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JEL classification: G21, G23, O33

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Technological Change and Financial Innovation in Banking:
Some Implications for Fintech

1. Introduction

Financial intermediation has changed dramatically over the past 30 years, due in large part to technological change arising from advances in telecommunications, information technology, and financial practice. This technological progress has spurred financial innovations that have altered many financial products, services, production processes, and organizational structures. To the extent that such financial innovations reduce costs or risks, social welfare may be improved. Of course, many financial innovations fail owing to fundamental design flaws or simply being replaced by better alternatives.

A good example of technological change that has been dramatically reshaping the financial services industry is the ongoing shift from relying on human judgment to automated analysis of consumer data. This has taken what had been largely local markets for banking services and opened them up to nationwide competition from other banks and nonbank financial institutions. For example, retail loan applications are now routinely evaluated using credit scoring tools built using comprehensive historical credit registry databases. This automated approach eliminates the need to have a local presence to make a loan and substantially reduces underwriting and compliance costs for lenders, and the resulting data can be leveraged to improve further their risk measurement and management. Such a reliance on hard information also makes underwriting transparent to third parties and hence facilitates secondary markets for retail loans through securitization, which allows nonbank firms that lack deposit funding to compete via capital market financing.

Given the growing importance of technology to financial services, it is perhaps not too surprising that the latest trend has been for technology-based firms to offer financial services, a development that is often called "fintech". Many fintech firms combine automated analysis of retail

customers with more user-friendly interfaces to provide services that are more convenient, and sometimes lower cost, to consumers. For example, "marketplace lending" platforms have emerged as a new organizational form that attracts borrowers with a simplified loan application process, leverages credit scoring tools to analyze these applications, and then matches creditworthy borrowers directly to investors. Furthermore, in some jurisdictions, machine learning (artificial intelligence) is now being leveraged to further improve retail loan risk measurement.

Another set of recent technological developments are being touted as having the potential to have an even more fundamental impact on the financial system, potentially eliminating the need for trusted third parties such as banks. Whether and to what extent blockchains and cryptocurrencies will disrupt the existing financial system remains to be seen, as the technology is too new and immature to draw firm conclusions. However, the potential benefits of cryptocurrencies and blockchain technology are sufficient to attract considerable interest from tech-knowledgeable individuals, large financial organizations, and even major governments.

This chapter surveys the research literatures pertaining to several specific financial innovations that have appeared in recent decades that were specifically driven by technological change. Particular attention is paid to innovations that may provide insights into the prospects for certain widely discussed fintech applications. To set the stage, we begin by providing some additional clarity about what is meant by financial innovation.

2. Financial Innovation: Definition and Determinants

As described by Merton (1992, p. 12), the primary function of a financial system is to facilitate the allocation and deployment of economic resources -- both spatially and across time -- in an uncertain environment. This function encompasses a payments system with a medium of exchange; the transfer

of resources from savers to borrowers; the gathering of savings for pure time transformation; and the reduction of risk through insurance and diversification.

The operation of a financial system involves real resources employed by financial intermediaries; and a large share of these resources are expended in the data collection and analyses to deal with problems of asymmetric information. There are also uncertainties about future states of the world that generate risks that represent costs to risk-averse individuals.

Hence, new or improved financial (i) production processes, (ii) products and services and (iii) organizational structures that can better satisfy financial system participants' demand and reduce costs and risk processes should generally be welcomed. Viewed in this context, Frame and White (2004) define a financial innovation as "something new that reduces costs, reduces risks, or provides an improved product/service/instrument that better satisfies financial system participants' demands." Importantly, Tufano (2003) emphasizes that financial innovation includes the process of both invention (the ongoing research and development function) and diffusion (or adoption) of new products, services, or ideas.

The centrality of finance in an economy and its importance for economic growth naturally raises the importance of financial innovations (and their diffusion).[1] Finance facilitates virtually all production activity and much consumption activity; and so improvements in the financial sector can have direct positive implications for an economy. Moreover, an improved financial sector can encourage more and better saving and investment decisions, making financial innovation even more valuable for an economy. This positive view of financial innovation has been discussed in a number of articles, including: Van Horne (1985), Miller (1986, 1992), Merton (1992, 1995), Tufano (2003), Berger (2003), and Frame and White (2004). However, the recent global financial crisis has led some observers to cast doubt on the

[1] See Levine (1997) for an extensive discussion of the relationship between financial development and economic growth in the context of the theoretical and empirical literature at that time. For subsequent empirical evidence, see: Levine (1998, 1999); Levine and Zervos (1998); Beck, Levine, and Loayza (2000); Levine, Loayza, and Beck (2000); Arestis, Demetriades, and Luintel (2001); and Beck and Levine (2004).

usefulness of most financial innovation – seeing such activity as being largely associated with financial malpractice and instability (e.g., Krugman 2007; Volcker 2009).[2] This negative view focuses on the "dark side" of financial innovation, which some view as the root cause of the recent Global Financial Crisis.

While such a reevaluation is natural in light of the crisis, it is important to recognize that not every financial innovation will be welfare-enhancing or successful. Innovation involves trial-and-error, and failures can be costly – especially for widely diffused innovations (e.g., Lerner and Tufano, 2011). So, financial innovation should more accurately be viewed as likely being beneficial "on net". Consistent with these conjectures, Beck, et al. (2016) conduct a cross-country analysis and find that financial innovation is associated with higher (but more volatile) economic growth and with greater bank fragility.

Campbell (1988) offers four environmental conditions that are conducive to financial innovation: The first relates to underlying technologies and the ability of their improvement to increase efficiency. For example, the information technology revolution has facilitated the creation and use of "big data" and applied statistics for financial risk measurement and management; and machine learning is now used to leverage the data further. A second condition is an unstable macroeconomic environment, as the concomitant fluctuating asset prices are likely to spur risk-transfer innovations. A third condition is regulation, which can inhibit some innovations and encourage others (often as a mechanism to avoid regulation). Finally, taxes can spur financial innovations to the extent that they create incentives to repackage (or re-label) specific income streams so as to reduce tax liability. Over the past 30 years, each of these environmental conditions was markedly altered and resulted in substantial changes to the practice of financial intermediation.

This remainder of this essay focuses mostly on Campbell's first environmental condition: the

[2] Thakor (2012) and Gennaioli, Shleifer, and Vishny (2012) are recent examples of theoretical research that attempts to tie financial innovation and financial instability. Both provide models where banks innovate by making new loans or creating new securities; but then altered information or beliefs results in runs or panics. Henderson and Pearson (2011) provide a recent empirical analysis of a welfare-reducing financial innovation.

role of technological change in driving financial innovation.

3. Process Innovation

The past 30 years have witnessed important changes in financial institution production processes. The use of electronic transmission of bank-to-bank retail payments, which had modest beginnings in the 1970s, has exploded owing to greater retail acceptance, online banking, and check conversion. In terms of intermediation, credit bureau data have been used to create credit scores that increasingly substitute for manual underwriting – and this has been extended even into historically relationship-oriented products, such as small business loans.

This trend toward hardening information has facilitated deep secondary consumer loan markets in the United States and has provided key inputs for risk management systems. Recently, the advent of blockchain/distributed ledger technology and significant advances in artificial intelligence/machine learning has raised important questions about the future of financial intermediation.

We discuss each of these topics below.

3.1 Research Evidence from Past Process Innovations

Automated Clearinghouse. An automated clearinghouse (ACH) is an electronic funds transfer network that connects banks and is primarily used for recurring, small-dollar payments. While several ACH networks emerged in the 1970s, volumes grew only modestly through the 1980s, with the networks' being used almost exclusively for direct payroll deposits. Over the past 20 years, however, consolidation has occurred, and volumes have soared. According to the National Automated Clearing House Association, in 2015 there were some 24 billion ACH payments totaling $41 trillion.

