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Stay Competitive in the Digital Age: The Future of Banks

by Estelle Xue Liu

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Abstract

The latest advancement in financial technology has posed unprecedented challenges for incumbent banks. This paper analyzes the implications of these challenges on bank competitveness, and explores the factors that could support digital advancement in banks. The analysis shows that the traditionally leading role of banks in advancing financial technology has diminished in recent years, and suggests that onoing efforts to catch up to the digital frontier could lead to a more concentrated banking industry, as smaller and less tech-savvy banks struggle to survive. Cross-country evidence has suggested that banks in high-income economies appear to have been the digital leaders, likely benefiting from a sound digital infrastructure, a strong legal and business environment, and healthy competition. Nonetheless, some digital leaders may fall behind in the coming years in adopting newer technologies due to entrenched consumer behavior favoring older technologies, less active fintech and bigtech companies, and weak bank balance sheets.

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I. INTRODUCTION

Now more than ever, technology is reshaping the financial ecosystem and the future of banks. New players, such as startup companies specializing in financial technology as well as existing technological companies, have started providing financial services traditionally provided by banks. At the same time, increasingly digitally advanced customers, notably millennials and post-millennials, are demanding more convenience and better customer services through mobile or tablet platforms. Moreover, the COVID-19 pandemic has resulted in an acceleration of the adoption of digital technologies in all areas including financial services. Hence, to stay competitive vis-à-vis new players, attract customers and reduce costs, major global banks have set digital transformation as a business priority in the coming years. This paper seeks to study the impact of the ongoing digital transformation on bank competitiveness and some of the main factors that have contributed to such a transformation.

Based on a review of the literature, this paper discusses the implications of digital challenges for bank competitiveness. A historical review of banks' digitalization suggests that although banks have been pivotal in advancing some major financial technologies, this leading role may have diminished since the Global Financial Crisis (GFC). The latest efforts by global banks to digitalize may have the potential to boost these banks' competitiveness by increasing their profitability, but large banks could potentially benefit more due to large initial investment needs and increasing returns to scale of the banking industry. Thus, digitalization could result in a more concentrated banking system with larger banks gaining market share, while smaller, less-profitable banks, and local banks with limited customer bases may eventually exit the market. One favorable consequence of banks' digitalization is improving financial inclusion, but less digitally advanced customers may find it even harder to access banking services, and some bank employees may lose their jobs due to automation.

The paper also explores the factors that could support banks' digital advancement. A cross-country comparison shows a global digital divide: banks' digital services are more widely used in high-income economies, while middle- and low-income countries experience lower penetration of such services. To understand this global digital divide, this paper examines a range of factors using a cross-sectional fractional model. These factors include the condition of the broader digital ecosystem (e.g., the digital infrastructure, the digital adoption of the population and the education level), labor market regulations, the business environment, the legal system, overall financial sector development (e.g. the usage of credit and debit card, the development of non-bank financial services), and banks' conditions (e.g., profitability, capital positions and ratios of non-performing loans or NPLs). To the best of the author's knowledge, this is the first empirical study of banks' digital transformation at the global level.[1]

[1] Cross-country data differentiating the digital advancement by banks from that of non-banks is lacking, although database on fintech and big techs are more readily available (e.g. BIS, 2020). This paper finds that the indicators from the World Bank Global Fintech database are the best possible proxies for banks' digital advancement.

Estimation results highlight several factors that could influence banks' digital transformation. An advanced digital infrastructure and a good legal and business environment could potentially support banks' digital advancement, while weak bank balance sheets (i.e. low profitability and high NPLs) could impede such advancement. The age structure of the population, surprisingly, does not appear to be an important factor. Maturity of the banking industry is negatively correlated with the level of bank digitalization in high-income economies, but this correlation turns positive for low-income countries. This finding could reflect the entrenched use of older technologies in high-income countries. Interestingly, the presence of new players (i.e. fintechs and bigtechs) tends to be positively correlated with the extent of banks' digitalization, pointing to their catalytic role in stimulating digitalization of the entire financial industry.

The structure of the paper is as follows. Section II introduces the definition of banks' digital transformation, reviews the history of the digital technology and discusses the potential implication of such transformation. Section III presents a global comparison of the usage of bank digital services. Section IV studies factors related to the global digital divide, and Section V concludes.

II. Digital Transformation in the Banking Industry

i. What is Digital Transformation?

Digital transformation is the use of new and fast changing digital technology to transform business activities, competencies, and business models. Virtually all modern electronics, such as computers and mobile phones, are digital i.e., they use information in the form of numeric code. Due to the widespread use of digital technology in our daily lives, the term "digital transformation" is often used interchangeably with "technological advancement". Many of the most visible new technologies are based on or intertwined with digital platforms, such as Google's search engine, the social platforms of Facebook or Twitter.

The digital transformation of the banking industry can be broadly summarized in two dimensions: technologies utilized and services impacted (Table 1). Some popular technologies that have been used in the banking industry include the cloud, artificial intelligence (AI), big data analytics, blockchain, mobile technology, and robo advisors. Meanwhile, banking services affected include payments, lending, asset management, and communication.[2] For example, an increasing number of banks are migrating to cloud technology to reduce onsite infrastructure management, AI-powered chat boxes that mimic human conversation and messaging applications are currently being tested to replace the

Although alternative data sources can be found, such as survey data in reports produced by consulting firms and banks, the coverage of these data is often limited to a few advanced economies or to a few major global banks. Efforts to consolidate data from various sources have started in recent years but remain inadequate for cross-country studies.

[2] The highest application of advanced digital technologies in financial services is in the category of payments, clearing and settlement (BIS, 2017). Within this category, many fintech firms are also active, with the majority represented by the retail payment services firms, as compared with wholesale payment service providers.

unpopular call centers, and robot advisory platforms are being developed to provide consumers asset management solutions, which are often cheaper with transparent cost structures.

Table 1. Two Dimensions of Financial Service Digitalization

Financial Services	Technology
▪ Payments, clearing, settlement ▪ Credit, deposits, and capital-raising ▪ Wealth Management ▪ Investment banking ▪ Communication	▪ Cloud ▪ AI/machine learning/advanced data analytics ▪ Big data ▪ Distributed ledger (DLT) ▪ Application programming interfaces (APIs) ▪ Robot advisor ▪ Mobile technology

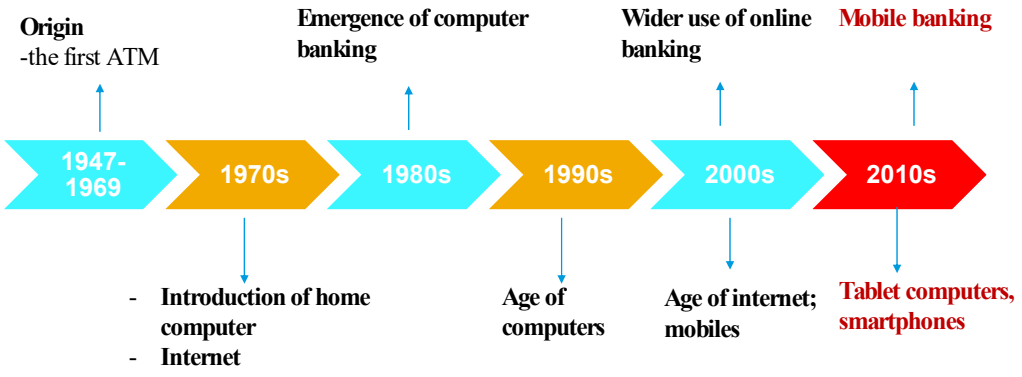
ii. The History of Digital Transformation: How have Banks Performed?

Digital technology has evolved alongside the development of the computer and the internet. The shift to digital technology from mechanical and analogue electronic technology started as early as the 1940s and led to the adoption of digital computers and digital record keeping. In the 1970s, the home computer was introduced, but it was not used widely until the 1990s. While only 8 percent of U.S. households owned a personal computer in 1984, by 2000, 51 percent of U.S. households owned a computer. In the same period, the internet, developed in the 1960s and 1970s, became one of the most prominent applicatios of digital technology. Wider internet usage, however, did not happen until the 2000s, once computers had become a common household appliance. In late 2005, the internet was used by a population reached one billion.

Another key development in diffusing digital technology has been the rapid rise of mobile technology. Over the past decade, mobile devices such as smart phones and tablets have replaced the use of computers. By the end of 2010, 3 billion people worldwide were using cellphones, and by 2015, tablet computers and smartphones had exceeded personal computers in internet usage. The wide-spread use of mobile devices and intrinsic advantages of a global network has led to an explosion of mobile-based innovations influencing all aspects of human lives. One prominent example is mobile-based payments.[3]

[3] According to Beaumont and others (2019), mobile based payment innovations tend to be diffused at a much faster speed than that of many past payments innovations, such as the diffusion of Swish--a mobile phone based payments system launched in 2010 by Sweden's commercial banks and the Riksbank.

Figure 1. History of Digital Technology



As digital technology has advanced, banks have often been leaders in adopting these new technologies (Figure 1). Citibank installed the first ATM machine in 1977,[4] but customers only started using ATMs on a regular basis in the 1980s. Similarly, online banking was piloted in the 1980s by Chemical Bank but was not used widely until the 2000s with more widespread internet usage.

However, banks' leadership in adopting newer technologies has weakened since the Global Financial Crisis (GFC). While banks have been busy repairing balance sheets and adopting stricter regulations, digital innovation has become a low priority.[5] In contrast, major industries such as retail, travel, communications, and mass media have undergone revolutionary changes in their technological platforms. With computer and internet proliferation, a younger generation of customers has quickly adapted to newer technology[6] and are demanding higher quality and more digital-based services. However, incumbent banks have often struggled to meet this new demand.

The gap between customer expectations and services that banks could offer was quickly picked up by new entrants: fintechs and bigtechs.[7] The increasing use of digital technology has led to higher demand for bank digital services, particularly demand from non-corporate bank clients. Since 2015, fintech and bigtech companies have expanded rapidly, backed by the

[4] By the end of 1977, all of Citibanks' New York branches had at least two machines operating 24/7.

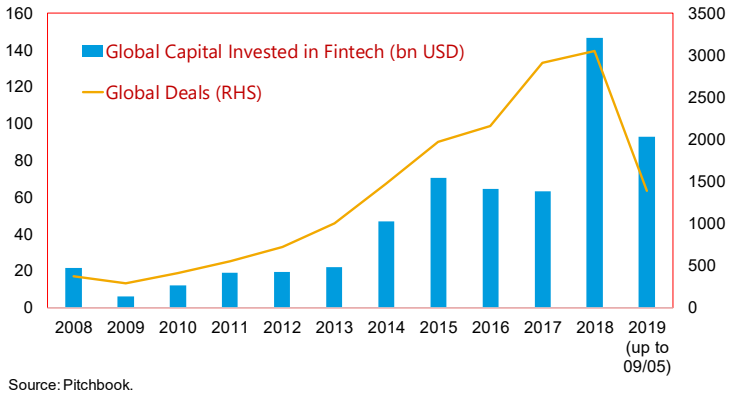
[5] According to Temenos (2019), in 2009, the biggest organization challenge for banks was "tighter regulations", while this challenge together with "profitability" and "satisfying customers" remained the top three challenges in 2018.

[6] The share of millennials and post-millennials has increased from 40 percent to 62 percent of the world population from 2000 to 2019.

