A Survey of Fintech Research and Policy Discussion

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Abstract

The intersection of finance and technology, known as fintech, has resulted in the dramatic growth of innovations and has changed the entire financial landscape. While fintech has a critical role to play in democratizing credit access to the unbanked and thin-file consumers around the globe, those consumers who are currently well served also turn to fintech for faster services and greater transparency. Fintech, particularly the blockchain, has the potential to be disruptive to financial systems and intermediation. Our aim in this paper is to provide a comprehensive fintech literature survey with relevant research studies and policy discussion around the various aspects of fintech. The topics include marketplace and peer-to-peer lending; credit scoring; alternative data; distributed ledger technologies; blockchain; smart contracts; cryptocurrencies and initial coin offerings; central bank digital currency; robo-advising; quantitative investment and trading strategies; cybersecurity; identity theft; cloud computing; use of big data, artificial intelligence, and machine learning; identity and fraud detection; anti-money laundering; Know Your Customers; natural language processing; regtech; insuretech; sandboxes; and fintech regulations.

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1. Introduction

The rapid advance in financial technology (fintech) since the global financial crisis in 2008 has played an important role in how financial products and services are produced, delivered, and consumed. Fintech has become one of the most popular discussion topics recently, primarily because of its potential disruption to the entire financial system. There has been a dramatic digital transformation in the financial landscape. The term *fintech*, however, is a broad term, and it tends to mean different things to different people. The goal of this paper is to describe the various aspects of fintech and its role in each segment of the financial market and the associated impact on consumers and the financial system overall.

Much data have been collected in recent years. For example, as of 2016, IBM estimated that 90 percent of all the global data was collected in the past year. The amount of data collection accelerated even more between 2016 and 2020. There have been new opportunities for data to be monetized, such as through data aggregation. Big data (including data from nontraditional sources and trended data) have been collected and used widely, in conjunction with advances in artificial intelligence (AI) and machine learning (ML) for digital identity and fraud detection, sales and marketing, security trading strategies, risk pricing and credit decisions, and so forth. More than 2 billion consumers are currently excluded from financial systems around the globe (especially in less developed countries such as Bangladesh, Nigeria, and Pakistan), who could potentially benefit from the use of more data and complex algorithms to access credit. There also have been new questions related to data ownership and the ethical use of data, such as who should have control over the ability to aggregate, use, and share data to safeguard consumer privacy and to avoid systemic misuse of consumer data.

Cloud storage and cloud computing have also played increasing roles in payment systems, financial services, and the financial system overall. Financial data and payment data have been stored in the cloud, and cloud computing has made it possible for many fintech innovations, such as real-time payment and instantaneous credit evaluations/decisions. Firms no longer need to commit a large investment (usually unaffordable for smaller firms) to in-house technology, but they could outsource to cloud computing service providers and share the cost with other firms. This has leveled the playing field; size is no longer the most important determinant for success. Consumers' preferences have also adapted to prioritize faster services, greater convenience, and increased transparency through online services and applications. There have been concerns among regulators about the impact on safety and soundness and financial stability, such as impacts on the payment

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system when a cloud service platform is rendered nonoperational, increased exposure to risk of cyberattack, and other similar events.

Blockchain and smart contracts have become the buzzwords in the fintech community, partly because blockchain is the technology underlying bitcoin transactions. Blockchain and other digital ledger technologies (DLT) have also been used in creating various cryptocurrencies, initial coin offerings (ICOs), other payment applications, and smart contracts — thus, leading some to believe that blockchain has the potential to become the mainstream financial technology of the future. There has been some disappointing evidence on the role and potential of blockchain in that it may not be as disruptive as initially expected, and one of the main obstacles seems to be its scalability. For example, bitcoin transactions take about 10 minutes to clear, and it is expected to take longer as the block length gets longer over the years. While thousands of tech start-ups and other tech experts have been working to resolve the issue, permissioned blockchain platforms have benefited some segments of the economy through their use for identity detection, supply chain management, digital-asset-backed lending, and securitization.