The modest literature on ACH networks has been done in relation to of the Federal Reserve's ACH pricing policies. On the supply-side, Bauer and Hancock (1995) estimate a cost function and find

that over the 1979-1994 period the cost of processing an ACH item fell dramatically -- owing to scale economies, technological change, and lower input prices.[3] Stavins and Bauer (1999), on the other hand, estimated ACH demand elasticities by exploiting FedACH price changes over time – finding ACH demand to be highly inelastic. More recently, two papers studied network externalities for ACH. Gowrisankaran and Stavins (2004) find support for significant network externalities, which they ascribe to technological advancement, peer-group effects, economies of scale, and market power. Ackerberg and Gowrisankaran (2006) identify large fixed costs of bank adoption as the barrier to greater use of ACH transactions and thus to society's capturing the accompanying potential cost savings.

Small Business Credit Scoring. Banks use a number of different approaches to lending to informationally opaque small businesses (Berger and Udell, 2006). One method that was introduced in the 1990s and continues to evolve is small business credit scoring (SBCS). This screening technology involves analyzing consumer data about the owner of the firm and combining it with relatively limited data about the firm itself, using statistical methods to predict future credit performance. Credit scores had long been pervasive in consumer credit markets (e.g., mortgages, credit cards, and automobile loans) – and resulted in widely available, low-cost, commoditized credits that are often packaged and sold into secondary markets.

The empirical literature that has studied SBCS has focused on the determinants of bank adoption and diffusion of this technology, as well as on how SBCS has affected credit availability. Two studies have statistically examined the determinants of the probability and timing of large U.S. banks' adoption of SBCS. Frame, Srinivasan, and Woosley (2001) and Akhavein, Frame, and White (2005) both find an important role for size and organizational structure in the adoption decision: Larger banking organizations with fewer bank charters and more bank branches were more likely to

[3] Using a much smaller sample, Bauer and Ferrier (1996) also found support for the existence of ACH scale economies as well as significant allocative inefficiencies.

adopt and also to adopt sooner. This suggests that large banks with a more "centralized" structure were more likely to adopt SBCS. More recent research suggests, however, that the use of credit scores for small business lending has subsequently diffused to small banks (Berger, Cowan, and Frame, 2007) and community development organizations (Fracassi, Germaise, Kogan, and Natividad, 2016).

Several studies have focused on the relationship between SBCS adoption and credit availability. Three studies documented increases in the quantity of lending (Frame, Srinivasan, and Woosley, 2001; Frame, Padhi, and Woosley, 2004; Berger, Frame, and Miller, 2005). One found evidence that is consistent with more lending to relatively opaque, risky borrowers (Berger, Frame, and Miller, 2005); another with increased lending within low-income as well as high-income areas (Frame, Padhi, and Woosley, 2004); and another with lending over greater distances (DeYoung, Frame, Glennon, and Nigro, 2011). In instances in which SBCS is used in conjunction with traditional underwriting methods to reduce information asymmetries, it is also shown to result in increased loan maturity (Berger, Espinosa-Vega, Frame, and Miller, 2005) and reduced collateral requirements (Berger, Espinosa-Vega, Frame, and Miller, 2011).

3.2 Fintech Process Innovations

Blockchain/Distributed Ledgers. One new production process that is being touted as potentially revolutionizing banking (as well as other areas of finance and even broader areas of databases and contracts generally) is the blockchain and related technologies. Interest in blockchain technology was sparked by a white paper by Nakamoto (2008), which developed a peer-to-peer "electronic cash" using blockchain technology that allowed electronic payments to be made without going through a financial intermediary. Nakamoto's paper has sparked a variety of innovative initiatives. Some of these are intended to replace financial institutions, including commercial banks and even central banks. Other initiatives have more modest goals, such as improving the efficiency

of existing financial intermediation.

Blockchains are an example of a distributed ledger, or a database that is shared across nodes in a network. In a blockchain, data are added to the ledger in blocks that are ordered by time and linked to each other using cryptology.[4] Blockchain technology is highly resistant to efforts to tamper with prior records in the database. Bitcoin, along with similar cryptocurrencies, uses blockchains to record ownership of a token (cryptocurrency) that its users value as a store of wealth and form of payment. In principle, these tokens could represent ownership of any asset, including physical assets such as gold or sovereign-issued fiat currency such as the U.S. dollar. However, almost all cryptocurrencies are simply electronic tokens on a blockchain and do not represent a claim to any external asset.

Distributed ledger technology is potentially useful wherever two or more parties need to share a common understanding about current conditions – such as who owns a particular asset or the terms of a financial contract to which they are both parties. Blockchains' potential for disrupting existing financial intermediaries arises from their ability to provide tamper-resistant records—indeed some claim the records are immutable. Catalini and Gans (2017) observe that an immutable record would facilitate costless verification and thereby facilitate new markets. In essence, the blockchain would substitute for the "trusted-third-party" role that large payment intermediaries currently serve, and for which they often charge fees that -- to casual observers and blockchain enthusiasts -- seem relatively high. However, Cong and He (2018) note that blockchains could also be used to facilitate collusion.

Unlike ACH, distributed ledgers do not necessarily benefit from network effects or exhibit

[4] The blockchain does this by creating a "cryptographic hash," or unique digital summary, for each block that includes the hash from the prior block. If any change is made to any given block, it will alter that block's hash and the change will carry through to every block that is subsequently added to the blockchain. (This occurs because the prior block's hash is part of each block in the chain). Thus, if one wants to rewrite the history of one block, then every subsequent block will have to be revised. Otherwise, anyone seeking to verify the blockchain will be able tell that an effort has been made to change one of the blocks.

economies of scale. The central concern -- but also the potential source of disruption, as we discussed above -- is how to determine which transactions are valid when there is no trusted central party to verify their authenticity. The solution adopted by some distributed ledgers is to limit the set of participants to a group of firms that have some trust in each other and some capital at risk if they are caught making invalid entries to the ledger, the so-called private, permissioned blockchains. Other distributed ledgers, especially the permissionless public blockchains, see openness to participation by any interested party as a key virtue. These blockchains benefit from network effects in that more people using the blockchain for more purposes increases the potential uses for all of the users. On the other hand, the very openness of these blockchains means that they must adopt measures that raise the cost of trying to change existing records. The way this is done by some blockchains, such as Bitcoin, has the effect of imposing limits on the number of transactions that may be made on that blockchain—that is imposing infinite diseconomies of scale beyond some transactions volume.

Machine Learning. The increasing capability of artificial intelligence (AI) and machine learning (ML) is another important technological advance affecting banking in recent years. Although there are not universal definitions of AI and ML, for current purposes AI can be defined as the development of computer systems to perform tasks that ordinarily require human intelligence. This definition incorporates expert systems -- where humans teach machines – and also machine learning, where the machines learn from data. Interest in ML in particular has become increasingly popular, due to a combination of more digitized data, faster computers, and better algorithms to analyze data.

ML is similar to statistics in that both seek to learn from the data and use many of the same tools, and the two disciplines are increasingly learning from each other. The biggest difference is that statistics has historically emphasized hypothesis testing and statistical inference, whereas ML emphasizes obtaining the best prediction. As a result, ML is not guided by economic (or other social sciences) theory (which would generate the hypotheses for statistical testing), which has the advantage

that ML sometimes identify relationships that are not (currently) predicted by theory. The disadvantage is that some of the relationships ML identifies will not be causal and, hence, cannot be usefully exploited.