[7] In this paper, fintech companies refers to companies whose initial and primary businesses are to deliver financial services using newer technologies, while bigtechs are companies whose initial primary business is to deliver digital services but started to offer financial services through their digital platforms. Fintech firms are often smaller scale and funded by venture capital, such as N26 in Germany and M-pesa in Africa. In contrast, bigtech firms are often large, blue-chip firms, such as Amazon (US), Facebook (US), Tencent (China) and Alibaba (China). Fintech firms can acquire a banking license and turned themselves completely into a bank or choose to cooperate with incumbent banks. Some of the fintech firms have been acquired by banks. For bigtech firms, financial services remain a subgroup of digital services.

swift adoption of newer technologies (Figure 2). Within a few years, innovation in financial and business services has greatly increased and spread globally.[8]

Figure 2. Development of Fintech Companies in the World



Source: Pitchbook.

Although some leading global banks have identified digitalization as one of their business priorities, maintaining a competitive edge remains challenging. Some European banks aspire to offer innovative payments on a par with those of new competitors (EBA, 2020). However, half-century old technological platforms are still widely used in the banking system, and such legacy systems inhibit banks from embracing innovation to thrive in the twenty-first century digital economy. The latest technological adoption in financial services, led by non-bank new entrants, has the potential to fundamentally disrupt the banking industry (BIS, 2017). For example, financial service platforms built by big techs, without the overhead of physical branches, could leverage parent companies' technology and data to streamline retail banking by offering more convenience and better pricing. To maintain market share, some leading global banks are accelerating their digital transformation to provide better and more digital-based customer services. However, these digitalization efforts are often considered futile.[9]

iii. Banks' Digital Transformation: Implications

Empirical studies on the implications of new technology usage in the financial sector are limited.[10]A few studies have examined linkages between information,communication and

[8] Silicon Valley is no longer the center of the tech universe. For example, Berlin is becoming a creative hub, Seoul has a vibrant startup ecosystem, Tel Aviv is the leader in security software, London has a growing financial tech center, Shenzhen is ground zero for hardware startups, and Hangzhou is home to Alibaba and its e-commerce offspring. Fintech activities in Europe, however, lags other regions, likely reflecting a pre-existing high level of banking development (IMF, 2020).

[9] As Mark Mullen, the CEO of Atom, a fintech bank, said: *"Banks are trying to be cool and hip and build super cool digital front ends. But it's like putting lipstick on a pig – ultimately it's still a pig and the new front end is still running into an awful digital back end."*

[10] According to Temenos (2015), banks, on average, spend more than 50 percent of their budgets on IT services, although the majority of this spending is on maintenance of existing digital platforms.

technology (ICT) investment and bank performance. [11]For example, Casolaro and others (2007) analyzed the effects of ICT investment in the financial sector using micro-data from a panel of 600 Italian banks over 1989–2000 and found that the shift of both the cost and profit frontiers, as well as efficiency gains, are strongly correlated with ICT capital accumulation. Studies on the impact of a specific ICT technology are even more limited. For example, in a survey, Frame and White (2004) could only identify eight studies six of which use the same data on ATM diffusion.

To assess the impact of digitalization, the experience of SWIFT adoption could be a useful reference. Scott and others (2017) studied 6,858 banks in 29 countries in Europe and the Americas to examine the impact of the adoption of SWIFT, a network-based technological infrastructure, on bank performance. They found that SWIFT adoption has a large impact on profitability in the long term. Initial investment can be costly, including investment in internal and external hardware, software, services, and new staff with information technology skills. However, recurrent costs in the medium to long term are expected to be lower, especially as newer, more flexible development technologies are adopted and banks spend less on inefficient legacy systems. The new technology would also allow banks to enhance their operational efficiency with fewer operational personnel and branches. For example, online distribution channels reduce investment in branches, branch staffs, and back-office departments.

More recent evidence largely supports the role of digitalization as a means to boost bank profitability. Although cross-country academic studies have been lacking, abundent work has been done by private consulting firms and banks. Citi (2019) has estimated that digitalization could cut banks' operational cost by 30 percent to 50 percent mainly due to fewer branches and employees, but revenues would also decline for all banks by 10 percent–30 percent due to enhanced competition and transparency.[12] A recent survey by Accenture (2019) suggested that digital maturity is associated with increased profitability: digital advanced banks have, on average, experienced an overall increase of return on equity (ROE) of 0.9 percent between 2011 and 2017, while less digitally advanced banks have seen a ROE decline of 1.1 percent, and this divergence of profitability is expected to widen in the following years.[13]

Nevertheless, the benefits from digitalization could vary by the size of banks and their business models, foretelling a possible more concentrated banking industry. Digital transformation calls for large initial investment, which could be unaffordable for smaller banks or unprofitable banks. Local banks with smaller and more concentrated customer bases could also be slow in adopting new technologies, and thus find their market shares encroached

[11] There have been more studies on the general impact of ICT adoption on firms' performance. Appendix II gives a brief discussion of these studies

[12] According to Citi (2019), more than 50 percent of bank workforces are working on operations and technology, taking data out of the systems, cleaning it up, and parsing it. Because of digitalization, most of these posts are expected to be eliminated.

[13] The survey on the Hong Kong banking industry (HKIMR, 2020) found similar results.

by digitally advanced international competitors. Consequently, the banking industry could become more concentrated with large banks, especially if the industry exhibits increasing returns to scale.[14]

One social benefit of financial technology advancement is enhanced financial inclusion. For example, mobile wallets in Africa have granted millions without a banking account access to financial services. In regions where banks remain the dominant financial service supplier, such as in Europe, a more digitally advanced banking industry could potentially enhance efficiency, reduce service costs, and extend customer reach. Karlan and others (2016) reviewed behavior of credit, savings, insurance and payments and found that digital financial services significnatly enhance client well-being both directly and through enabling a broader ecosystem.

However, for some bank employees and less digitally capable customers, bank digitalization may foreshadow difficult times ahead. Ernst and Young (2019)[15] studied the impact of three technolgy trends— Robotic Process Automation, Advanced Analytics, and AI—on the future financial service workforce, and identified 40 out of the 121 job roles as highly impacted, with the potential for convergence or displacement. In addition, as digitalization is often accompanied with branch closings and transitioning to more IT-advanced customer interface, those customers who are less prone to adopting new technology or live in remote areas may find themselves with no access to customer services. As reported by the Financial Times (FT, 2019): "bank branches in the U.K. are closing at an 'alarming' rate,' many people, especially those living in the rural areas, could be shut out of vital financial services."

III. The Digital Transformation of Banks: A Global Comparison

i. Data

Cross-country databases on the digitalization of the financial industry are unavailable, but alternative databases could serve as a proxy.[16] This study uses the Global Findex database (GFd) that has been produced by the World Bank every three years since 2011 (more details of the GFd data, its caveats and other alternative database—IMF FAS, are discussed in Appendix I). Among a few hundreds GFd indicators, only one qualifies as a proxy for the level of bank digitalization**:** *used a mobile phone or internet to access a financial institution*

[14] A number of research papers (Hughes and Mester, 2013; Wheelock and Wilson, 2017) has found significant evidences for and increase in a return to scale in the banking industry.

[15] This study was commissioned by the Institute of Banking and Finance (IBF) and the Monetary Authority of Singapore, Singapore's central bank and financial regulatory authority.

[16] There are numerous reports and surveys that have provided analysis and data on financial service digitalization, but these could not be used for cross-country studies. First, such analyses have been mainly conducted by private consulting firms, banks or technology companies, with underlying data unavailable to the public. Second, the sample banks or countries are biased towards certain countries or regions that could not be used for the purpose of cross-country studies on a global scale.

account in the past years (% of 15+ with a financial institution account).[17] This indicator focuses on banks' digital services rather than all the financial institutions that also include non-bank firms. In addition, by controlling the number of the adult population (15+) with a financial institution account, this indicator is not influenced by access to finance. However, data for this indicator is available for only 2017, and a sample of 139 countries. Appendix III show a list of these countries. Despite its limitation, this indicator might be the best available indicator for cross-country comparison on bank's digitalization.

ii. Banking Digitalization Around the World: Which Countries are Leading?

A cross-country comparison suggests that digital banking is more widely used in high-income countries (Figure 3). Countries with the highest usage of banks' digital services are mostly located in North America, and Western and Northern Europe. The top ten countries are Norway, Denmark, Finland, Sweden, the Netherlands, New Zealand, the United States, Estonia, South Korea, and Canada, where the share of banking customers who use mobile or internet to access their accounts ranges from 70 percent to 85 percent[18]

High divergence exists among European countries (Figure 4). Scandinavians are among the most digitally advanced in the world, followed by a few higher-income economies, including Germany, Belgium, Luxembourg, France, Poland and Switzerland. European countries with lower income levels have one of the lowest digitalization levels such as Bulgaria, Georgia, and Albania, which rank at 100th, 101st and 123rd places, respectively, among the 139 countries in the sample. On average, banks in the European Union perform better in the digital space.

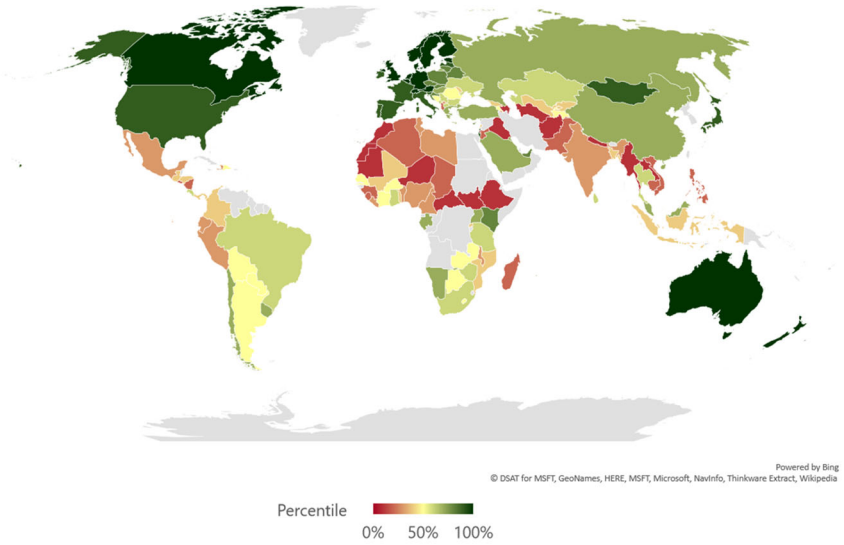
Countries with a lower usage of bank digital services, however, may experience a faster development in non-bank digital financial services. For example, China, which is usually seen as the most advanced country in mobile payments, is not ranked very high based on the usage of digital bank services (Figure 4). One reason could be that in China, digital financial services such as mobile payment are mostly offered by non-bank bigtechs, such as Alibaba and Tencent. Figure 5 shows the usage of mobile devices for paying utility bills, without differentiating whether such payment service is offered by banks or non-banks. With the exception of Scandinavia, European countries are lagging in the usage of mobile payment, while China and some African countries are among the most advanced.

[17] See Appendix II for the selection process of this indicator.

[18] As noted in Appendix II, the cross-country indicator on digital banking (Figure 4) narrowly focuses on one aspect of the usage of digital financial service—the mobile/internet access to financial institution account, thus is not representative for the overall advancement of a country's digital finance which would cover a wider variety of products, breadth of services.