Fintech activities have been progressing quickly, penetrating all areas of the financial system. Fintech has produced great benefits to a large number of consumers around the world and has made the financial system more efficient. The rapid growth of bank-like services provided by fintech firms has raised potential concerns among bank supervisors. There have also been legal challenges and concerns associated with fintech around consumer privacy and the potential fintech disruption to overall financial stability. While fintech could greatly improve credit access and enhance efficiencies (providing faster, better, or cheaper services) in the financial system, risk cannot be completely eliminated. The dramatic rise of fintech also led to a rapidly growing literature. Goldstein, Jiang, and Karolyi (2019) describe the recent fintech phenomenon and divide the current research into three groups: application of blockchain in business and finance, technology in financial services, and the use of big data in finance. Thakor (2020) reviews the existing studies on the interaction between fintech and banking. Cecchetti and Schoenholtz (2020) review what has changed and what has not in financial service, given the rise of fintech, and they project that the impact of fintech is likely to contribute the most where the existing suppliers lack competition and sophistication. In this paper, we provide a comprehensive summary of what research studies have found so far, what the experts (academic, industry, and regulators) are working on, and the potential evolving nature of fintech's impact on consumer privacy and well-being, the structure of the financial and payment systems, the role of financial intermediation, and the effectiveness of existing regulatory policies. The rest of the paper is organized as follows, and

Table 1 provides a summary of fintech literature and findings for each of the subtopics in Section 2 to Section 9 below.

In Section 2, we discuss recent enhanced systems for credit scoring using AI/ML and alternative data, the roles of marketplace lending and peer-to-peer (P2P) lending, and digital banking and investment services. Section 3 discusses how fintech has played a critical role in digital payment, such as e-wallet and allowing a large number of the unbanked population around the world to be included in financial systems for the first time. The roles of alternative data in financial inclusion, improving credit access, and more accurate risk pricing will also be discussed in this section.

Section 4 describes the roles of blockchain, other distributed ledger technologies (DLTs), and smart contracts. As mentioned earlier, the blockchain and other DLTs have been the underlying technologies for cryptoassets and initial coin offerings (ICOs), which will be discussed in Section 5. There are frictions in the current payment system, especially cross border payments. Consumers have come to expect faster or real-time payments with minimal fees. Digital currencies could potentially deliver these, and the payment processes have been evolving rapidly toward a cash-lite (or potentially cashless) economy. Section 5 will also discuss the developments around the potential for central banks to issue fiat digital currencies, so-called central bank digital currency (CBDC). This idea of CBDC acknowledges that trust is the most important factor in payments, and private sectors may not be able to accomplish the goal of originating and supporting the value of the digital currencies it issues. There are also fears around CBDC: Several key considerations need to be incorporated into the design and implementation of the CBDC to avoid a potential adverse impact on the financial system and to preserve the ability to conduct effective monetary policy.

Section 6 deals with fintech's roles in securities trading and markets, such as the high-frequency trading or program trading that uses big data and ML algorithms to deliver superior performance. Section 7 discusses the impact of fintech on cybersecurity, which has been one of the top concerns among corporate CEOs and senior management teams. While the advanced technology has delivered vast benefits, the technology has also allowed for more sophisticated cyberattacks. Given all of these innovations and the rapid digital transformation, existing regulations need to adapt to keep up with the new financial landscape.

Section 8 discusses the increasing roles of BigTech and cloud computing in financial services, their potential impact on interconnectedness between financial institutions, and how these activities are likely to evolve in the near future. There are just a handful of cloud service providers for all financial institutions, and these providers are currently not subject to supervision by bank regulators. There have been concerns about quality control, data security, and a possible

conflict of interest that need to be addressed in the new fintech regulatory framework. Some of the technologies have also been used to assist regulators in regulatory compliance examination, such as the natural language programming (NLP) and the ML techniques used in RegTech, which will be discussed in Section 9, along with the various factors to be considered in designing fintech regulations to protect consumers and the financial systems while continuing to promote responsible fintech innovations.

Finally, Section 10 provides conclusions and policy implications, such as those related to open banking policy, ethical use of consumer data, and whether a cashless economy is expected in the near future. Quantum computing has also been transitioning from theory into practice, with potential implications/disruptions in the financial services industry and the overall economy in the coming decade. It is debatable whether the future mainstream financial technology will be blockchain and DLTs, quantum computing, or something else — and how the industry and policymakers can best be prepared to keep pace with the evolving technologies and the new adoption. We will also discuss potential directions for future fintech research.