AI and ML are general-purpose technologies that may be used in a wide variety of areas within a financial institution. These include refinements to existing products, such as better credit and risk management, tools for uncovering asset pricing anomalies, and helping institutions comply with regulatory requirements; this is a related field called "RegTech". However, AI and ML are also essential inputs into the creation of a variety of new financial services. At the consumer level, AI and ML are being used in personal financial management products that analyze an individual's expenses and revenues to provide recommendations that help the user obtain their financial goals. Another new product that relies on AI and ML is a "robo-advisor", which provides automated personalized investment advice and, with the customer's agreement, automated portfolio selection and rebalancing based on each investor's goals, financial assets, and risk tolerance.

Machine learning algorithms generally benefit from access to large amounts of high quality data that are pertinent to the question they are addressing. According to Wall (forthcoming), firms that are able to assemble such datasets may have a competitive advantage that can be leveraged to increase their market share and build even larger datasets. The author notes that one way of reducing this advantage is through the sharing of data across firms -- provided that the sharing satisfies appropriate privacy concerns. Another way of reducing the advantage would be for governments to take the position that consumers own -- i.e., have property rights with respect to -- their own data and have the right to share it as they choose, as is currently being done in the European Union under Payments Systems Directive 2 (sometimes called PSD2).

Although there is a large academic literature in computer science on AI and ML algorithms and a growing literature on their application to finance, the academic literature on their application to new

bank products, such as personal financial management and robo-advising, is not very well developed. The banking application that has received the most academic attention is credit analysis, which is discussed later in this chapter in the context of marketplace lending.

4. Product Innovation

The increased reliance on hard information for lending decisions over time has improved credit market efficiency, as evidenced by greater use of risk-based pricing and expanded credit availability to marginal borrowers. However, the U.S. subprime mortgage crisis raised questions about the efficacy of this approach, as a staggering number of such borrowers defaulted on their home mortgages and lost their homes. The secular decline in the cost and quality of computing resources in recent decades, coupled with the Internet, resulted in substantial improvement in payment system efficiency. Most recently, blockchain and distributed ledger technology appears to have the potential to disrupt payments further through cryptocurrencies and initial coin offerings.

4.1 Research Evidence from Past Product Innovations

Subprime Lending. Subprime lending to U.S. households has become mainstream over the past couple of decades. As a general matter, these are loans to borrowers with weak credit histories and limited down payments available for financing homes and automobiles. Historically, such borrowers had been rationed out of fixed-price loan markets and were hence credit-constrained. However, the availability of large historical performance databases has allowed for the development of statistical models that improve risk measurement and facilitate risk-based loan pricing. Subprime lending has the potential benefit of expanding access to credit to potentially creditworthy borrowers who had previously been denied credit. However, it also raises the question about whether subprime borrowers are using expanded access wisely; and also whether the lenders are properly pricing and managing the increased risk exposure.

The recent U.S. mortgage crisis highlighted the personal and social costs associated with subprime lending in the face of a macroeconomic shock.

Before discussing subprime mortgage lending in depth, we note some key recent empirical studies of subprime automobile and credit card lending. Two papers study the U.S. subprime auto loan market using loan-level data from a single institution. Evidence that expanded access to credit may be valuable comes from Adams, Einav, and Levin (2009), who find that subprime auto loan demand is highly sensitive to down-payment requirements and rises sharply during tax rebate season – consistent with the presence of credit constraints. Evidence that lenders are managing this risk may be found in their response to risk factors. Auto loan default rates are found to increase in loan size, and riskier borrowers demand larger loans; but lenders are found to limit loan sizes and use credit scores to risk-based price borrowers in an effort to reduce moral hazard.

Evidence that borrowers may not be using the credit wisely is found in a closely related paper by Einav, Jenkins, and Levin (2012). Using the same data as the prior paper, they show how car prices have little effect on borrower purchase or down-payment decisions, but rather simply translate into larger loans. For the lender, down-payment requirements create a tradeoff between loan volume and quality that is managed using credit scores to risk-base the pricing of these loans. Additional evidence that borrowers may not be using their expanded access wisely may be found from a study of subprime credit card lending by Alan and Loranth (2013). They study borrower price sensitivity using a randomized interest rate experiment for existing loans. The authors find that for a large increase in interest rates (five percentage points), overall credit demand declines only modestly for their sample. These results reflect substantial heterogeneity as the lowest-risk borrowers reduce credit demand significantly, while the highest-risk borrowers do not.[5]

[5] This finding is consistent with earlier research by Ausubel (1991) describing the "failure of competition" in the U.S. credit card market. The notion is that the riskiest borrowers have inelastic credit demand owing to liquidity constraints and always intend to use cards to finance purchases.

As for the subprime mortgage market: The boom in subprime mortgage lending demonstrates the extent to which borrowers were taking advantage of the expanded access. During that time, the U.S. subprime mortgage market grew rapidly and averaged about 20 percent of residential mortgage originations between 2004 and 2006. This credit boom facilitated an expansion in the pool of potential homeowners and helped to lead the U.S. to a record homeownership rate in 2004 of 69.2% -- even in the face of declining housing affordability in many areas of the country. Subprime mortgages outstanding ultimately peaked at $1.2 trillion in 2007, but has since declined steadily since the onset of the market meltdown as new loan originations ceased.

Whether borrowers were using their access wisely or were being exploited is the subject of ongoing debate. Some of the early arguments that borrowers were being exploited were based on a comparison of the structure of subprime mortgages versus those taken by prime borrowers. A 30-year fixed rate loan with an embedded prepayment option is the most common type of residential mortgage in the U.S. By contrast, the typical subprime mortgage during the housing boom was a 30-year adjustable rate mortgage (with a fixed rate for the initial 2-3 years) that included a prepayment penalty. Mayer, Pence, and Sherlund (2009) provide a set of "subprime mortgage facts" through the financial crisis period, including information about various loan contract structures, degree of underwriting documentation, presence of second liens, and borrower occupancy status.[6] However, the mere fact that subprime contract terms were different from those on prime mortgages does not mean that subprime borrowers were being exploited. A series of theoretical papers by Piskorski, and Tchistyi (2010, 2011) and Mayer, Piskorski, and Tchistyi (2013) suggest that subprime borrowers benefited from the contract terms that distinguish their mortgages from prime mortgages.

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[6] Related to documentation, the authors describe the concomitant rise in the so-called Alt-A market, which is characterized by lower observed risk (e.g., better credit scores and larger down-payments), but little/no documentation/verification of borrower income/assets.

Another hypothesis is that reliance on the originate-to-distribute model created a moral hazard problem for loan underwriters (e.g., Ashcraft and Schuermann 2008). A large fraction of the subprime loans were packaged together and sold as securities, transferring a substantial fraction of the credit risk from underwriters to investors. As a result, underwriters were not sufficiently rigorous in underwriting subprime mortgages. One line of inquiry focuses on the quality of loan-level information provided to investors. For example, Piskorski, Seru, and Witken, (2015) provide evidence that there was incomplete information about the presence of subordinate financing (i.e., second liens). Jiang, Nelson, and Vytlacil (2014) and Griffin and Maturana (2016) find that borrowers misrepresented their income and occupancy status, respectively. According to Griffin and Maturana (2016) such data problems led to higher default propensities and loss severities than would have otherwise been the case.

However, it is not clear that the deleterious effects were disproportionately borne by outside investors. Papers by Jiang, Nelson, and Vytlacil (2013) and Elul (2016) suggest that securitized and non-securitized subprime loans performed similarly (conditional on observable information) due to investor-required loan seasoning prior to securitization. There is also research that suggests that subprime mortgage lenders were lax in their screening of applicants with FICO credit scores above 620 (Keys, Mukherjee, Seru, and Vig, 2010; Keys, Seru, and Vig, 2012), although this interpretation has recently come into doubt (Bubb and Kauffman 2014).[7] See Frame (2018) for a review of the literature pertaining to agency conflicts in residential mortgage securitization.