Figure 3. Bank Service Digitalization Around the World

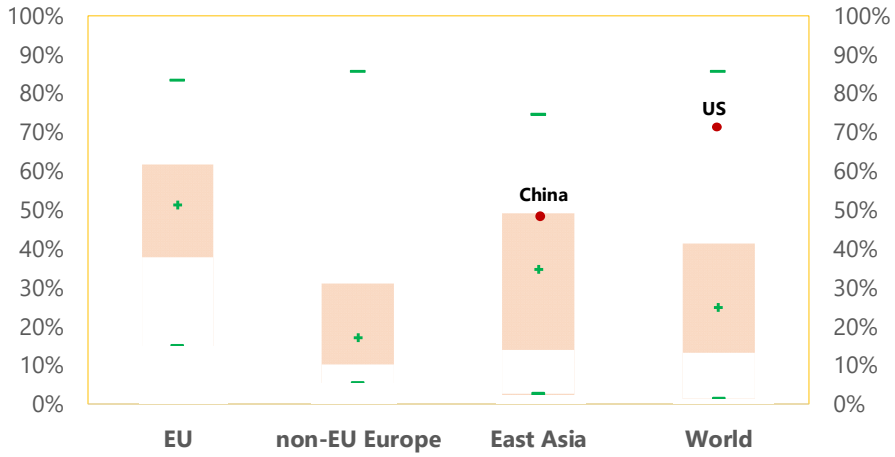
Mobile or Internet Access to Financial Account, 2017
(% of age 15+, with financial institutions account)



Source: World Bank Global Findex Database.

Figure 4. Bank Service Digitalization: A Comparison by Geographic Regions

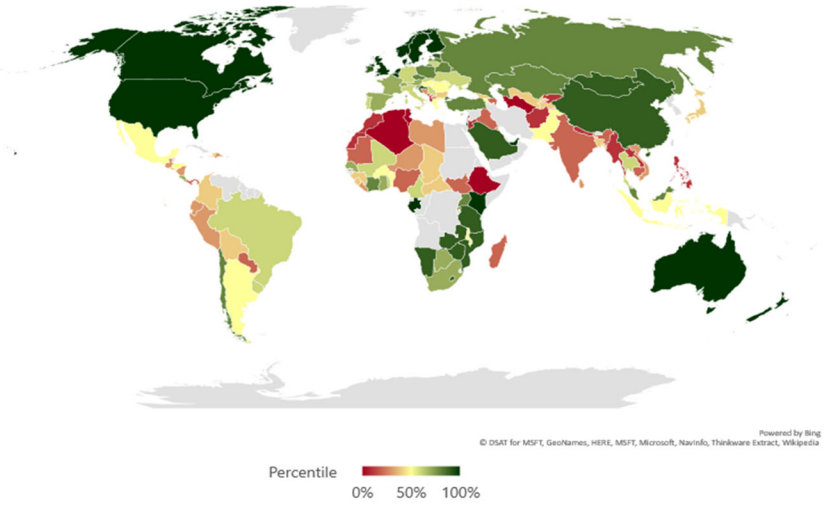
Mobile or Internet to Access to Financial Institution Account, 2017
(% of Age 15+ with financial institutions account; high, low, interquartile and median)



Sources:World Bank Global Findex Database and IMF staff Calculations.

Figure 5. Digital Financial Services: A Global Comparison

Payment for Utility Bills via Mobile, 2017
(% total payment on utility bills)



Source: World Bank Global Findex Database.

Two indicators from the GFd database could help differentiate advancements in digital finance offered by banks and non-banks. These two indicators are "*digital (mobile or internet) access to financial account"* and "*digital (mobile or internet) access to account,"* which both measure shares of the digitally active adult population (age 15+) with an financial institution account or an account[19]. If financial services in a country are solely offered by financial institutions (banks), these two indicators should have identical values. However, if a non-negligible share of the financial services in a country is offered by non-bank firms and if the financial services offered by these non-banks are more widely used, then the second indicator, "*digital access to account,"* should have a higher value than the first indicator, *"the digital access to financial account."*

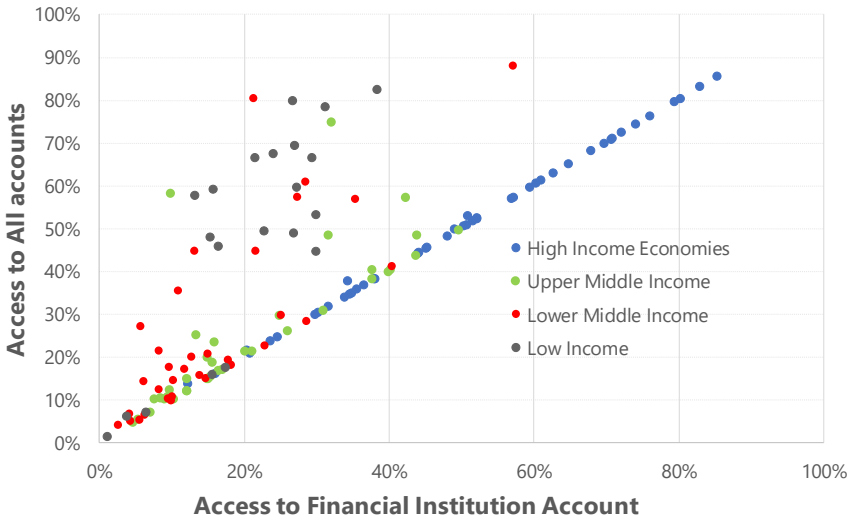
Figure 6 presents a comparison between these two indicators. In higher-income economies, digital finance advancement appears to be mainly supported by banks, while in middle- and lower-income economies, it appears to be mainly driven by non-banks. In particular, sub-saharan African countries (SSAs) are the most prominent examples of which the usage of digital financial services is mainly through non-bank accounts (countries above the 45 degree line). China, however, does not stand out as a country with highly digitalized non-bank financial services, possibly because that the 2017 data may not

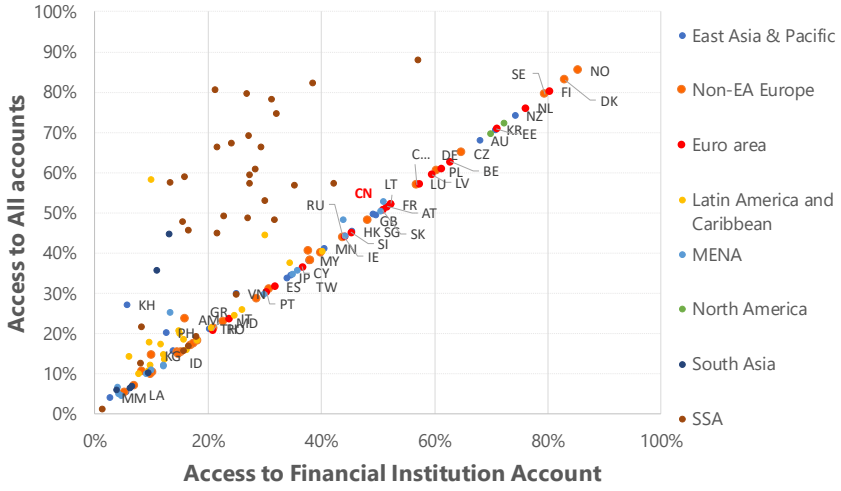
[19] "Account" here includes both accounts with financial institutions as well as others such as mobile wallets which are based on technical platforms.

have captured the latest smobile payment developments. Another possible reason is that the data only describe the most basic digital services using mobile devices and the internet, and the bigtechs in China could fare better than banks in more sophisticated financial technologies.

Figure 6. Digital Financial Services vs. Digital Banking Services

Mobile or Internet Access to Financial Account, 2017
(% age 15+, with financial institution accounts or with accounts)





Source: World Bank Global Findex Database.

IV. WHAT EXPLAINS THE GLOBAL DIGITAL DIVIDE?

i. Potential Explanatory Factors

This section seeks to empirically explore factors correlated with the pace of bank digitalization. Although whether a bank decides to digitalize its IT infrastructure and customer services is a business decision based on a standard cost and benefit analysis, a range of additional factors could matter. These factors can be broadly classified under three thematic categories: i) the digital ecosystem; ii) the broader business environment; and iii) the financial sector development.

Digital Ecosystem

When assessing the adoption of digital technology in the banking industry, the digital ecosystem is especially relevant. This paper focuses on four major elements of the digital ecosystem: (i) the digital infrastructure; (ii) the degree and pervasiveness of technological know-how within the general population; (iii) the adoption rate of the underlying digital technology in a society; and (iv) demographic factors that could affect the adoption rate. Another important explantory factor to the global digital divide is the regulatory environment, but this factor is not included as there is no cross-country data.

- **Digital Infrastructure.** Adequate, affordable and high-quality digital infrastructure is a key attribute for the evolvement of digital services (WEF, 2014). For example, the coverage of internet and mobile-cellular signals has been an important indicator for digital infrastructure. A recent paper by DeStefano and others (2017) found that firms with access to broadband increase their investment in several complementary hardware and software technologies. In this regard, the economy-wide investment in R&D, and digital technologies in particular is regarded as pivotal in promoting digital technology development (Govindarajan and others, 2019).

- **Technological knowhow.** Efforts to upgrade the digital infrastructure need to be accompanied by the development of skills to fully exploit the benefits of technological advancement. Banks with greater human capital, particularly in the field of ICT, could adopt and implement new technologies in a more effective manner. In addition, major digital transformations, such as AI, machine learning and big data analytics, are changing the skills required and impacting capacity-building for the digital economy.

- **The digital technology adoption rate.** The adoption of digital technology is often uneven, shaped by politics, regulations, level of human capital and economic development. Taking the cellular network as an example, despite having most mobile cellular subscriptions in the world (1.65 billion),[20] China has a relatively isolated digital market with the absence of the major global players, leading to its unique path of mobile technology development. India, with around 1.2 billion cellular subscribers, has a digital

[20] According to the World Bank, in 2018, mobile cellular subscriptions amounted to 7.86 billion, with the subscriptions in China ranked number one at 1.65 billion, followed by India at 1.18 billion.

economy representing arguably the greatest market potential for global players; however, it operates in multiple languages and infrastructures that pose challenges for future development. The European Union has 545 million cellular subscribers, but its market is fragmented as it is still in the process of creating a "digital single market." In many countries, certain websites or digital companies are blocked. Around the world, digital access itself is far from uniform: barely 50 percent of the world's population has access to the internet today.

- **Digitally literate consumer base.** So far, demand for bank digital services has concentrated on consumer products such as mobile banking and payment, which are mainly from non-corporate individual clients. Therefore, digital literacy is important to understand such demand. For example, age could have a significant effect on adoption of modern ICT technologies. Previous studies (e.g. Chung and others, 2010; Tarhini and others, 2014; Wang and others, 2009) have tested the impact of age on technology usage behavior and have often found negative relationships between age and utilization of newer technology. Cheong (2002) analyzed the various characteristics of internet users and non-users, in which it was observed that most internet users are young adults, who are more educated with higher incomes. Other demographic variables such as gender, income and education could also have a significant relationship with internet application.

Broader Business Environment

Economic theory highlights the need for competition, enforceable property rights and flexible labor market for promoting investments. The OECD (2015) discussed the importance of the policy environment for innovation and economic performance through the adoption of new technologies including general-purpose technologies. For example, flexible labor market policies help reduce potential risks of exiting the market in the event of a macro shock, thereby allowing firms to make costly investments today (Bartelsman, 2013). Sitbon (2015) documented several areas where "competition bottlenecks" have emerged in developing markets. The author cautioned that policy interventions targeting monopolistic behavior need to be carefully timed and must balance the benefits of monopoly power as an incentive to invest and drive growth against the drawbacks of higher prices and slower innovation.