2. Credit Scoring, Digital Banking, and Marketplace Lending

2.1 Credit Scoring Using AI/ML and Alternative Data

Credit scores, such as FICO® or VantageScore, have served as the primary factors in credit decisions, especially for credit card applications. Previous studies, such as Mester, Nakamura, and Renault (2007), Norden and Weber (2010), and Hibbeln, Norden, Usselmann, and Gurtler (2019) have documented the importance of consumer credit history and other financial and accounting data in credit risk evaluation by lending institutions. However, about 26 million American consumers have thin credit files or do not have bank accounts (unbanked); thus, they do not have FICO scores because of an insufficient credit history. More recently, there has been a breakthrough in which consumers' default probability could be estimated not only from their official credit history or credit ratings but rather from more complex statistical methods using AI and ML techniques, along with (nontraditional) alternative data. These big data and complex algorithms have been rapidly adopted by fintech lenders to overcome the limitations of traditional models and data in evaluating borrowers' credit risk and their ability to pay back loans.

Fintech lending, which started in personal lending after the 2008 financial crisis, has expanded to cover small business lending and mortgage lending in recent years. Previous research studies that compare traditional default prediction models with more advanced techniques using AI/ML seem to suggest that there are significant lifts in predictive ability. Jagtiani and Lemieux

(2019), Goldstein, Jagtiani, and Klein (2019), and Croux, Jagtiani, Korivi, and Vulanovic (2020) have documented that the information asymmetry, which used to be one of the critical issues in evaluating borrower risks, could be overcome through AI/ML and alternative data, especially for borrowers with limited credit history and the unbanked population. Soft information about borrowers can be obtained without being in close proximity to the borrowers in peer-to-peer (P2P) lending. This includes information on friendship and social networks,[1] online footprints, and text-based analysis; see Iyer, Khwaja, Luttmer, and Shue (2016); Hildebrandt, Puri, and Rocholl (2017); Lin, Prabhala, and Viswanathan (2013); Gao, Lin, and Sias (2018); Dorfleitner et al. (2016); and Berg, Burg, Gombovic, and Puri (2020).

In addition, Fuster, Goldsmith-Pinkham, Ramadorai, and Walther (2018) examine the mortgage market by comparing the traditional logit models with ML techniques in predicting borrowers' default probability. They find that using ML models would result in a slightly larger number of borrowers who would have access to credit, and ML models would also marginally reduce disparity in the acceptance ratios across racial and ethnic groups.[2] Overall, they find evidence of the higher out-of-sample predictive accuracy for default when using ML technology compared with simpler logistic models. Similarly, Jagtiani, Lambie-Hanson, and Lambie-Hanson (2021) find some evidence that fintech mortgage lenders have helped to expand credit access. Specifically, they find that fintech mortgage lenders have greater market shares in areas with lower average credit scores and in areas with higher mortgage denial rates (by nonfintech lenders).

Gao, Lin, and Sias (2018) use NLP technique, a form of AI, to analyze textual information from borrowers' writing on online lending platforms. This allows them to efficiently quantify the informational content of lengthy personal text descriptions, which were not previously possible. The authors use a combination of well-developed computational linguistics measures and advances in ML to examine the roles of linguistic style for borrowers on the Prosper (fintech lending)

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[1] A large literature examines the effect of social networks on financial and economic activities. More recently, a body of research has begun using data on social networks from online social media such as Facebook, LinkedIn, and Twitter. For example, Bailey, Cao, Kuchler, Stroebel, and Wong (2018) construct a new measure of social connectedness ("Social Connectedness Index") at the U.S. county level using friendship links on Facebook. Using their new measure, they find social network is strongly associated with trading activity and spread of innovation. Jackson, Rogers, and Zenou (2017) survey the literature on the economic consequences of the structure of social networks. Furthermore, Jackson (2020) provides a typology of social capital and argues that most forms of social capital (information capital, brokerage capital, coordination and leadership capital, reputation capital, etc.) can be identified using network-based measures. Network strategies have also been largely applied in research on financial intermediation. Jackson and Pernoud (2020) provide an overview of the relationship between financial networks and systemic risks.

[2] However, they also note that the cross-group disparity of equilibrium interest rates increases when using ML models. They attribute these changes primarily to greater flexibility.

platform. They find that lenders tend to bid more aggressively, are more likely to grant credit, and charge lower interest rates to borrowers whose writing is more readable, more positive, and contains a lower level of deception cues. Again, the evidence supports an argument that advanced technology used in credit decision could expand credit access to more consumers based on nontraditional data. Lenders, however, are required to demonstrate that the use of alternative data does not result in biased credit decisions against a certain segment of borrowers, such as race and gender.