Another hypothesis is that borrowers and lenders acted rationally given their expectations for residential real estate price appreciation. That is, the greater risk of distress among subprime borrowers was not a problem so long as house prices continued to appreciate. Distressed borrowers with positive

[7] Standard FICO credit scores range from 300 to 850. About 70 percent of U.S. consumers have a score greater than 650. Most financial institutions perceive consumers with FICO scores below 620 as definitely being subprime, although some lenders use slightly higher score cut-offs (e.g., 640) for this definition.

equity could borrow against this equity or simply sell the home and pocket any net proceeds. Hence, negative equity (owing more than the home is worth) is a *necessary condition* for mortgage default (see, for example, Foote, Gerardi, and Willen, 2008). The problem is that the massive expansion of subprime mortgage lending in the mid-2000s was concurrent with rapid house price appreciation; and both borrowers and lenders began to form unreasonably favorable expectations about future home price growth (e.g., Brueckner, Calem, and Nakamura, 2012). Escalating prices reduced housing affordability, and an assumption of continued future price growth would have made parties more comfortable with extreme leverage as borrowers would be expected to "grow out of it" soon. In this view, the declining underwriting standards likely emanated from the recent and expected growth in home prices, which seemingly masked the heightened risk (Bhardwaj and Sengupta, 2014). Once housing prices stopped appreciating and then started declining, distressed borrowers were unable to sell or remortgage their house, leading to the observed sharp increase in delinquencies and foreclosures.

Thus, subprime lending in general has seemingly been successful at expanding credit availability to marginal borrowers. However, that success in residential mortgage lending depended to a very large degree on the factor that was ultimately its downfall: a dependence on expectations of increasing housing prices. This experience is a reminder that it often takes an economic downturn to reveal fully the weaknesses in an innovation. Whether privately financed subprime lending on a smaller scale could have been a successful product absent the boom is unclear. What is clear is that the combination of the scale and scope of the recent crisis, the findings of negligence and malfeasance, the political and legal uncertainty, and the sensitivity to housing displacement among vulnerable populations mean that private subprime mortgage lending is unlikely to return en masse anytime soon.[8]

4.2 Payment Services

[8] Nevertheless, subprime borrowers continue to have broad access to mortgage finance through U.S. Government mortgage insurance programs (through the Federal Housing Administration, the Department of Veterans Affairs, and the Department of Agriculture) – and such loans have been very popular since the onset of the recent crisis.

Recent retail banking service innovations primarily relate to enhanced deposit account access and new methods of payment – each of which better meets consumer demands for convenience and ease. Debit cards, which bundle ATM access with the ability to make payment from a bank account at the point-of-sale, became ubiquitous in the 1990s. In the 2000s, online banking, which allows customers to monitor accounts and originate payments using "electronic bill payment," became widely used. Notably, besides improving convenience and ease, retail payment innovations may also improve access to the banking system for unbanked consumers (e.g., Gross, Hogarth, and Schmeiser, 2012; Hayashi 2016).

Debit Cards. Debit cards are essentially "pay-now" instruments linked to a checking account whereby transactions can happen either instantaneously using online (PIN-based) methods or in the near future with offline (signature based) methods. Consumers typically have the choice of using online or offline methods, and their selection often hinges on the respective benefits: Online debit allows the cardholder also to withdraw cash at the point-of-sale, while offline provides float. According to the U.S. Federal Reserve (2016), there were approximately 69.5 billion debit transactions in the U.S. during 2012 that totaled almost $2.6 trillion.

Much of the research that pertains to debit cards relates to identifying the most likely users of this payment instrument. Such demand-side explorations have been conducted individually as well as jointly across multiple payment options. Stavins (2001), for example, uses data from the 1998 Survey of Consumer Finances (SCF) and finds that debit usage is positively related to educational attainment, homeownership status, marital status, business ownership, and being a white collar worker; and usage is negatively related to age and net worth. Klee (2006) extends this analysis to consider the 1995, 1998, and 2001 SCFs and reports a secular increase in adoption driven by similar demographic factors.[9] Additional U.S. evidence is provided by: Mantel and McHugh (2001), who use survey data from Vantis International;

[9] See Anguelov, Hilgert, and Hogarth (2004) for the relevant statistics that pertain to these surveys.

Hayashi and Klee (2003), who use data from a 2001 survey conducted by Dove Consulting; Borzekowski and Kiser (2008) and Borzekowski, Kiser, and Ahmed (2008), who use 2004 data from the Michigan Surveys of Consumers; and Hayashi and Stavins (2012), who use the Boston Fed's Consumer Payment Choice surveys.

Some additional analysis by Hayashi and Klee (2003) studied the circumstances under which consumers are likely to use debit cards and found that these are more often used at grocery stores and gas stations than at restaurants. Related to this, the authors also find that debit card usage is positively related to the incidence of self-service transactions. Zinman (2009) finds that the choice of debit cards is positively related to being near credit card balance limits; and Fusaro (2013) shows that debit cards are used to pay-down credit card balances. Finally, Hayashi and Stavins (2012) provide evidence that a recent U.S. law raising the cost of debit card transactions had an especially negative effect on low credit score consumers, which tend to have lower and more volatile incomes and be less educated.

Online Banking. As households and firms rapidly adopted Internet access during the late 1990s, commercial banks established an online presence. According to DeYoung (2005), the first bank websites were launched in 1995; and by 2002 nearly one-half of all U.S. banks and thrifts operated transactional websites. Today virtually all U.S. commercial banks offer transactional websites.

The primary line of research that related to online banking has been aimed at understanding the determinants of bank adoption and how the technology has affected bank performance. In terms of online adoption, Furst, Lang, and Nolle (2002) found that U.S. banks were more likely to offer transactional websites if they were: larger, younger, affiliated with a holding company, located in an urban area, and had higher fixed expenses and non-interest income. Hernandez-Murillo, Llobet, and Fuentes (2010) later confirmed many of these findings using updated data, but also found that online adoption was positively related to county-level demographics (median household income, education, Internet access) and market concentration and was negatively related to additional bank characteristics

(branching intensity, ratio of capital-to-total assets, and nonperforming loans). Finally, Dow (2007) analyzes data for U.S. credit unions and finds that online banking adoption is related to institution size and having a lower proportion of nonperforming loans. On the flip side, Goddard, McKillop, and Wilson (2009) find that credit unions that do not provide transactional websites are more likely to fail and/or be acquired.

With respect to online bank performance, DeYoung, Lang, and Nolle (2007) report that Internet adoption improved U.S. community bank profitability – primarily through deposit-related charges. In a related study, Hernando and Nieto (2007) find that, over time, online banking was associated with lower costs and higher profitability for a sample of Spanish banks. Both papers conclude that the Internet channel is a complement to – rather than a substitute for – physical bank branches. Additional evidence is offered by Ciciretti, Hasan, and Zazzara (2009), who also find that Italian banks that offered Internet-related services had higher profitability (and stock returns) relative to their peers. However, a contemporaneous study of U.S. credit unions found no relationship between online banking adoption and profitability, but did find significantly higher operating expenses (Dandapani, Karels, and Lawrence, 2008).

Other studies examine the demand-side for online banking services. Mantel (2000) studies the demographic characteristics of users of electronic/online bill payment. Among other things, the author finds that electronic bill payers tend to be: older, female, higher income, and homeowners. Bauer and Hein (2006), who analyze data from the Survey of Consumer Finances, find that younger customers and those with previous experience with remote banking technologies are more likely to use online banking.