Financial Sector Development

Overall development of the financial sector could influence banks' digital advancement, but the eventual impact is uncertain. A more mature banking system with a history of adopting the latest technology e.g., represented by the prevalent usage of credit cards may continue to stay at the frontier of technology.[21] Also, the fast development of the non-bank financial institutions could force banks to prioritize catching up with the latest technology. As indicated in Conway and others (2006), markets with considerable competitive pressure incentivize firms to invest in emerging technology in order to maintain market share and

[21] This statement should be interpreted with caution, as a lower usage of credit cards may also be due to customer preference.

competitiveness. The opposite, however, could also be true—that is, a developed financial sector with adequate supply of financial services may reduce incentives for developing new financial products based on the latest technologies, especially if inertia has set in among customer usage of the existing financial services.

Other Factors

Bank characteristics. As digital transformation is a business decision, the goal is to boost an individual bank's competitiveness, strength, and ultimately its long-term profitability. The size of the bank, its profit margins, capital positions and business models could all influence the success and long-term benefits of digital transformation. For example, the nature of new technologies and the necessary large initial investment tend to favor large banks with stronger balance sheets rather than smaller banks with weaker balance sheets. In addition, although a bank's profitability could also be an important consideration in its decision on digital transformation, the impact could be uncertain. That is, a highly profitable bank could be in a better position in financing investment in digital technology, but it also may feel less pressure to digitalize as a means to boost its future profitability.

ii. Data

The primary data source for the digital ecosystem is the Enhanced Digital Access Index (EDAI) compiled by Alper and Miktus (2019). The EDAI is a digital connectivity index based on a range of ICT variables computed by imposing a modelling structure on these variables. It is divided into five sub-indices that summarize a country's ability to access ICT: i) infrastructure); ii) knowledge; iii) affordability; iv) quality; and (v) actual internet usage.[22] As an alternative, I also use "cellular subscriptions" and "broadband subscriptions" from the "Innovation and Technology" database of OECD. Additional variables on the level of education, share of STEM graduates and R&D expenditures are from the World Bank, and the share of young people (millennials and post-millennials) is calculated based on the population database of the United Nation.

Data on the broader business environment could be roughly divided into five groups: i) the rule of law and the quality of the legal system; ii) property rights, iii) credit market regulations; iv) labor market flexibility, and v) business regulations. The index for the rule of law is from World Bank governance database, while the legal system indicators are from the Economic Freedom of the World by Fraser Institute. Indicators for property rights are from the Heritage Foundation, complemented by data from Economic Freedom of the World (Fraser Institute). Additional data on banks' own conditions and financial sector development are drawn from the Financial Stability Indicator (FSI) of the IMF and the GFd database of the World Bank. Summary statistics of these data are given in Appendix IV.

[22] I also investigated alternative database, including the Digital Adoption Index by International Telecommunication Union, and the Digital Adoption Index of the World Bank, which yield similar results. Overall, these indices do not move significantly over years.

iii. Bivariate Correlations Analysis

As the first step, I study the bivariate correlations between the level of digital banking and potential explanatory factors (Table 2). The absolute values of pair-wise correlations are calculated and grouped by quartiles.

As expected, a more advanced digital ecosystem, and a better business environment and legal system are positively associated to the level of digital banking. The magnitude of correlation differs greatly. Internet usage, knowledge in ICT, and R&D expenditures are highly correlated with the usage of banks' digital services, while labor market regulations appear to be less relevant. Surprisingly, however, a higher share of the younger population is negatively correlated with digital banking. One potential explanation could be that the bilateral correlation ignores other important explanatory factors, such as the overall development of the financial sector or the digital infrastructure quality. For example, as indicated in Figure 3, Western and Northern European countries are more advanced in digital banking compared with sub-Saharan African countries, but the latter often have a younger population.

Bank conditions, on the other hand, do not appear to be important factors. Higher capital positions are positively correlated with the level of digital banking, while higher NPL ratios are associated with a lower level of digital banking. Higher profitability, as represented by the return on assets (ROA) and return on equity (ROE), tend to be followed by lower levels of digital banking, possibly reflecting the reduced pressure for profitable banks to digitalize to stay competitive. However, the magnitude of all these correlations are small, possibly indicating their lower importance in determining the digital advancement of banking services.

On aggregate, development of the financial sector is accompanied by higher levels of bank digitalization. A higher share of credit card or debit card ownership, as an indicator of advancement in the banking industry, is associated with a higher level of bank digitalization. In addition, a positive correlation exists between the share of people that use mobile phones to pay for utilities and bank digitalization, but this correlation requires caution to interpret. A higher share of people that use mobile phones to pay for utilities could represent either the advancement of bank digitalization or the advancement in non-bank digital financial services depending on which financial institutions supply such services. If the former, this indicator is simply another proxy for bank digitalization. If the latter, the positive correlation could mean that the development of non-bank digital financial services could be a stimulant for banks' digital transformation. A more direct indicator for the non-bank digital financial services is the usage of mobile money accounts: this indicator's positive and high correlation with the level of bank digitalization supports the story that the development of non-bank financial institutions could stimulate technological adoption by banks rather than suppress it.

Table 2. Simple Correlation Analysis

Bank Digitalization Proxy: Uses of internet or mobile to access financial institutions accounts (% of 15+ with financial institutions account), 2017

Related variables	Obs.	Corr.
Digital ecosystem (201–2016 average)		
DAI: infrastructure	136	0.3
DAI:quality	136	0.2
DAI: affordability	136	0.3
DAI: knowledge	136	0.6
DAI: internet usage	136	0.7
EDAI	136	0.5
DESI: digital public services	26	0.5
Cellular subscriptions	133	0.2
Broadband subscriptions	133	0.7
R&D expenditure	96	0.7
Education	95	0.0
Stem graduates	95	0.2
Millenials and post-millenials	135	-0.5
Government policies and broader competitive environment (2016)		
Legal: Rule of law	135	0.8
Legal: Judicial independence	130	0.6
Legal: legal enforcement of contracts	135	0.4
Legal: integrity of legal system	120	0.7
Property rights: property rights	135	0.7
Property rights: regulatory restrictions real propert	134	0.2
Property rights: legal system property rights	135	0.7
credit market regulations	135	0.3
Labor: hiring regulations	134	0.3
Labor: centralized collective bargaining	130	0.0
Labor: hours regulations	135	0.0
Labor: mandated cost worker	135	0.4
Labor: labor market regulations	135	0.3
Business: admin requirements	135	0.3
Business: bureaucracy costs	135	0.5
Business: starting a business	135	0.2
Business: extra payments	130	0.6
Business: licensing restrictions	135	0.1
Business: tax compliance	135	0.4
Business: regulation	135	0.5

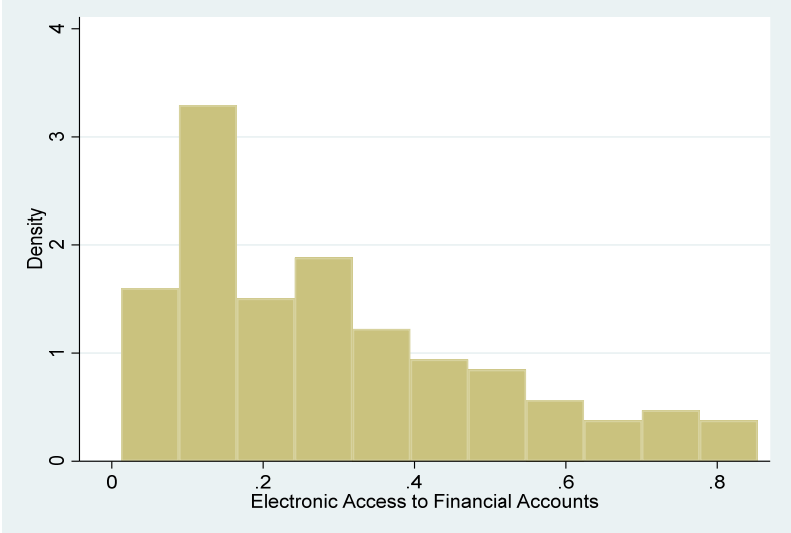
Related variables	Obs.	Corr.
Banks' own condition (2014–2016 average)		
Total capital ratio	108	0.2
Tier 1 capital ratio	108	0.2
NPL ratios	107	-0.2
ROA	108	-0.2
ROE	108	-0.1
Financial sector development (2017)		
Credit card ownership	135	0.7
Debit card ownership	135	0.8
Bank concentration (2016)	130	0.1
Mobile phone to pay utility bills	139	0.5
Mobile money accounts	74	0.7

Note: The color scheme follows the 25th, 50th and 75th percentiles of the correlations. Variables with negative correlations with the dependent variable are highlighted in red.

iv. Multivariate Analysis

To further understand the relationship between various factors and bank digitalization, I use fractional logit regressions. This method acknowledges the fractional nature of the dependent variables (Figure 7) that can be employed for both discrete and continuous variables and it can handle the extreme values of 0 and 1 without manipulating the data (Papke and Wooldridge, 1996; Baum, 2008; and Mullahy, 2010). Moreover, fractional logit models allow one to capture non-linear relationships, particularly when outcome variable is 0 or 1 (Ramalho and others, 2011). The description of the model can be found in Appendix V. Given the limited numbers of observations, it is challenging to establish causal relationships between the explanatory variables and the dependent variable. To confront this issue, lagged explanatory variables are used, and the assessment of whether the relationship is causal is based on both the empirical and economic significance of the coefficients for each variable. [23]

Figure 7. Histogram of the Dependent Variable



Considering the limited number of observations, I implement stepwise regressions to reduce the number of explanatory variables. This methodology consists of iteratively adding and removing regressors to find a subset of variables resulting in the best performing model. [24] I implement the stepwise regressions and drop variables that do not pass the

[23] For example, overall development of the digital infrastructure before 2017 is less likely to be influenced by bank digitalization than vice versa.

[24] Stepwise regression is useful for high-dimensional data containing multiple predictor variables. Principal components-based regression methods were also considered, including the principal component regression (PCR) and partial least squares (PLS). The principal component options can be an effective tool for reducing dimensionality in problems where many variables are measured, particularly when there are strong linear relationships among variables. Nevertheless, to interpret the principal components, one must filter through the coefficients (or loadings) of the linear combinations and identify patterns. This can be quite challenging in problems with many variables.

significance test of 5 percent. Appendix VI gives the details of the stepwise regressions and the procedure for selection of explanatory variables.

I first estimate the fractional model with variables selected from the stepwise regressions for the full sample (Table 3, column 1).[25] [26] The results confirm findings in the previous section, emphasizing the positive correlation of banks' digital advancement with a better digital ecosystem and business environment, as well as advancement of the financial sector and healthy banks' balance sheets. In the category of the digital ecosystem, the results underscore the importance of ensuring the *ease of internet use*, which might be achieved through widely available and affordable high-quality internet network. However, the impact of the youth population—the share of millennials and post-millennials, shows up as insignificant, likely indicating that the age factor is not important in explaining the use of digital financial services as expected. The significant and positive impact of the broader business environment highlights the *rule of law* and *credit market regulations* as important supporting factors for banks' digital advancement.[27] Of the remaining explanatory variables, the negative coefficient of the *NPL ratio* underscores the importance of a healthy banking balance sheet and speedy NPL resolutions to maintain a reasonable NPL ratio. Finally, the overall development of financial sector, represented by *debit card ownership* and *use of mobile phone to pay utility bills,* could be positively correlated with banks' digitalization progress.

