables are in log. Regressions are weighted by the population of the baseline period and include time and municipality fixed effects. Regressions on banks and branches used a Poisson distribution, to account for the high asymmetry in the data. Controls include literacy rate (Census 2010), share of rural population (Census 2010) and GDP of the baseline period (2012). Standard errors in parentheses are clustered at the municipality level. These results are robust to two alternative specifications: the first one implements municipality-bank fixed effects instead of municipality fixed effects, to account for time-invariant characteristics for banks decisions (as in Jiang et al., 2022). The second specification changes the correction of the standard errors by implementing a two-way clusterization at the level of municipalities (to account for correlation over time) and at the level of microrregions in each year (to account for within-microrregion-year correlation) (as in Guriev et al., 2019).

Table 4: Main Results - Credit and Savings Deposits

Dep. Variable	CreditPr	CreditPu	SavingsPr	SavingsPu	DepositsPr	DepositsPu
12 months	-0.038*	-0.020	-0.011	-0.048**	-0.125***	-0.041
	(0.022)	(0.024)	(0.016)	(0.023)	(0.035)	(0.060)
24 months	-0.041	-0.094***	-0.079***	-0.111***	-0.256***	-0.056
	(0.030)	(0.034)	(0.024)	(0.031)	(0.053)	(0.092)
36 months	-0.031	-0.180***	-0.162***	-0.229***	-0.435***	-0.030
	(0.038)	(0.044)	(0.034)	(0.040)	(0.073)	(0.115)
48 months	-0.124**	-0.288***	-0.227***	-0.414***	-0.715***	-0.133
	(0.058)	(0.059)	(0.043)	(0.057)	(0.103)	(0.179)
60 months	-0.135**	-0.345***	-0.239***	-0.463***	-0.813***	-0.167
	(0.058)	(0.065)	(0.047)	(0.061)	(0.114)	(0.199)
Obs.	165,740	130,336	157,433	128,834	158,399	123,651
Mun x Time FE	y	y	y	y	y	y
Controls	y	y	y	y	y	y

Note: *** p<0.01, ** p<0.05, * p<0.1. Abbreviations are used for private (Pr) and public (Pu) banks. Deposits refer to the long-term deposits. All variables are in log. Regressions are weighted by the population of the baseline period and include time and municipality fixed effects. Controls include literacy rate (Census 2010), share of rural population (Census 2010) and GDP of the baseline period (2012). Standard errors in parentheses are clustered at the municipality level. These results are robust to two alternative specifications: the first one implements municipality-bank fixed effects instead of municipality fixed effects, to account for time-invariant characteristics for banks decisions (as in Jiang et al., 2022). The second specification changes the correction of the standard errors by implementing a two-way clusterization at the level of municipalities (to account for correlation over time) and at the level of microrregions in each year (to account for within-microrregion-year correlation) (as in Guriev et al., 2019).

Table 5: Distibutional Impact - Banks and Branches

	BanksPr	BanksPu	BranchesPr	BranchesPu
4Gcov [all]	-0.058*	-0.014	-0.111***	-0.007
	(0.034)	(0.020)	(0.019)	(0.021)
4Gcov [rich]	-0.079**	-0.036	-0.110**	-0.077***
	(0.039)	(0.035)	(0.053)	(0.025)
4Gcov [poor]	0.090***	0.056	-0.016	0.069
	(0.033)	(0.029)	(0.051)	(0.045)
4Gcov [urban]	-0.066*	0.001	-0.134***	0.006
	(0.033)	(0.023)	(0.009)	(0.027)
4Gcov [rural]	0.073*	-0.002	-0.061	-0.075
	(0.035)	(0.029)	(0.066)	(0.047)
4Gcov [big]	-0.059*	-0.013	-0.113***	-0.010
	(0.034)	(0.024)	(0.022)	(0.026)
4Gcov [small]	-0.089***	-0.022	-0.091	-0.076***
	(0.033)	(0.022)	(0.056)	(0.027)
4Gcov [high lit]	-0.079*	-0.058***	-0.108*	-0.059***
	(0.040)	(0.018)	(0.055)	(0.017)
4Gcov [low lit.]	0.002	0.124***	-0.090*	0.094*
	0.043	(0.039)	(0.051)	(0.047)
Obs.	32,742	32,742	32,742	32,742
Mun x Time FE	y	y	y	y
Controls	y	y	y	y