4.3 Fintech Product Innovations

Two specific applications of blockchain technology -- cryptocurrencies and initial coin

offerings -- have garnered the most attention from the public and academics.[10] Bitcoin, the oldest and largest blockchain (by market value in July 2018), has been studied from a variety of perspectives. Huberman, Leshno, and Moallemi (2017) observe that no one owns Bitcoin and that the blockchain's protocol is "almost immutable." This raises the question of the underlying economics of the system: Specifically, what is the source of the revenue for financing Bitcoin's operations? The answer is that the equilibrium level of transactions fees and infrastructure level is set by a congestion queuing game arising from limits set by the Bitcoin protocol on the blockchain's throughput (transactions volume). Budish (2018) analyzes the economics of Bitcoin's operations in terms of the incentive of infrastructure-providers (called "miners") to rewrite the blockchain in a way that would allow them to spend the same Bitcoin twice. He notes that Bitcoin has not been subject to such a successful attack through mid-2018 but argues that this is due in part because the size of Bitcoin transactions has been small, limiting the gains from double-spending.

Bitcoin and some other cryptocurrencies are being traded against each other and against some sovereign-issued fiat currencies (such as the U.S. dollar), prompting the development of a small literature analyzing the returns and return volatility of cryptocurrencies.[11] However, most cryptocurrency trading takes place outside the direct supervision of securities regulators and, thus, may be more open to manipulation than are financial instruments that trade on securities and derivatives exchanges. Gandal, Hamrick, Moore, and Oberman (2018) analyze pricing data on one of the cryptocurrency exchanges, Mt. Gox, and find that prices rose an average of four percent on

[10] A potential substitute for cryptocurrency for some uses is government-issued digital currency. Government-issued digital currency could, but need not, use a blockchain for record keeping. See Humphrey (2018) for a discussion of government-issued digital currency.

[11] See Athey, Parashkevov, Sarukkai, and Xia (2016) for a theoretical model of Bitcoin pricing and some descriptive analysis of the market. A listing of major cryptocurrency exchanges -- along with some volume and price data -- may be obtained from CoinMarketCap at https://coinmarketcap.com/exchanges/volume/24-hour/.

days with suspicious trades but were slightly down on days without such trading. Similarly, Griffin and Shams (2018) find evidence consistent with market manipulation.

Along with cryptocurrencies, a popular use of blockchain tokens is as a vehicle for obtaining financing for start-up technology firms. Indeed, this form of financing -- called initial coin offerings (ICOs) -- provided more start-up financing than venture capitalists in June and July of 2017.[12] Catalini and Gans (2018) analyze ICOs where the token on sale may be redeemed for the firm's product (which is the form the tokens often take) and find that tokens may help entrepreneurs by revealing aspects of consumer demand. Howell, Niessner, and Yermack (2018) analyze post-issuance transaction data for tokens listed on CoinMarketCap and find that liquidity is greater for issuers that engage in voluntary disclosure and credibly commit to the project.

5. Organizational Innovation

New organizational forms for financial institutions have emerged in the United States and other countries over the past few decades. While some of these forms arose from regulatory developments, two related structures -- Internet-only banks and marketplace lenders -- are directly tied to technological change.

Internet-Only Banks. The rapid rise in Internet access and usage during the 1990s created the possibility of a new organizational form for intermediaries: the Internet-only (or Internet-primary) banks. Research by Delgado, Hernando, and Nieto (2007) reports that, as of mid-year 2002, there were some 35 Internet-only banks operating in Europe and another 20 in the U.S. In Europe, virtually all of these banks were affiliated with existing institutions, while in the U.S. they tended to be de novo operations. This may explain why U.S.-based Internet-only banks have disappeared (through acquisition, liquidation, or closure) or established a physical presence to supplement their Internet

[12] Kharpal (2017) documents the role of ICOs in providing more early-stage financing than did venture capitalists in the early summer of 2017. See Wall (2018a, 2018b) for an overview of the issues raised by ICOs as a funding tool for new ventures.

base.

DeYoung (2001, 2005) finds that, as compared with conventional de novo banks, the Internet de novo banks are less profitable due to low business volumes (fewer deposits and lower non-interest income) and high labor expenditures. However, the author also reports that the financial performance gaps narrow quickly over time due to scale effects. Relatedly, Cyree, Delcoure, and Dickens (2009) find that Internet-primary banks are larger and have lower net interest margins and loan losses. Delgado, Hernando, and Nieto (2007) report that European Internet banks demonstrate technology-based scale economies.

Although Internet-only banks failed to take hold in the early 2000s, new opportunities opened for innovative organizational forms in the 2010s as a result of two developments: (a) the continuing advance of technology; and (b) the need to recover from the 2007-09 financial crisis in the U.S. and from the sovereign debt crisis in the EU that started in 2009. The introduction of the iPhone in 2007 was one marker of the continuing advancement of a broad array of technologies.[13] These advances allowed technology firms to enter a wide variety of commercial and financial activities, often providing superior service to that provided by incumbent firms. Moreover, while technology firms were looking for profitable opportunities to disrupt existing industries, the need to recover from the financial crisis distracted bank management and reduced the resources that banks had to invest in new technology and to make new loans. One of the most well-known sets of new online financial institutions is marketplace lenders.

Marketplace Lenders. Marketplace lenders, which match consumers and small firms with lenders/investors using online platforms, have been popping-up all over the world. In the United States, these lending arrangements generally work in the following way: First, borrowers apply on the

[13] Mobile retail payments using cellular phones is widespread in Africa, most notably in Kenya with Safaricoms' M-Pesa program. See Beck and Frame (2018) for further details and a review of the related literature.

platform and are subject to automated underwriting based on standard criteria (such as a credit score) plus additional information and assigned a proprietary risk rating. Second, institutional investors purchase loans in bulk from the marketplace lenders, principally based on the risk ratings.[14] The online marketplaces themselves generally have no direct exposure to the credit risk of the loans through their platforms, as they do not typically hold the loans or otherwise retain an interest in them or guarantee their performance.[15] Instead, marketplace lenders principally generate revenue from loan origination and servicing fees. Marketplace lending is growing rapidly, but it remains a very small part of the $3.3 trillion U.S. consumer lending market.

Much of what constitutes marketplace lending is actually not new. As discussed above, for many years, larger banks and finance companies have used credit registry data, credit scores, and borrower income information as inputs for statistical models to estimate risk and price consumer loans. However, marketplace lenders appear to be increasingly supplementing their models with additional information. Jagtiani and Lemieux (2018) find that LendingClub's credit scores had an 80 percent correlation with FICO scores in 2007, but that the correlation drops about 35 percent for loans originated in 2014-15. The authors suggest that the change is likely due to a combination of LendingClub using alternative data and machine learning as the platform gains more experience with consumer lending.[16] In complementary research that uses information from Prosper (which is a

[14] While marketplace lending originally involved raising funds from individuals, the bulk of financing today is provided by institutional investors.

[15] For legal reasons, marketplace loans in the U.S. are actually originated on the balance sheet of a partner bank. This allows the marketplace lender to: (1) purchase the loans without needing to obtain individual state banking/lending licenses; and (2) charge interest rates that are legal in the partner bank's state but may not be legal in the borrowers' state. The partner bank holds the loan for a few days before selling it to the marketplace lender, which in turn sells them to investors.

[16] Berg, Burg, Gombovic, and Puri (2018) discuss the use of alternative data to improve default prediction by a German e-commerce company. The authors identify various pieces of the customers' digital footprint as aiding in prediction: access device type, operating system, access channel, allowing for location tracking, time of day, email service provider, and various customer typing conventions.

prominent marketplace lender), Balyuk and Davydenko (2018) discuss that lender's use of secondary screening to identify suspicious applications and to verify automatically some borrower-provided information. The authors report that this additional screening has led to cancellation of 27 percent of the previously accepted loan applications since 2013.