I also examine the potential impact of non-bank financial service digitalization for the full sample (Table 3, column2). The use of non-bank digital financial services is proxied by the number of mobile money account (column 2). As this indicator is only available for 77 countries, most of which are lower-income economies, it is not used for the majority of regressions. Regression results indicate a significant and positive correlation between the number of mobile money account and banks' digitalization level, suggesting that the development of non-bank financial services could act as a constructive rather than disruptive force for the technological advancement of the banking industry. This implies the importance of building an enabling environment for fintech firms and bigtechs.

Estimations by income levels reveal the heterogeneous impact of the explanatory variables (Table 3, columns 3-5). However, these results should be interpreted with caution considering the limited observations.

- The results for high-income economies (column 3) show that the coefficient of the *share of millennials and post millennials* turns significant but negative. This is puzzling and against intuition: while further studies are needed, one potential

[25] In all regressions, GDP per capita is used as a control variable.

[26] Potential endogeneity is an issue that I cannot address due to the lack of a "good" instrument for the cross-sectional nature of the data used in the estimation. In that sense, I refrain from attributing causation and emphasis on the magnitudes of the coefficients in the analysis and I focus more on the strength of the correlations as well as the sign of the coefficients. With better data availability in the future, panel and distributed lag models could be considered as a valuable extension of further work in this area.

[27] This negative correlation between business regulation and banks' digitalization is counter-intuitive, but all later regressions suggest insignificant correlation between these two variables. Therefore, the negative correlation should not to be over-interpreted.

explanation is that in these economies, younger adults often have lower income and net worth,[28] and thus may face less need for high value transactions that are mostly digital. In addition, the impact of the financial sector development on digital banking is likely to be negative. The negative and significant coefficient of *ownership of credit card* could imply that entrenched behavior of the use of existing banking services supported by older technologies, such as the use of credit cards, could reduce the pressure for the banking industry to innovate as customers are less likely to switch to alternative financial service providers.

- Estimation results for low-income economies (column 4) underscore the importance of a flexible labor market regulation, while the estimation results for middle income countries (column 5) highlight the importance of young population in the banking digitalization process.
- A healthy bank balance sheet with low NPL ratios is particularly important across all income groups.

The impact of R&D is analyzed separately due to a smaller number of observations (Table 4). Overall, the impact of R&D expenditure on banks' digital advancement is positive in high-income economies but appear to be negative in low- and middle-income economies. The negative correlation may be due to some omitted variables, such as the efficiency of R&D investment.

[28] For example, in the US, net worth varied from just 3,662 USD for households headed by adults younger than 35 to 170,494 USD for households headed by adults ages 65 and older (PEW, 2011).

Table 3. Fractional Logit Regressions

Dependent Variable: Electronic Access to Financial Accounts (0–1)

VARIABLES	(1) All	(2) All	(3) High-income	(4) Low-income	(5) Middle Income	(6) Europe	(7) EU	(8) Euro area
Digital ecosystem								
DAI: infrastructure (0-100)	-0.00534	-0.00215	0.00571	0.00341	-0.00909***	0.000461	0.00262	0.000281
	(0.00325)	(0.00321)	(0.00474)	(0.00272)	(0.00212)	(0.00496)	(0.00595)	(0.00309)
DAI: internet usage (0-100)	0.0201***	0.0118*	0.0209**	-0.0342	0.0334***	0.0178*	0.00187	0.0296***
	(0.00618)	(0.00693)	(0.00888)	(0.0208)	(0.00898)	(0.00930)	(0.00871)	(0.00792)
Millennials and post millennials (%)	0.732	2.501***	-4.905***	-5.161**	6.233***	3.684***	0.104	-11.66***
	(1.016)	(0.895)	(1.591)	(2.062)	(1.090)	(1.036)	(3.508)	(2.844)
Broader business environment								
Rule of Law (index)	0.338**	0.271*	0.548***	-0.122	0.285	0.139	0.799**	0.910***
	(0.135)	(0.139)	(0.180)	(0.187)	(0.297)	(0.203)	(0.344)	(0.173)
Credit market regulations (rating)	0.102*	0.0521	0.155**	-0.115	0.00530	0.0958	0.0711	-0.353***
	(0.0563)	(0.0821)	(0.0650)	(0.0815)	(0.0553)	(0.0698)	(0.118)	(0.132)
Labor: hiring regulations (rating)	0.0274	0.0132	-0.000392	0.0704	0.0154	0.0357	-0.000919	-0.0231
	(0.0194)	(0.0248)	(0.0233)	(0.0460)	(0.0258)	(0.0337)	(0.0441)	(0.0244)
Labor: mandated cost worker (rating)	0.0117	-0.0100	-0.0162	0.0792***	-0.0342	-0.0115	-0.0120	0.0780***
	(0.0197)	(0.0175)	(0.0349)	(0.0257)	(0.0251)	(0.0353)	(0.0467)	(0.0262)
Business: regulation	-0.226*	-0.129	-0.106	0.239	-0.221	-0.228	-0.104	-0.105
	(0.137)	(0.165)	(0.195)	(0.190)	(0.164)	(0.241)	(0.348)	(0.192)
Banks' own conditions								
NPL ratios (%)	-0.0117*	0.00538	-0.0136**	-0.0861***	-0.00448	-0.0432***	-0.0181	0.0186*
	(0.00607)	(0.0174)	(0.00590)	(0.0233)	(0.0112)	(0.0109)	(0.0128)	(0.0112)
ROA (%)	-0.0549	0.00473	0.171***	-0.144	-0.117***	-0.211***	0.210	0.802***
	(0.0364)	(0.0511)	(0.0591)	(0.131)	(0.0401)	(0.0496)	(0.133)	(0.183)
Financial sector development								
Credit card ownership (%)	0.00217	0.00829	-0.0134***	0.0134**	0.0162	-0.0296***	-0.0281***	-0.0178***
	(0.00435)	(0.00963)	(0.00519)	(0.00624)	(0.0195)	(0.00676)	(0.00568)	(0.00422)
Debt card ownership (%)	0.0139***	0.0128**	-0.00636	0.00703	0.0335***	0.0193***	0.00425	-0.0251***
	(0.00429)	(0.00544)	(0.00605)	(0.00450)	(0.00792)	(0.00637)	(0.00852)	(0.00659)
Mobile phone to pay utility (%)	0.0265***	0.0145***	0.0424***	0.0412***	0.0181***	0.0361***	0.0325***	0.0503***
	(0.00390)	(0.00344)	(0.00697)	(0.00809)	(0.00390)	(0.0106)	(0.0101)	(0.00725)
Mobile money account (%)		0.00998*						
		(0.00562)						
ln(GDP/capita)	-0.222**	-0.0564	0.0468	0.611	-0.176*	0.321*	0.280	0.615***
	(0.0996)	(0.118)	(0.208)	(0.422)	(0.102)	(0.187)	(0.215)	(0.200)
Constant	-0.504	-3.274**	-1.126	-4.256*	-3.881***	-6.030***	-3.574	0.0204
	(1.094)	(1.467)	(1.815)	(2.316)	(1.293)	(2.040)	(2.344)	(1.600)
Observations	98	48	41	28	29	39	26	18

Robust standard errors in parentheses

Table 4. Fractional Logit Regressions: with R&D Investment

Dependent Variable: Electronic Access to Financial Accounts (0–1)

VARIABLES	(1) All	(2) All	(3) High-income	(4) Low-income	(5) Middle Income	(6) Europe	(7) EU	(8) Euro area
Digital ecosystem								
DAI: infrastructure (0-100)	-0.00361	0.00262	0.00282	0.00519***	-0.0255***	0.000532	0.00231	-0.000933
	(0.00361)	(0.00652)	(0.00516)	(0.00188)	(4.98e-06)	(0.00502)	(0.00578)	(0.00115)
DAI: internet usage (0-100)	0.0169**	0.0172*	0.0120	-0.0254**	0.0259***	0.0175*	0.00355	0.0330***
	(0.00659)	(0.00922)	(0.00839)	(0.0102)	(1.40e-05)	(0.00928)	(0.00960)	(0.00239)
R&D expenditure (% of GDP)	0.228***	0.226	0.252***	-0.381**	-2.582***	-0.0205	0.123	0.377***
	(0.0629)	(0.224)	(0.0850)	(0.161)	(0.000742)	(0.167)	(0.198)	(0.0263)
Millennials and post millennials (%)	0.257	1.376	-0.897	-4.192***	1.934	3.628***	0.856	-11.60***
	(1.121)	(1.461)	(2.097)	(0.967)	(0)	(1.064)	(3.030)	(0.911)
Broader business environment								
Rule of Law (index)	0.146	0.240	0.425***	-0.166	1.945***	0.162	0.636	0.468***
	(0.150)	(0.212)	(0.162)	(0.113)	(0.000542)	(0.254)	(0.483)	(0.0700)
Labor: hiring regulations (rating)	0.00687	0.00471	-0.0351	0.0437	-0.0893***	0.0380	-0.0155	-0.0772***
	(0.0224)	(0.0320)	(0.0330)	(0.0331)	(3.30e-05)	(0.0452)	(0.0530)	(0.00605)
Business: regulation	-0.0507	-0.0882	0.114	-0.0178	-0.762***	-0.244	-0.00652	0.233***
	(0.149)	(0.228)	(0.243)	(0.184)	(0.000534)	(0.307)	(0.417)	(0.0351)
Banks' own conditions								
NPL ratios (%)	-0.0152*	-0.00271	-0.00869	-0.0531***	0.0859***	-0.0435***	-0.0177	0.0264***
	(0.00898)	(0.0517)	(0.00643)	(0.0164)	(4.38e-05)	(0.0116)	(0.0130)	(0.00360)
ROA (%)	-0.0671	0.00683	0.155**	-0.170	-0.0937***	-0.212***	0.235	0.958***
	(0.0448)	(0.0885)	(0.0716)	(0.126)	(9.17e-05)	(0.0503)	(0.147)	(0.0473)
Financial sector development								
Credit card ownership (%)	-0.00686	0.00837	-0.0147***	-0.00205	-0.0778***	-0.0296***	-0.0274***	-0.0185***
	(0.00493)	(0.00883)	(0.00493)	(0.00450)	(4.52e-05)	(0.00680)	(0.00559)	(0.00200)
Debt card ownership (%)	0.0128**	0.0105	0.00450	0.00654	0.0415***	0.0190***	0.00198	-0.0324***
	(0.00514)	(0.00827)	(0.00605)	(0.00458)	(2.91e-05)	(0.00689)	(0.0103)	(0.00237)
Mobile phone to pay utility (%)	0.0300***	0.00905	0.0355***	0.0854***	0.00623***	0.0360***	0.0320***	0.0510***
	(0.00646)	(0.00674)	(0.00750)	(0.00961)	(7.50e-06)	(0.0116)	(0.0104)	(0.00212)
Mobile money account (%)		0.0219**						
		(0.0109)						
ln(GDP/capita)	-0.0784	-0.211	-0.148	0.786***	-0.202***	0.325*	0.278	0.680***
	(0.135)	(0.223)	(0.223)	(0.225)	(0.000175)	(0.187)	(0.212)	(0.0477)
Constant	-2.101	-2.125	-2.196	-5.613***	1.199	-5.884***	-4.039	-1.832***
	(1.284)	(1.855)	(1.844)	(1.350)	(0)	(2.218)	(2.564)	(0.638)
Observations	74		39	21	14	38	26	18

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

V. CONCLUSION

The ongoing digital transformation is important for banks' long-term competitiveness, and more broadly, for financial stability and inclusion. A review of bank digitalization evolution suggests a diminishing role for banks in leading advancement in financial technology and rising competition from non-bank fintech firms and bigtechs. By comparing banks' digital advancement across the world, this paper finds that in high-income economies, banks are dominant players in offering digital financial services, while in lower-income economies, non-banks may be leading the progress.