Note: *** p<0.01, ** p<0.05, * p<0.1. Abbreviations are used for private (Pr) and public (Pu) banks. The dummies rich/poor, big/small, and high literacy/low literacy are 1 if above median of national average of the GDP (2012), population size (2012), and literacy rate (2010). Rural and urban are defined according to IBGE (2017). All regressions include time and municipality fixed effects. Standard errors in parentheses are clustered at the municipality level. Coefficients correspond to the end of the five-year period post 4G implementation.

Table 6: Distibutional Impact - Credit and Savings

	CreditPr	CreditPu	SavingsPr	SavingsPu	DepositsPr	DepositsPu
4Gcov [all]	-0.135**	-0.345***	-0.239***	-0.463***	-0.813***	-0.167
	(0.058)	(0.065)	(0.047)	(0.061)	(0.114)	(0.199)
4Gcov [rich]	0.023	-0.363***	-0.151	-0.370***	-0.459**	-0.124
	(0.090)	(0.095)	(0.095)	(0.072)	(0.216)	(0.155)
4Gcov [poor]	0.227**	-0.186	-0.136	-0.310***	-0.652***	-0.023
	(0.104)	(0.147)	(0.112)	(0.109)	(0.153)	(0.330)
4Gcov [urban]	-0.196***	-0.241***	-0.197***	-0.422***	-0.595***	-0.140
	(0.063)	(0.071)	(0.054)	(0.077)	(0.130)	(0.269)
4Gcov [rural]	0.278	0.365	0.209	0.015	-0.324	0.057
	(0.229)	(0.249)	(0.196)	(0.163)	(0.226)	(0.264)
4Gcov [big]	-0.111*	-0.306***	-0.296***	-0.469***	-1.047***	-0.315
	(0.067)	(0.076)	(0.059)	(0.072)	(0.149)	(0.238)
4Gcov [small]	-0.172	-0.331***	-0.056	-0.036	-0.303	0.193
	(0.142)	(0.138)	(0.091)	(0.121)	(0.100)	(0.239)
4Gcov [high lit]	0.058	-0.464***	-0.151	-0.442***	-0.511***	-0.451**
	(0.095)	(0.081)	(0.099)	(0.072)	(0.227)	(0.210)
4Gcov [low lit.]	0.008	0.062	-0.072	-0.275	-0.596***	0.167
	(0.155)	(0.159)	(0.118)	0.186	(0.157)	(0.322)
Obs.	165,740	130,336	157,433	128,834	158,399	123,651
Mun x Time FE	y	y	y	y	y	y
Controls	y	y	y	y	y	y

Note: *** p<0.01, ** p<0.05, * p<0.1. Abbreviations are used for private (Pr) and public (Pu) banks. The dummies rich/poor, big/small, and high literacy/low literacy are 1 if above median of national average of the GDP (2012), population size (2012), and literacy rate (2010). Rural and urban are defined according to IBGE (2017). All regressions include time and municipality fixed effects. Standard errors in parentheses are clustered at the municipality level. Coefficients correspond to the end of the five-year period post 4G implementation.