Vallee and Zeng (2018) observe that, while the fintech platforms are using their own models to grade loans and determine credit spreads, informationally sophisticated investors may be able to differentiate credit quality within these ratings grades. The authors derive a model allowing for such a split in investor sophistication, which results in a trade-off for the platform in terms of the contribution of sophisticated investors in improving loan quality but also creating adverse selection for less sophisticated investors. The volume-maximizing solution for the platform is to provide intermediate levels of screening and information to investors. Consistent with their model, the authors find that loans purchased by more informationally sophisticated investors were less likely to default for the universe of investments made through Lending Robot from 2014-2017.[17] They also observe that one marketplace lender, LendingClub, reduced the amount of information it provided to investors and this caused a reduction in the ability of sophisticated investors to "cherry-pick" loans with lower default rates.

Beyond marketplace lenders specifically, there has been a general increase in online lending. According to Fuster, Plosser, Schnabl, and Vickery (2018), fintech mortgage lenders have increased their market share from two to eight percent between 2010 and 2016. The authors find the biggest benefit provided by fintech lenders is an average reduction in the time from application to closing of 10 days (20 percent) after controlling for borrower and loan characteristics. They also find that fintech lenders can scale up the volume of mortgages they process more readily than can other lenders.

The information technology underlying such an automated approach to underwriting is

[17] LendingRobot is an automated tool for investors in loans that are originated by LendingClub and Prosper.

subject to significant scale economies (large fixed costs and very low marginal costs), which provides strong incentives to grow large quickly. This suggests that the consolidation of the marketplace lending industry is very likely. Moreover, as marketplace lenders become more successful, they are likely to find themselves facing increased competition from incumbent consumer lenders.

Conclusions

This chapter reviewed some of the more developed literatures relating technological change and financial innovation in banking over the past 30 years. In terms of process and product innovations, the empirical research record provides us with information about the characteristics of users and adopters of technology-driven financial innovations and the attendant welfare implications. Faster computing and widespread adoption of the Internet has resulted in a more efficient payment system with related product innovations quickly diffusing to a large part of the population. Technological change has also transformed consumer lending by moving from human to automated underwriting based on credit scores and other pieces of hard information. This has resulted in expanded credit availability along both intensive and extensive margins.

The recent emergence of fintech has greatly expanded interest in financial innovation as new products, services, production processes, and organizational forms are being created and deployed. Blockchain and distributed ledger technologies are currently being used for the issuance and transfer of widely distributed crypto-currencies as well as for early-stage funding for technology companies via initial coin offerings. Artificial intelligence and machine learning are being used: in lending environments for marketing and monitoring account activity, to provide low-cost advisement services, and to further improve credit decisions through the use of expanded information. This is a very exciting time to study financial innovation and the continued evolution of the banking business.

References

Ackerberg, D.A. and Gowrisankaran, G. (2006). Quantifying Equilibrium Network Externalities in the ACH Banking Industry, *RAND Journal of Economics* 37(3), 738-761.

Adams, W., Einav, L. and Levin, J. (2009). Liquidity Constraints and Imperfect Information in Subprime Lending, *American Economic Review* 99(1), 49-84.

Akhavein, J., Frame, W.S. and White, L.J. (2005). The Diffusion of Financial Innovations: An Examination of the Adoption of Small Business Credit Scoring by Large Banking Organizations. *Journal of Business* 78(2), 577-596.

Alan, S. and Loranth, G. (2013). Subprime Consumer Credit Demand: Evidence from a Lender's Pricing Experiment, *Review of Financial Studies* 26(9), 2353-2374.

Anguelov, C.E., Hilgert, M.A. and Hogarth, J.M. (2004). U.S. Consumers and Electronic Banking: 1995-2003, *Federal Reserve Bulletin* 90(1), 1-18.

Arestis, P., Demetriades, P.O., Luintel, K.B. (2001). Financial Development and Economic Growth: The Role of Stock Markets, *Journal of Money, Credit, and Banking* 33, 16–41.

Ashcraft, A. and Schuermann, T. (2008). Understanding the Securitization of Subprime Mortgage Credit, Federal Reserve Bank of New York Staff Report no. 318, March.

Athey, S., Parashkevov, I., Sarukkai, V. and Xia, J. (2016). Bitcoin Pricing, Adoption, and Usage: Theory and Evidence. Stanford Working Paper, available at: https://www.gsb.stanford.edu/gsb-cmis/gsb-cmis-download-auth/423411

Ausubel, L.M. (1991). The Failure of Competition in the Credit Card Market, *American Economic Review* 81(1), 50-81.

Balyuk, T. and Davydenko, S. (2018). Reintermediation in FinTech: Evidence from Online Lending, Available at SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3189236

Bauer, K. and Hein, S. (2006). The Effect of Heterogeneous Risk on the Early Adoption of Internet Banking Technologies, *Journal of Banking and Finance* 20, 1713-1725.

Bauer, P.W. and Ferrier, G.D. (1996). Scale Economies, Cost Efficiencies, and Technological Change in Federal Reserve Payment Processing, *Journal of Money, Credit, and Banking* 28(4), 1004-1039.

Bauer, P.W. and Hancock, D. (1995). Scale Economies and Technological Change in Federal Reserve ACH Payment Processing, *Economic Review*, Federal Reserve Bank of Cleveland, Third Quarter, 14-29.

Beck, T., Chen, T., Lin, C., and Song, F.M. (2016). Financial Innovation: The Bright and the Dark Sides, *Journal of Banking and Finance* 72, 28-51.

Beck, T. and Frame, W.S. (2018) Technological Change, Financial Innovation, and Economic Development, in *Handbook of Finance and Development* edited by T. Beck and R. Levine. Cheltenham

UK: Edward Elgar.

Beck, T. and Levine, R. (2004). Stock Markets, Banks, and Growth: Panel Evidence, *Journal of Banking and Finance* 28, 423-442.

Beck, T., Levine, R., and Loayza, N. (2000). Finance and the Sources of Growth, *Journal of Financial Economics* 58*,* 261-300.

Berger, A.N. (2003). The Economic Effects of Technological Progress: Evidence from the Banking Industry, *Journal of Money, Credit and Banking* 35, 141-176.

Berger, A.N., Cowan, A. and Frame, W.S. (2007). The Surprising Use of Credit Scoring in Small Business Lending by Community Banks and the Attendant Effects on Credit Availability, Risk, and Profitability, *Journal of Financial Services Research* 39, 1-17.

Berger, A.N., Espinosa-Vega, M., Frame, W.S. and Miller, N. (2005). Debt Maturity, Risk, and Asymmetric Information, *Journal of Finance* 60(6), 2895-2923.

Berger, A.N., Espinosa-Vega, M., Frame, W.S. and Miller, N. (2011). Why Do Borrowers Pledge Collateral? New Empirical Evidence on the Role of Asymmetric Information, *Journal of Financial Intermediation* 20, 55-70.

Berger, A.N., Frame, W.S. and Miller, N. (2005). Credit Scoring and the Availability, Price, and Risk of Small Business Credit, *Journal of Money, Credit, and Banking* 37(2), 191-222.

Berger, A.N. and Udell, G.F. (2006). A More Complete Conceptual Framework for SME Finance, *Journal of Banking and Finance* 30(11), 2945-2966.

Bhardwaj, G. and Sengupta, R. (2014). Subprime Cohorts and Loan Performance, *Journal of Banking and Finance* 41(2), 236-252.

Borzekowski, R. and Kiser, E. (2008). The Choice at the Checkout: Quantifying Demand across Payment Instruments, *International Journal of Industrial Organization* 26(4), 889-902.