This paper also explores potential reasons for the digital divide in the banking sector across countries. The findings underscore the importance of adequate digital infrastructure and good legal and business environment in supporting digital advancement, while weak bank balance sheets could impede such progress. In addition, the development of the non-bank financial industry could encourage the adoption of newer digital bank technology. Although banks in high-income economies are relatively digitally advanced, several factors may impede further digital advancement, including the entrenched use of financial services backed by older technology (i.e., credit cards) and relatively weaker bank balance sheets.

These results indicate that some policy efforts can help banks to catch up with the digital frontier. Such efforts include investments in digital infrastructure, a strong business environment with the rule of law and a healthy competitive environment with the non-bank fintech sector. The diffusion of digital technologies occurs at an accelerated pace, and thus the initial digital divide could be quickly widened against the backdrop of rapid technological development. The COVID-19 pandemic has highlighted the importance of digital services in all activities including banking. The rapid migration to digital technologies spurred by the pandemic will likely continue into the recovery. As such, countries with lagging development on the digital front will increasingly find themselves less resilient their citizens will be disadvantaged owing to lower access to digital services.

Substantial questions remain unanswered. Left for future research are the following questions: What nurtures the development of fintechs and bigtechs? What are the implications of banks' digital transformationon on cyber security? Will more digitalized banking services increase or reduce financial inclusiveness? As private firms, governments and international institutions make substantial ongoing efforts to understand the digital economy, the availability and the quality of data will improve over time, creating more opportunities for deeper and more thorough studies.

REFERENCES

Accenture (2019), "Caterpillars, Butterflies, and Unicorns: Does Digital Leadership in Banking Really Matter?," *Winning in the Digital Economy Series.*

Alper, C. Emre and Michal Miktus (2019), "Digital Connectivity in Sub-Saharan Africa: A Comparative Perspective*," IMF Working Paper wp/19/210*.

Bank for International Settlements (2017), "Sound Practices: Implications of Fintech Developments for Banks and Bank Supervisors," *Basel Committee on Banking Supervision.*

_____ (2020), "Fintech and Big Tech Credit: A New Database," *BIS Working Papers No 887,* September 2020

Bartelsman, E. (2013), "ICT, Reallocation and Productivity," *European Economy-Economic Papers, p. 486.*

Baum, Christopher F. (2008), "Stata tip 63: Modeling Proportions," *The Stata Journal*, 8(2), pp.299–303.

Beaumont, Craig, Tommaso Mancini-Griffoli, Maria Soledad Martinez Peria, Florian Misch, and Bjorn Segendorf, (2019), "The Diffusion of Payment Innovations: Insights from the Stellar Rise of Swish," *IMF working paper*, forthcoming.

Brynjolfsson, Erik (1993), 'The Productivity Paradox of Information Technology," *Article in Communications of the ACM*, December 1993.

Brynjolfsson, Erik and L. Hitt (1995), "Information Technology as a Factor of Production: The Role of Differences Among Firms." *Economics of Innovation and New Technology.* 3:4, pp. 183–200.

Brynjolfsson, Erik and L. Hitt. (1996). "Paradox Lost? Firm-level Evidence on the Returns to Information Systems Spending." *Management Science* 42:4, pp. 541–58.

Brynjolfsson, Erik, Andrew McAfee, Michael Sorell, and Feng Zhu (2008), "Scale Without Mass: Business Process Replication and Industry Dynamics." *Harvard Business School Technology & Operations Mgt. Unit Research Paper* No. 07–016.

Cainelli, G., Rinaldo Evangelista, and Maria Savona, (2006), "Innovation and Economic Performance in Services: a Firm-Level Analysis." *Cambridge Journal of Economics* Vol. 30, No. 3 (May 2006), pp. 435–458.

Casolaro, L. and Giorgio Gobbi (2007), "Information Technology and Productivity Changes in the Banking Industry." *Economic Notes by Banca Monte dei Paschi di Siena SpA*, Vol. 36, no. 1–2007, pp. 43–76.

Cheong, Weng Hin (2002), "Internet Adoption in Macao." *Journal of Computer Mediated Communication*, 7(2), 11–18.

Chung, J.E., Park, N., Wang, H., Fulk, J., and Mclaughlin, M. (2010), "Age Differences in Perceptions of Online Community Participation Among Non-Users; An Extension of the Technology Acceptance Model," *Computers in Human Behavior,* 26 (6), 1674–1684.

Citi Group (2019), "Bank X: The New New Banks." *Citi GPS: Global Perspectives & Solutions* .

Conway, Paul, Donato De Rosa, Giuseppe Nicoletti and Faye Steiner (2006), "Product Market Regulation in OECD Countries: 1998 to 2003," *OECD Economics Department Working Papers,* No. 419, OECD Publishing, Paris.

DeStefano, Timothy, Koen De Backer, and Laurent Moussiegt (2017), "Determinants of Digital Technology Use by Companies," *OECD Science, Technology and Innovation*, Policy Papers, June 2017 No. 40.

The Economist 1843 (2012), "What's the Greatest Invention of All Time?" January/February.

Ernst and Young (2019), "The Impact of Wider Integration of Data Analytics and Automation on Manpower in the Singapore Financial Service Sector," Commissioned by the *Institute of Baning and Finance and the Monetary Authority of Singapore.*

European Banking Association (EBA)(2020), "The Future of European Payments: Strategic Choices for Banks." November 2020.

Financial Times (2019), "More than a Third of Bank Braches Axed in Past Four Years," September 27, 2019.

Frame, W. S. and Lawrence J. White (2004), "Empirical Studies of Financial Innovation: Lots of Talk, Little Action," *Journal of Economic Literature* Vol. 42, No. 1, March 2004, pp 116–144.

Govindarajan, Vijay, Shivaram Rajgopal, Anup Srivastava, and Luminita Enache (2019), "It's Time to Stop Treating R&D as a Discretionary Expenditure,*" Harvard Business Review*, January 29, 2019.

Huang, Jimmy, Ola Hendridsson, Martin Liu, and Sue Newell (2017), "Growing on Steroids: Rapidly Scaling the User Base of Digital Ventures Through Digital Innovation." *MIS Quarterly,* (41:1) pp. 301–314.

Hong Kong Institute for Monetary and Financial Research (HKIMR, 2020), "Fintech: Adoption and Innovation in the Hong Kong Banking Industry," *HKIMR Applied Research Report* No. 1/2020.

Hughes, Joseph P. and Loretta J. Mester (2013), "Who Said Large Banks Don't Experience Scale Economies? Evidence from a Risk-Return-Driven Cost Function," *FRB of Philadelphia Working Paper* No. 13–13, forthcoming in the Journal of Financial Intermediate.

International Monetary Fund (IMF, 2020). "Fintech in Europe: Promises and Threats," *IMF Working Paper,* WP/20/241.

Karlan, Dean, Jake Kendall, Rebecca Mann, Rohini Pande, Tavneet Suri, and Jonathan Zinman (2016), "*Research and Impacts of Digital Financial Services.*" NBER Working paper 22633.

Kurz, Mordecai (2017), "On the Formation of Capital and Wealth: IT, Monopoly Power and Rising Inequality."

Mullahy, John (2015). "Multivariate Fractional Regression Estimation of Econometric Share Models." *Journal of Econometric Methods,* 4(1), pp.71–100.

OECD (2015), "The Future of Productivity." *OECD Publishing*, Paris.

Papke, L.E. and Wooldridge, J.M. (1996), "Econometric Methods for Fractional Response Variables with an Application to 401 (k) Plan Participation Rates*," Journal of Applied Econometrics*, 11(6), pp. 619–632.

Pew Research Center (2011), "Social & Demographic Trends," November 7, 2011

Romalho, E.A., J.J. Ramalho, and J.M., 2011, "Alternative Estimating and Testing Empirical Strategies for Fractional Regression Models*." Journal of Economic Surveys*, 25(1), pp.19–68.

Scott, S. V., and John Van Reenen, and Markos Zachariadis (2017), "The Long-term Effect of Digital Innovation on Bank Performance: An Empirical Study of Swift Adoption in Financial Services," *Research Policy*, Elsevier, vol. 46(5), pages 984–1004.

Shumpeter, J. A. (1943), "Capitalism in the Postwar World," in Harris, Seymour E. (ed.), *Postwar economic problems,* New York, New York London: McGraw-Hill.

Sitbon, Elisa. (2015), "*Addressing Competition Bottlenecks in Digital Financial Ecosystems.*" Journal of Payments, Strategy and Systems 9(3).

Solow, Robert M (1987), "We'd Better Watch Out," *New York Times* (July 12), Book Review, 36.

Tarhini, Ali, Kate Hone, and Xiaohui Liu (2014), "Measuring the Moderating Effect of Gender and Age on E-learning Acceptance in England: A Structural Equation Modelling Approach of an extended Technology Acceptance Model," *Journal of Educational Computing Research,* 51(2), 163–184.

Temenos (2015), "Shifting Sands: Banking in the Digital ERA," *the Eighth annual Temenos survey of challenges, priorities and trends in the financial services sector*, 2015.

_____ (2019), "The 10th Annual Temenos Survey of Challenges, Priorities and Trends in the Financial Services Sector," *Temenos White Paper,* 2019.

Wang, Yi-Shun, Ming-Cheng Wu and Hsiu-Yuan Wang (2009), "Investigating the Determinants and Age and Gender Differences in the Acceptance of Mobile Learning," *British Journal of Educational Technology,* 40(1), 92–118.

Wheelock, David C. and Paul W. Wilson (2018), "The Evolution of Scale Economies in U.S. Banking," *Journal of Applied Econometrics,* Volumn 33, Issue 1, January/February 2018.

World Economic Forum (WEF, 2014), *"*Delivering Digital Infrastructure: Advancing the Internet Economy" *World Economic Forum*, prepared in collaboration with the Boston Consulting Group.

APPENDIX I. ADVANCEMENT IN TECHNOLOGY AND FIRMS' PERFORMANCES

The theoretical tradition recognizes the importance of technological changes and innovations as key drivers of the economic growth and firms' performance. According to the Shumpeterian theory (Shumpeter, 1943), innovation puts in motion the mechanism of "creative destruction" in which technological advances override pre-existing market conditions. In the process, firms introduce new products, services and organizational processes thus gaining market share at the expense of their non-innovating competitors.