Table 7: Contrasting Dynamic DiD and the New Literature on DiD

	D: banksPr	SA: banksPr	D: branchesPr	SA: branchesPr
12 months	0.019**	-0.001***	-0.023***	-0.013***
	(0.009)	(0.005)	(0.007)	(0.005)
24 months	0.011	0.001	-0.046***	-0.027***
	(0.012)	(0.000)	(0.010)	(0.009)
36 months	-0.010	-0.015***	-0.066***	-0.005
	(0.009)	(0.001)	(0.013)	(0.021)
48 months	-0.037*	-0.043***	-0.074***	-0.063***
	(0.019)	(0.005)	(0.016)	(0.016)
60 months	-0.058*	-0.041***	-0.111***	-0.083***
	(0.034)	(0.004)	(0.019)	(0.019)
Obs.	32,742	32,742	32,742	32,742
Mun. x Time FE	y	y	y	y
Controls	y	y	y	y

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. "D": dynamic differences-in-differences. "SA": Sun & Abraham (2020) methodology applied (eventstudyinteract in Stata). Variables are in log. Regressions are weighted by population at the baseline level and calculated globally for private (Pr) banks. Panel regressions at the municipality-branch on a set of semi-year dummies around the event defined as the month upon which the municipalities of Brazil started to count on 4G mobile network. Time and municipality fixed effects fixed effects included. Standard errors in parentheses are clustered at the municipality level.

Table 8: 2SLS/IV Regressions

	First Stage	Second Stage		
	Has 4G	+12 months	+24 months	+60 months
High Freq. L. Strikes(d=1)	-0.083***			
	(0.000)			
BranchesPr		-0.030***	-0.041***	-0.083***
		(0.011)	(0.013)	(0.016)
BranchesPu		0.021	0.013	0.004
		(0.014)	(0.017)	(0.021)
BanksPr		-0.022**	-0.038***	-0.058***
		(0.011)	(0.016)	(0.026)
BanksPu		0.000	0.000	-0.005
		(0.013)	(0.017)	(0.022)
CreditPr		0.027	-0.092*	-0.209***
		(0.043)	(0.047)	(0.057)
CreditPu		-0.437***	-0.474***	-0.649***
		(0.077)	(0.094)	(0.112)
SavingsPr		-0.165***	-0.231***	-0.293***
		(0.034)	(0.039)	(0.045)
SavingsPu		-0.543***	-0.616***	-0.745***
		(0.069)	(0.067)	(0.083)
DepositsPr		-0.425***	-0.594***	-0.802***
		(0.075)	(0.092)	(0.111)
DepositsPu		-0.021	-0.183	-0.438**
		(0.256)	(0.193)	(0.175)
Obs.	64,619		See Notes	
F-stat of excluded instrument	10.57	-	-	-
Extended list of controls	y	y	y	y
Mun x Time FE	-	y	y	y

Notes: the first stage of the 2SLS/IV regression was estimated by using a probit model to calibrate the entrance of the 4G network given the high frequency of lightning strikes, plus relevant controls (share of rural population, literacy rate, and GDP of the baseline level). The model also included a separate linear time trend to capture the growth of the mobile network over time (as in Guriev, 2021). The regression was run on a monthly basis and was weighted by the population of the municipalities at the baseline level. The predicted value of the first stage regression (p-hat) was estimated and the standard threshold of non-linear models was applied (phat>0.5) to consider when the municipality started being covered by 4G mobile network (Belyadi & Haghighat, 2021). The IV is a dummy variable to reflect the high-frequency of lightning strikes and controls are in logarithm form. F-statistic of excluded instrument: no controls. Sources: strikes (WWLLN), time trend (Teleco), branches (Central Bank of Brazil), all others (IBGE). Number of observations varies according to the outcome of interest (NA).

Table 9: Dictionary of Variables

Variable	Type	Source of Data	Unit of Measurement
Banks	Outcome	Central Bank of Brazil	Unit
Branches	Outcome	Central Bank of Brazil	Unit
Total Credit	Outcome	Central Bank of Brazil	Real BR Currency (R$)
Savings Accounts	Outcome	Central Bank of Brazil	Real BR Currency (R$)
Long-Term Deposits	Outcome	Central Bank of Brazil	Real BR Currency (R$)
Population	Control	IBGE	Unit
Population Density	Control	IBGE	Unit/square km^2
Literary Rate	Control	IBGE	Percentage
Rural Population	Control	IBGE	Below or above median
4G Network	Treatment	Teleco/Anatel	1/0
Lightning Strikes	Instrument	WWLLN	1/0