Borzekowski, R., Kiser, E., and Ahmed, S. (2008). Consumers' Use of Debit Cards: Patterns, Preferences, and Price Response, *Journal of Money, Credit, and Banking* 40(1), 149-172.

Brueckner, J., Calem, P., and Nakamura, L. (2012). Subprime Mortgages and the Housing Bubble, *Journal of Urban Economics* 71, 230-243.

Bubb, R. and Kaufman, A. (2014). Securitization and Moral Hazard: Evidence from Credit Score Cutoff Rules, *Journal of Monetary Economics* 63, 1-18.

Budish, E. (2018). The Economic Limits of Bitcoin and the Blockchain. National Bureau of Economic Research Paper Number 24717.

Berg, T., Burg, V., Gombovic, A., and Puri, M. (2018). On the Rise of FinTechs – Credit Scoring using Digital Footprints. Available at SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3163781

Campbell, Tim S. (1988). *Money and Capital Markets*. Glenview, IL: Scott, Foresman.

Catalini, C. and Gans, J.S. (2018). Initial Coin Offerings and the Value of Crypto Tokens. Available at SSRN: https://ssrn.com/abstract=3137213 or http://dx.doi.org/10.2139/ssrn.3137213.

Catalini, C. and Gans, J.S. (2017). Some Simple Economics of the Blockchain. Available at SSRN: https://ssrn.com/abstract=2874598 or http://dx.doi.org/10.2139/ssrn.2874598.

Ciciretti, R., Hasan, I. and Zazzara, C. (2007). Do Internet Activities Add Value? Evidence from Traditional Banks, *Journal of Financial Services Research* 35(1), 81-98.

Cong, L.W. and He, Z. (2018). Blockchain Disruption and Smart Contracts. NBER Working Paper No. w24399. Available at SSRN: https://ssrn.com/abstract=3138382.

Cyree, K.B., N. Delcoure, and R. Dickens. (2009). An Examination of the Performance and Prospects for the Future of Internet-primary Banks, *Journal of Economics and Finance* 33(2), 128-147.

Dandapani, K., Karels, G.V., and Lawrence E.R. (2008). Internet Banking Services and Credit Union Performance, *Managerial Finance* 34(6), 437-446.

Delgado, J., Hernando, I, and Nieto, M.J. (2007). Do European Primarily Internet Banks Show Scale and Experience Efficiencies?, *European Financial Management* 13(4), 643-671.

DeYoung, R. (2001). The Financial Performance of Pure Play Internet Banks, *Economic Perspectives*, Federal Reserve Bank of Chicago, 25, 60-75.

DeYoung, R. (2005). The Performance of Internet-Based Business Models: Evidence from the Banking Industry, *Journal of Business* 78(3), 893-947.

DeYoung, R., Lang, W.W. and Nolle, D.L. (2007). How the Internet Affects Output and Performance at Community Banks, *Journal of Banking and Finance* 31(4), 1033-1060.

DeYoung, R., Frame, W.S., Glennon, D. and Nigro, P. (2011). The Information Revolution and Small Business Lending: The Missing Evidence*, Journal of Financial Services Research* 39, 19-33.

Dow, J.P. (2007). The Adoption of Web Banking at Credit Unions, *Quarterly Review of Economics and Finance* 47, 435-448.

Einav, L., Jenkins, M., and Levin, J. (2012). Contract Pricing in Consumer Credit Markets, *Econometrica* 80(4), 1387-1432.

Elul, R. (2016). Securitization and Mortgage Default, *Journal of Financial Services Research* 49(2), 281-309.

Foote, C.L, Gerardi, K. and Willen, P. (2008). Negative Equity and Foreclosure: Theory and Evidence, *Journal of Urban Economics* 64(2), 234-245.

Fracassi, C., Germaise, M., Kogan, S., and Natividad, G. (2016). Business Microloans for U.S.

Subprime Borrowers, *Journal of Financial and Quantitative Analysis* 51(1), 55-83.

Frame, W.S. (2018). Agency Conflicts in Residential Mortgage Securitization: What Does the Empirical Literature Tell Us? *Journal of Financial Research* 41(2), 237-251.

Frame, W.S., Padhi, M. and Woolsey, L. (2004). The Effect of Credit Scoring on Small Business Lending in Low- and Moderate Income Areas, *Financial Review* 39(1), 35-54.

Frame, W.S., Srinivasan, A. and Woosley, L. (2001). The Effect of Credit Scoring on Small Business Lending, *Journal of Money, Credit, and Banking* 33(3), 813-825.

Frame, W.S. and White, L.J. (2004). Empirical Studies of Financial Innovation: Lots of Talk, Little Action? *Journal of Economic Literature* 42(1), 116-144.

Furst, K., Lang, W. and Nolle, D. (2002). Internet Banking, *Journal of Financial Services Research* 22(1/2), 95-117.

Fuster, A., Plosser, M., Schnabl, P., and Vickery, J. (2018), The Role of Technology in Mortgage Lending, Federal Reserve Bank of New York Staff Report No. 836.

Fusaro, M. (2013). Why do People Use Debit Cards: Evidence from Checking Accounts?" *Economic Inquiry* 51(4), 1986-2001.

Gandal, N., Hamrick, J. T., Moore, T., and Oberman, T. (2018). Price Manipulation in the Bitcoin Ecosystem, *Journal of Monetary Economics 95*, 86-96.

Gennaioli, N., Shleifer, A., and Vishny, R. (2012), Neglected Risks, Financial Innovation, and Financial Fragility, *Journal of Financial Economics* 104, 452-468.

Gerardi, K., Lehnert, A., Sherlund, S.M., and Willen, P. (2008). Making Sense of the Subprime Mortgage Crisis, *Brookings Papers on Economic Activity* Fall, 69-159.

Goddard, J. McKillop, D. and Wilson, J.O.S. (2009), Which Credit Unions Are Acquired?' *Journal of Financial Services Research*, 36, 231-252

Gowrisankaran, G. and Stavins, J. (2004). Network Externalities and Technology Adoption: Lessons from Electronic Payments, *RAND Journal of Economics* 35(2), 260-276.

Griffin, J. and Maturana, G. (2016). Did Dubious Mortgage Origination Practices Distort House Prices? *Review of Financial Studies* 29, 1671-1708.

Griffin, J. M. and Shams, A. (2018). Is Bitcoin Really Un-Tethered? Available at SSRN: https://ssrn.com/abstract=3195066 or http://dx.doi.org/10.2139/ssrn.3195066.

Gross, M., Hogarth, J., and Schmeiser, M. (2012). Use of Financial Services by the Unbanked and Underbanked and the Potential for Mobile Financial Services Adoption, *Federal Reserve Bulletin* 98(4), 1-20.

Hayashi, F. (2016). Access to Electronic Payments Systems by Unbanked Consumers, Federal Reserve Bank of Kansas City *Economic Review*, Third Quarter, 5-30.

Hayashi, F. and Klee, E. (2003). Technology Adoption and Consumer Payments: Evidence from Survey Data, *Review of Network Economics* 2(2), 175-190.

Hayashi, F. and Stavins, J. (2012). Effects of Credit Scores on Consumer Payments Choice, Federal Reserve Bank of Kansas City Working Paper 2012-13.

Henderson, B. J. and Pearson, N. D. (2011). The Dark Side of Financial Innovation: A Case Study of the Pricing of a Retail Financial Product, *Journal of Financial Economics* 100, 227-47.

Hernández-Murillo, R., Llobet, G., and Fuentes, R. (2010). Strategic Online Banking Adoption, *Journal of Banking and Finance* 34(7), 650-1663.

Hernando, I. and Nieto, M.J. (2007). Is the Internet Delivery Channel Changing Banks' Performance? The Case of Spanish Banks, *Journal of Banking and Finance* 31(4), 1083-1099.