Much of the early research on the relationship between the digital technology and economic performance found little evidence of a relationship. Brynjolfsson (1993) summarized these studies. These findings corroborated the 'productivity paradox', which was appropriately characteraized by Robert Solow's famous quote that "you can see the computer age everywhere but in the producitivty statistics" (Solow, 1987). CEOs and line managers have increasely begun to question their huge investments in computers and related technologies. The lack of good quantitative measures for output and value created by IT has made the IT manager's job of justifying investmetns particularly difficult. Academics have had similar problems assessing the contribution of this critical new technology, and this has been generally interpreted as a negative signal of its value.[1]

More recent studies, however, found mounting evidences confirming that digital technology does yield sizable economic returns at both macro and micro levels. In the early 1990s, analysis at the firm-level were beginning to find evidence that computers had a substantial effect on firms' producitivty levels. Brynjolfsson and Hitt (1995, 1996) and Lichtenberg (1995) used data from over 300 large firms over the period of 1988–92, and found that that ICT capital generates up to 10 times more output than other forms of capital. At the macro level, most studies focus on measures of economy-wide productivity and labor productivity growth to make claims regarding the aggregate contribution of invesment in technology. They argue that technologically advanced countries are able to leverage their new competitive position and gradually accumulate "monopolistic rents", increasing their profitability still further (Cainelli et al., 2006). The product innovation meanwhile result in a new business model enabled by digital technology platforms, and also leads to a changing entrepreneurial culture: digital ventures can grow at a massive rate and scale (Huang et al. 2017) and founders can create temporary monopolites or oligopolies with less external capital (Kurz 2017). These findings are consistent with the Schumpeterian economic theoretical tradition. The nature of new technologies often favors large firms as opposed to small firms or entrants. This may trigger 'winner takes all' dynamics that benefit a minority of leading frontier firms (OECD 2015 and Brynjolfsson et al., 2008).

[1] See Brynjolfsson (1993) for a list of these studies.

APPENDIX II. DATABASE ON FINANCIAL SERVICE DIGITALIZATION

In this paper, indicators for financial service digitalization are from the Global Findex database (GFd) published by the World Bank. The GFd is one of the most comprehensive databases on adults' behavior in saving, borrowing, making payments, and managing risks. This database has been published every three years since 2011. The data are collected through nationally representative surveys of more than 150,000 adults in over 140 economies. The 2017 edition, the latest edition of the database, added new data on financial technology usage, including the use of mobile phones and internet to conduct financial transactions.

The GFd dataset contains 14 broad cateogoies of indicators that represent a limited scope of the digital finance (TableA1). These indicators narrowly focus on internet and mobile phone usage to access financial services. No information is available on other aspects of financial industry digital advancement, such as the development of back-end technologies, cloud usage, AI, and other technologies. In addition, these indicators do not differentiate between digital financial services offered by banks and those offered by non-bank financial institutions. For example, in Africa and China, payment via mobile phone is mainly through mobile wallets provided technology firms, such as Mpesa in Africa and Tentent and Alibaba in China, while mobile payments in Europe and the U.S. are often channeled through mobile applications linked to a bank account.[2]

Five of these fourteen GFd indicators could be potentially used to represent digital services offered by banks. These five indicators include (Table A2): 1) *used internet to pay bills in the current year;* 2) *paid online for internet purchases*; 3) and 4) *used a mobile phone or internet to access a financial institutions account in the past year, both as a share of the adult population and as a share of adults with financial institution accounts*; and 5) *used a mobile phone or the internet to check account balance in the past year*.

Another data source is the Financial Access Survey (FAS) compiled by the IMF. Launched in 2009, the FAS is a supply-side dataset on the access to and use of financial services aimed at supporting policymakers to measure and monitor financial inclusion and benchmark progress against peers. The FAS is based on administrative data collected by central banks and other financial regulators. The dataset covers 189 countries spanning more than 10 years and contains 121 time-series on financial access and usage.

[2] Mobile payment through the mobile/digital wallet runs on big-tech company platforms such as Tencent or Alibaba in China. Digital wallet stores money and consumer payment credentials electronically. Such digital wallet is different from other forms of mobile payment, such as Apple Pay which is mostly used in the U.S. and Europe. Apple Pay is more a digital representation of a credit card, which simply substitutes the physical card for a virtual one.

The FAS has evolved over time to adapt to the changing landscape of financial services, including the rise of fintech. In 2014, country-level data on mobile money were introduced and the FAS's coverage of innovations in traditional banking services was expanded, including branchless banking and debit and credit cards in circulation. However, these indicators are only available for at most 56 countries, with a concentration on low-income economies. The 2019 FAS, the latest edition of the database, introduced new data series on mobile and internet banking for deposit-taking microfinance institutions. Although the number of countries reporting mobile money data increased from 66 to 71, there remain substantial gaps.

Table A1. Indicators on Financial Service Digitalization Usage

Global Findex Database

	Indicator Name	Definition	Years available
1(a)	Used the internet to pay bills in the past year (% age 15+)	The percentage of respondents who report using the internet to pay bills in the past 12 months.	2017
1(b)	Used the internet to pay bills or to buy something online in the past year (% age 15+)	The percentage of respondents who report using the internet to pay bills or buy something online in the past 12 months.	2017
2(a)	Used the internet to buy something online in the past year(% age 15+)	The percentage of respondents who report using the internet to buy something online in the past 12 months.	2017
2(b)	Paid online for internet purchase (% internet purchasers, age 15+)	Among respondents reporting using the internet to buy something online in the past 12 months, the percentage who report paying online for their internet purchase.	2017
3(a)	Sent or received domestic remittances: through a mobile phone (% age 15+)	The percentage of respondents who report personally sending any of their money in the past 12 months to, or receiving any of it from, a relative or friend living in a different area of their country through a mobile phone.	2017
3(b)	Sent or received domestic remittances: through a mobile phone (% senders and recipients, age 15+)	Among respondents reporting personally sending any of their money in the past 12 months to, or receiving any of it from, a relative or friend living in a different area of their country, the percentage who report doing so through a mobile phone.	2017
4(a)	Paid utility bills: using a mobile phone (% age 15+)	The percentage of respondents who report personally making regular payments for water, electricity, or trash collection in the past 12 months through a mobile phone.	2017
4(b)	Paid utility bills: using a mobile phone (% paying utility bills, age 15+)	Among respondents reporting personally making regular payments for water, electricity, or trash collection in the past 12 months, the percentage who report making these payments through a mobile phone.	2017
5(a)	Received wages: through a mobile phone (% age 15+)	The percentage of respondents who report receiving any money from an employer in the past 12 months in the form of a salary or wages for doing work through a mobile phone.	2017
5(b)	Received wages: through a mobile phone (% wage recipients, age 15+)	Among respondents reporting receiving any money from an employer in the past 12 months in the form of a salary or wages for doing work, the percentage who report receiving this money through a mobile phone.	2017
6(a)	Received private sector wages: through a mobile phone (% age 15+)	The percentage of respondents who report being employed in the private sector and receiving any money from an employer in the past 12 months in the form of a salary or wages for doing work through a mobile phone.	2017
6(b)	Received private sector wages: through a mobile phone (% wage recipients, age 15+)	Among respondents reporting being employed in the private sector and receiving any money from an employer in the past 12 months in the form of a salary or wages for doing work, the percentage who report receiving this money through a mobile phone.	2017
7(a)	Received public sector wages: through a mobile phone (% age 15+)	The percentage of respondents who report being employed by the government, military, or public sector and receiving any money from an employer in the past 12 months in the form of a salary or wages for doing work through a mobile phone.	2017
7(b)	Received public sector wages: through a mobile phone (% wage recipients, age 15+)	Among respondents reporting being employed by the government, military, or public sector and receiving any money from an employer in the past 12 months in the form of a salary or wages for doing work, the percentage who report receiving this money through a mobile phone.	2017

	Indicator Name	Definition	Years available
8(a)	Paid school fees: using a mobile phone (% age 15+)	The percentage of respondents who report personally making regular payments for school fees in the past 12 months through a mobile phone.	2017
8(b)	Paid school fees: using a mobile phone (% paying school fees, age 15+)	Among respondents reporting personally making regular payments for school fees in the past 12 months, the percentage who report making these payments through a mobile phone.	2017
9(a)	Received a public sector pension: through a mobile phone (% age 15+)	The percentage of respondents who report personally receiving a pension from the government, military, or public sector in the past 12 months through a mobile phone.	2017
9(b)	Received a public sector pension: through a mobile phone (% pension recipients, age 15+)	Among respondents reporting personally receiving a pension from the government, military, or public sector in the past 12 months, the percentage who report receiving the pension through a mobile phone.	2017
10(a)	Received government transfers: through a mobile phone (% age 15+)	The percentage of respondents who report personally receiving any financial support from the government in the past 12 months through a mobile phone.	2017
10(b)	Received government transfers: through a mobile phone (% transfer recipients, age 15+)	Among respondents reporting personally receiving any financial support from the government in the past 12 months, the percentage who report receiving this financial support through a mobile phone.	2017
11(a)	Received payments from self-employment: through a mobile phone (% age 15+)	The percentage of respondents who report personally receiving money from their business, from selling goods, or from providing services (including part-time work) in the past 12 months through a mobile phone.	2017
11(b)	Received payments from self-employment: through a mobile phone (% payment recipients, age 15+)	Among respondents reporting personally receiving money from their business, from selling goods, or from providing services (including part-time work) in the past 12 months, the percentage who report receiving this money through a mobile phone.	2017
12(a)	Used a mobile phone or the internet to access a financial institution account in the past year (% age 15+)	The percentage of respondents who report using a mobile phone or the internet to make a payment, to make a purchase, or to send or receive money through their financial institution account in the past 12 months.	2017
12(b)	Used a mobile phone or the internet to access a financial institution account in the past year (% with a financial institution account, age 15+)	Among respondents with a financial institution account, the percentage who report using a mobile phone or the internet to access their financial institution account in the past 12 months.	2017
13	Made or received digital payments in the past year (% age 15+)	The percentage of respondents who report using mobile money, a debit or credit card, or a mobile phone to make a payment from an account, or report using the internet to pay bills or to buy something online, in the past 12 months. It also includes respondents who report paying bills, sending or receiving remittances, receiving payments for agricultural products, receiving government transfers, receiving wages, or receiving a public sector pension directly from or into a financial institution account or through a mobile money account in the past 12 months	2011, 2014, 2017
14	Mobile money account (% age 15+)	The percentage of respondents who report personally using a mobile money service in the past 12 months	2011, 2014, 2017

Table A2. Indicators on Banking Service Digitalization Usage

Global Findex Database (GFd)

Indicator Name	Short definition	Years available
1. Used the internet to pay bills in the past year (% age 15+)	The percentage of respondents who report using the internet to pay bills in the past 12 months.	2017
2. Paid online for internet purchase (% internet purchasers, age 15+)	Among respondents reporting using the internet to buy something online in the past 12 months, the percentage who report paying online for their internet purchase.	2017
3. Used a mobile phone or the internet to access a financial institution account in the past year (% age 15+)	The percentage of respondents who report using a mobile phone or the internet to make a payment, to make a purchase, or to send or receive money through their financial institution account in the past 12 months.	2017
4. Used a mobile phone or the internet to access a financial institution account in the past year (% with a financial institution account, age 15+)	Among respondents with a financial institution account, the percentage who report using a mobile phone or the internet to access their financial institution account in the past 12 months.	2017
5. Used a mobile phone or the internet to check account balance in the past year (% age 15+)	The percentage of respondents who report using a mobile phone or the internet to check their balance for a financial institution account in the past 12 months.	2017

Source: World Bank Global Findex Database.