Higgins, E.J. and Mason, J.R. (2004). What is the Value of Recourse to Asset-backed Securities? A Clinical Study of Credit Card Banks, *Journal of Banking and Finance* 28(4), 875-899.

Howell, S. Niessner, M., and Yermack, D. (2018). Initial Coin Offerings: Financing Growth with Cryptocurrency Token Sales, NBER Working Paper No. 24774.

Huberman, G., Leshno, J., and Moallemi, C.C. (2017). Monopoly without a Monopolist: An Economic Analysis of the Bitcoin Payment System. Available at SSRN: https://ssrn.com/abstract=3025604 or http://dx.doi.org/10.2139/ssrn.3025604.

Humphrey, D. (2018). Payments. This Book.

Jagtiani, J. and Lemieux, C. (2018). The Roles of Alternative Data and Machine Learning in Fintech Lending: Evidence from the Lending Club Consumer Platform. Federal Reserve Bank of Philadelphia Working Paper No. 18-15.

Jiang, W., Nelson, A., and Vytlacil, E. (2014). Liar's Loan? Effects of Origination Channel and Information Falsification on Mortgage Delinquency, *Review of Economics and Statistics* 96(1), 1-18.

Jiang, W., Nelson, A., and Vytlacil, E. (2013). Securitization and Loan Performance: Ex Ante and Ex Post Relations in the Mortgage Market, *Review of Financial Studies* 27(2), 454-483.

Keys, B., Seru, A., and Vig, V. (2012). Lender Screening and the Role of Securitization: Evidence from the Prime and Subprime Mortgage Markets, *Review of Financial Studies* 25(7), 2071-2108.

Keys, B., Mukherjee, T., Seru, A., and Vig, V. (2010). Did Securitization Lead to Lax Screening? Evidence from Subprime Loans, *Quarterly Journal of Economics* 125(1), 307-362.

Kharpal, A. (2017). "Initial coin offerings have raised $1.2 billion and now surpass early stage VC funding" CNBC (August 9). Available at https://www.cnbc.com/2017/08/09/initial-coin-offerings-

surpass-early-stage-venture-capital-funding.html.

Klee, E. (2006). Families' use of payment instruments during a decade of change in the U.S. payment system, Federal Reserve Board, Finance and Economics Discussion Series, #2006-01.

Krugman, P.R. (2007). Innovating our way to financial crisis. *New York Times*, December 3, 2007; available at http://www.nytimes.com/2007/12/03/opinion/03krugman.html?_r=0.

Lerner, J. and Tufano, P. (2011). The Consequences of Financial Innovation: A Counterfactual Research Agenda. NBER Working Paper No. 16780; available at: http://www.nber.org/papers/w16780.pdf.

Levine, R., (1999). Law, Finance, and Economic Growth, *Journal of Financial Intermediation* 8, 36–67.

Levine, R., (1998). The Legal Environment, Banks, and Long-run Economic Growth, *Journal of Money, Credit, and Banking* 30, 596–613.

Levine, R. (1997). Financial Development and Economic Growth: Views and Agenda, *Journal of Economic Literature* 35(2), 688-726.

Levine, R., Loayza, N., Beck, T. (2000). Financial Intermediation and Growth: Causality and Causes, *Journal of Monetary Economics* 46, 31–77.

Levine, R., Zervos, S. (1998). Stock Markets, Banks, and Economic Growth, *American Economic Review* 88, 537–558.

Mantel, B. (2000). Why do Consumers Pay Bills Electronically? An Empirical Analysis, *Economic Perspectives*, Federal Reserve Bank of Chicago, Fourth Quarter, 32-47.

Mantel, B. and McHugh, T. (2001). Competition and Innovation in the Consumer E-payments Market? Considering Demand, Supply, and Public Policy Issues, Federal Reserve Bank of Chicago, Emerging Payments Occasional Working Paper #EPS-2001-4.

Mayer, C., Pence, K., and Sherlund, S. (2009). The Rise in Mortgage Defaults, *Journal of Economic Perspectives* 23(1), 27-50.

Mayer, C., Piskorski, T., and Tchistyi, A. (2013). The Inefficiency of Refinancing: Why Prepayment Penalties are Good for Risky Borrowers, *Journal of Financial Economics* 107: 694-719.

Merton, R.C. (1992). Financial Innovation and Economic Performance, *Journal of Applied Corporate Finance* 4(4), 12-22.

Merton, R.C. (1995). Financial Innovation and the Management and Regulation of Financial Institutions, *Journal of Banking and Finance* 19(3-4), 461-81.

Miller, M.H. (1986). Financial Innovation: The Last Twenty Years and the Next, *Journal of Financial and Quantitative Analysis* 21(4), 459-71.

Miller, M.H. (1992). Financial Innovation: Achievements and Prospects, *Journal of Applied Corporate Finance*

4(4), 4-12.

Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System, Available at https://bitcoin.org/bitcoin.pdf.

Piskorski, T., Seru, A., and Witken, J. (2015). Asset Quality Misrepresentation by Financial Intermediaries: Evidence from the RMBS Market, *Journal of Finance* 70, 2635-78.

Piskorski, T. and Tchistyi, A. (2011). Stochastic House Appreciation and Optimal Mortgage Lending, *Review of Financial Studies* 24(5), 1407-1446.

Piskorski, T. and Tchistyi, A. (2010). Optimal Mortgage Design, *Review of Financial Studies* 23(8), 3098-3140.

Stavins, J. (2001). Effect of Consumer Characteristics on the Use of Payment Instruments, *New England Economic Review*, Federal Reserve Bank of Boston, 2001(3), 19-31.

Stavins, J. and Bauer, P.W. (1999). The Effect of Pricing on Demand and Revenue in Federal Reserve ACH Payment Processing, *Journal of Financial Services Research* 16(1), 27-45.

Thakor, A. (2012). Incentives to Innovate and Financial Crises, *Journal of Financial Economics* 103(1), 130-148.

Tufano, P. (2003). Financial Innovation, in *Handbook of the Economics of Finance: Volume 1A Corporate Finance*. G.M. Constantinides, M. Harris, and R. Stulz, eds. Amsterdam: North Holland, 307-335.

U.S. Federal Reserve (2016). *Federal Reserve Payments Study*. Available at: https://www.federalreserve.gov/newsevents/press/other/2016-payments-study-20161222.pdf.

Vallee, B. and Zeng, Y. (2018). Marketplace Lending: A New Banking Paradigm?. Available at SSRN: https://ssrn.com/abstract=3102984 or http://dx.doi.org/10.2139/ssrn.3102984

Van Horne, J.C. (1985). Of Financial Innovations and Excesses, *Journal of Finance* 40(3), 621-36.

Volcker, P.A. (2009). Paul Volcker: Think More Boldly. *Wall Street Journal*, December 14, 2009; available at http://online.wsj.com/article/SB10001424052748704825504574586330960597134.html.

Wall, L.D. (2018a). The Initial Coin Offerings Market (Part 1), *Notes from the Vault*, Federal Reserve Bank of Atlanta (March). Available at https://www.frbatlanta.org/cenfis/publications/notesfromthevault/03-the-initial-coin-offerings-market-2018-03-09.aspx.

Wall, L.D. (2018b). The Initial Coin Offerings Market (Part2), *Notes from the Vault*, Federal Reserve Bank of Atlanta (April). Available at https://www.frbatlanta.org/cenfis/publications/notesfromthevault/04-the-initial-coin-offerings-market-part-2-2018-04-20.aspx.

Wall, L. D. (forthcoming). Some Financial Regulatory Implications of Artificial Intelligence. *Journal of Economics and Business*.

Zinman, J. (2009). Debit or Credit? *Journal of Banking and Finance* 33(2), 358-366.