APPENDIX III. COUNTRY LIST

East Asia & Pacific	Europe & Central Asia (cont'd)	North America
Australia	Romania	Canada
Cambodia	Russian Federation	United States
China	Serbia	
Hong Kong SAR, China	Slovak Republic	South Asia
Indonesia	Slovenia	Afghanistan
Japan	Spain	Bangladesh
Korea, Rep.	Sweden	India
Lao PDR	Switzerland	Nepal
Malaysia	Tajikistan	Pakistan
Mongolia	Turkey	Sri Lanka
Myanmar	Turkmenistan	
New Zealand	Ukraine	Sub-Saharan Africa
Philippines	United Kingdom	Benin
Singapore	Uzbekistan	Botswana
Thailand		Burkina Faso
Taiwan, Province of China	Latin America & Caribbean	Cameroon
Vietnam	Argentina	Central African Republic
	Bolivia	Congo, Dem. Rep.
Europe & Central Asia	Brazil	Congo, Rep.
Albania	Chile	Côte d'Ivoire
Armenia	Colombia	Ethiopia
Austria	Costa Rica	Gabon
Azerbaijan	Dominican Republic	Ghana
Belarus	Ecuador	Guinea
Belgium	El Salvador	Kenya
Bosnia and Herzegovina	Guatemala	Lesotho
Bulgaria	Haiti	Liberia
Croatia	Honduras	Malawi
Cyprus	Mexico	Mali
Czech Republic	Nicaragua	Mauritania
Denmark	Panama	Mauritius
Estonia	Paraguay	Mozambique
Finland	Peru	Namibia
France	Trinidad and Tobago	Nigeria
Georgia	Uruguay	Rwanda
Germany	Venezuela, RB	Senegal
Greece		Sierra Leone
Hungary	Middle East & North Africa	South Africa
Ireland	Algeria	Tanzania
Italy	Bahrain	Togo
Kazakhstan	Egypt, Arab Rep.	Uganda
Kosovo	Iran, Islamic Rep.	Zambia
Kyrgyz Republic	Iraq	Zimbabwe
Latvia	Israel	
Lithuania	Jordan	
Luxembourg	Kuwait	
Macedonia, FYR	Lebanon	
Moldova	Libya	
Montenegro	Malta	
Netherlands	Morocco	
Norway	Saudi Arabia	
Poland	Tunisia	
Portugal	United Arab Emirates	

APPENDIX IV. SUMMARY STATISTICS AND DATA SOURCES

	Ob.	Mean	Std. Dev.	Min	Source
Dependent variable					
Electronic access to financial accounts	139	0.3	0.2	0.0	GFd database (WB)
Explanatory variables					
Digital ecosystem (2014-2016 average)					
DAI: infrastructure (0-100)	192	62	24	0	Alper and Miktus (2019)
DAI:quality (0-100)	192	23	18	0	Alper and Miktus (2019)
DAI: affordability (0-100)	192	20	8	0	Alper and Miktus (2019)
DAI: knowledge (0-100)	192	61	21	0	Alper and Miktus (2019)
DAI: internet usage (0-100)	192	42	28	0	Alper and Miktus (2019)
EDAI (0-100)	192	75	14	0	Alper and Miktus (2019)
DESI: digital public services	26	7	2	4	European Commission
Cellular subscriptions (per 100 inhabitants)	199	106	40	10	WB
Broadband subscriptions (per 100 inhabitants)	198	13	14	0	WB
R&D expenditure (% of GDP)	109	1	1	0	WB
Education (% of labor with advanced eduction)	115	78	7	58	WB
Stem graduates (% of graduates)	117	21	8	2	WB
Millenials and post-millenials (%)	185	60	14	34	United Nations
Broader Business Environment (2016)					
Legal: Rule of law (index)	194	0.0	1.0	-2.3	WB Governance Database
Legal: Judicial independence (rating)	152	5.0	2.1	0.2	WB Governance Database
Legal: legal enforcement of contracts (rating)	162	4.3	1.5	0.0	Economic Freedome of the
Legal: integrity of legal system (rating)	137	6.1	2.2	1.7	World (EFW, Fraser Institute)
Property rights: property rights (rating)	178	42.3	24.9	5.0	Heritage Foundation
Property rights: regulatory restrictions real property (rating)	160	7.5	1.6	2.0	EFW (Fraser Institute)
Property rights: legal system property rights (rating)	162	5.2	1.5	1.9	EFW (Fraser Institute)
credit market regulations (rating)	162	8.2	1.5	3.3	EFW (Fraser Institute)
Labor: hiring regulations (rating)	161	6.4	2.8	0.0	EFW (Fraser Institute)
Labor: centralized collective bargaining (rating)	152	6.4	1.2	2.1	EFW (Fraser Institute)
Labor: hours regulations (rating)	161	7.9	2.0	2.0	EFW (Fraser Institute)
Labor: mandated cost worker (rating)	159	6.4	2.9	0.0	EFW (Fraser Institute)
Labor: labor market regulations (rating)	162	6.4	1.4	2.1	EFW (Fraser Institute)
Business: admin requirements (rating)	152	4.1	1.2	1.1	EFW (Fraser Institute)
Business: bureaucracy costs (rating)	162	5.3	2.8	0.0	EFW (Fraser Institute)
Business: starting a business (rating)	162	9.1	0.9	3.3	EFW (Fraser Institute)
Business: extra payments (rating)	152	4.4	1.8	1.5	EFW (Fraser Institute)
Business: licensing restrictions (rating)	159	8.3	1.1	5.0	EFW (Fraser Institute)
Business: tax compliance (rating)	162	7.3	1.7	0.0	EFW (Fraser Institute)
Business: regulation (rating)	162	7.0	1.0	2.5	EFW (Fraser Institute)
Additional Explanatory Variables					
Banks' own condition (2014-2016 average)					
Total capital ratio (%)	136	18.5	5.6	8.6	
Tier 1 capital ratio (%)	136	16.2	5.6	8.2	Financial stability indicator
NPL ratios (%)	136	7.5	7.7	0.1	(FSI, IMF)
ROA (%)	137	1.5	1.5	-7.4	
ROE (%)	137	15.3	29.2	-73.2	
Financial sector development (2017)					
Credit card ownership (% of age 15+)	138	19.3	21.0	0.0	
Debit card ownership (% of age 15+)	138	44.6	31.4	1.7	
Bank concentration (%, 2016)	155	65.9	19.6	18.4	GFd (World Bank)
Mobile phone to pay utility bills (% of total pay)	143	0.1	0.1	0.0	
Mobile money accounts (% of age 15+)	77	0.1	0.1	0.0	
Income level: Ln (GDP/capita)	189	8.6	1.4	5.7	World Economic Outlook (IMF)

APPENDIX V. FRACTIONAL LOGIT REGRESSION

The Fractional logit model (Papke and Wooldridge, 1996) has the following structure:

$$E(y|X) = G(\beta X)$$

,

where X represent a set of explantory variables, and $G(\cdot)$ is the link-function as the follows:

$$G(\cdot) = \frac{exp(\cdot)}{1 + exp(\cdot)}$$

$G(\cdot) \in [0,1]$.

APPENDIX VI. STEPWISE REGRESSIONS FOR VARIABLE SELECTIONS

Step 1. Divide variables in each of the four group variables into sub-groups.
Step 2. Run fractional logit regressions for each subgroup, and select variables that are significant at 5 percent level.
Step 3. Run fractional logit regressions for each group with variables selected from step 2.
Step 4. Select variables that are significant at the 10 percent level from Step 3.

Table A3-6 present regression results from the abovementioned steps, and variables selected from step 4 are highlighted in yellow.

Table A3. Stepwise Regressions: Digital Ecosystem

Dependent Variable: Electronic Access to Financial Accounts (0–1)						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
DAI: infrastructure	0.0108***					-0.00853**
	(0.00384)					(0.00406)
DAI: quality	0.0103***					0.00302
	(0.00362)					(0.00354)
DAI: affordability	0.0308**					-0.00185
	(0.0143)					(0.0140)
DAI: internet usages		0.0158**				0.0205***
		(0.00652)				(0.00703)
Cellular subscriptions		-0.00393				
		(0.00270)				
Broadband subscriptions		0.0289**				0.0279**
		(0.0114)				(0.0140)
DAI: knowledge			0.0569***			0.00736
			(0.0118)			(0.0106)
Education			-0.0145			
			(0.0181)			
Stem graduates			-0.000177			
			(0.0154)			
Millennials and post-millenials				-3.882***		2.621**
				(0.546)		(1.115)
R&D expenditure					0.707***	0.268***
					(0.0979)	(0.0998)
Constant	-2.476***	-1.645***	-3.918**	1.342***	-1.392***	-4.028***
	(0.294)	(0.274)	(1.918)	(0.323)	(0.109)	(1.063)
Observations	136	132	72	135	96	91

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A4. Stepwise Regressions: Broader Business Environment

Dependent Variable: Electronic Access to Financial Accounts (0–1)					
VARIABLES	(1)	(2)	(3)	(4)	(5)
Legal: Rule of Law	0.628***				0.890***
	(0.165)				(0.273)
Legal: judicial independence	-9.23e-05				
	(0.0507)				
Legal: legal enforcement of contra	0.0462				
	(0.0595)				
Legal: integrity of legal system	0.0662				
	(0.0526)				
Property rights		0.0140***			-0.00233
		(0.00523)			(0.00652)
Regulatory restricion on real property		-0.00748			
		(0.0391)			
Legal system property rights		0.261***			0.0460
		(0.0942)			(0.129)
Labor: hiring regulation			0.0955**		0.0639**
			(0.0409)		(0.0295)
Labor: centralized bargaining			-0.0280		
			(0.0702)		
Labor: hours regulations			-0.00549		
			(0.0520)		
Labor: mandated cost worker			0.120***		0.0549**
			(0.0317)		(0.0237)
Labor: market regulations			-0.00839		
			(0.124)		
Business: admin requirements				-0.240***	0.0155
				(0.0741)	(0.0780)
Business: bureaucracy costs				0.0125	
				(0.0465)	
Business: starting a business				-0.130	
				(0.127)	
Business: extra payments				0.403***	-0.00362
				(0.0725)	(0.0997)
Business: licensing restrictions				-0.0581	0.0113
				(0.0657)	(0.0611)
Business: tax compliance				0.0360	
				(0.0475)	
Business: regulations				0.216*	-0.409**
				(0.128)	(0.205)
Credit market regulations					0.167**
					(0.0795)
Constant	-1.531***	-2.862***	-1.954***	-1.894	-0.566
	(0.433)	(0.355)	(0.559)	(1.354)	(0.843)
Observations	113	131	127	129	121

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A5. Stepwise Regressions: Bank Conditions

Dependent Variable: Electronic Access to Financial Accounts (0–1)			
VARIABLES	(1)	(2)	(3)
ROA	-0.522**		-0.409*
	(0.211)		(0.220)
ROE	0.0512**		0.0240
	(0.0223)		(0.0253)
Total capital ratio		-0.0188	
		(0.0771)	
Tier 1 capital ratio		0.0559	
		(0.0689)	
NPL			-0.0488**
			(0.0215)
Constant	-0.716***	-1.298**	-0.219
	(0.105)	(0.513)	(0.225)
Observations	108	108	107

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A6. Stepwise Regressions: Financial Sector Development

Dependent Variable: Electronic Access to Financial Accounts (0–1)						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Credit card owernship	0.0341***					0.0161***
	(0.00303)					(0.00609)
Debit card ownership		0.0262***				0.0129***
		(0.00196)				(0.00376)
Bank concentration index			0.00573			0.00188
			(0.00528)			(0.00275)
Mobile money account				0.0313***		0.0216***
				(0.00330)		(0.00505)
Mobile phone for utility payment					0.0338***	0.0130***
					(0.00672)	(0.00456)
Constant	-1.610***	-2.178***	-1.202***	-1.878***	-1.371***	-2.619***
	(0.0893)	(0.121)	(0.326)	(0.101)	(0.106)	(0.172)
Observations	135	135	130	74	139	68

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1