Similarly, Iyer, Khwaja, Luttmer, and Shue (2016) use data from the same Prosper lending platform, and they find that nontraditional information tends to play an important role in credit risk evaluation and allows credit access for borrowers who are less creditworthy by traditional measures, such as those with credit scores below prime.[3] The authors cited the following basic proxies for soft information — whether the borrower posts a picture, the number of words used in the listing text descriptions, friend endorsements, etc. Their findings suggest that, while traditional information such as credit score, requested loan amount, and current delinquencies are important in credit decisions, lenders also use alternative data (nonstandard information about the borrowers), especially for less creditworthy and borrowers with thin files who have fewer alternate funding options.

Consistent with these findings, Berg, Burg, Gombovic, and Puri (2020) analyze the information content of borrowers' digital footprints, such as the activities people do online. The proprietary data set is from an ecommerce company in Germany. This includes a basic set of variables, such as whether individuals' emails contain their real name, whether they make purchases at nighttime, and the number of typing mistakes, all of which are found to be important. Their empirical investigations suggest that even the simple, easily accessible variables from the digital footprint could be valuable for consumers' default prediction. In addition, they find that alternative data sources warrant an in-depth discussion, particularly if the use of digital footprints leads people to change their behavior to increase their own credit access. Overall, they show that the digital footprint variables complement (rather than substitute) standard traditional information from consumer credit bureaus. Therefore, lenders could enhance their credit and risk pricing decisions by looking at both the traditional risk scores and alternative data.

More recently, fintech giants Alibaba and WeChat Pay Points Credit by Tencent in China have built their new credit scoring system based on alternative data they collect from nontraditional

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[3] However, due to difficulties in coding, they do not fully quantify the large selection of soft information available in Prosper listings.

sources, including social media, online shopping, payment applications, cell phone accounts, and others. This type of scoring provides a more comprehensive view of consumers' financial lives, and it is meant to help fill the credit gap for people who cannot get a loan because of their lack of credit history.

In addition to using alternative data and AI/ML to potentially expand credit access, another important question is the price of credit. Jagtiani and Lemieux (2019) use loan-level data from the LendingClub consumer lending platform, and they compare interest rates (APRs including the origination fees) charged by LendingClub with the interest rate that borrowers would have to pay by carrying a credit card balance (i.e., contractual interest rate from Y-14M stress test data reported by CCAR banks). They find that the use of alternative data by LendingClub has allowed some below-prime consumers to receive credit at a much lower cost. The rating grades assigned by LendingClub (using information not related to FICO scores) also perform better in predicting loan outcomes. Related to this, Hughes, Jagtiani, and Moon (2019) find that LendingClub also became more efficient than other lenders in its peer group size as of 2016 (after more alternative data have been incorporated into credit scoring and pricing) compared with 2013.

2.2. Internet-Based Banking and Investment Services

Recent retail banking services innovations primarily rely on technological advances such as faster Internet access and improved payment process. The fast-growing Internet access since the late 1990s has spurred the adoption of online banking. In 1995, the Security First Network Bank was the first online-only bank created, and Wells Fargo was the first brick-and-mortar bank to launch online banking (checking account) websites around the same time (Hernandez-Murillo, Llobet, and Fuentes (2010)). By 2001, eight banks in the U.S. had more than 1 million online customers. Banks in other countries around the globe also started to develop software applications to allow customers to access their accounts online. Digital banking was being adopted along with some new regulatory frameworks to address the associated new risks (Arner, Barberis, and Buckley (2016a)).

The determinants of the adoption of Internet-based banking has been well documented by existing literature. Furst, Lang, and Nolle (2002) use a cross-section sample of banks in 1999 and show that important factors that determine a bank's decision to adopt new Internet technologies for online banking services are those that are more profitable, have a larger asset size, have presence in urban markets, and are a subsidiary of a bank holding company (BHC). Hernandez-Murillo, Llobet, and Fuentes (2010) use a more recent sample of U.S. banks and confirm that, in addition to bank characteristics (branching intensity, capital-to-asset ratio, nonperforming loan

ratio, being subsidiary of a BHC), bank customers' demographic factors (household income, education, Internet access) are also important determinants for online banking adoption. A similar finding has been documented by Kowalewski and Pisany (2020), using cross-country data.

The adoption of online banking also affects bank performance. Previous studies have documented that, over time, Internet adoption reduces the bank's operating costs and improves its profitability. Interestingly, DeYoung, Lang, and Nolle (2007) and Hernando and Nieto (2007) find that Internet banking services would not replace bank branches because online banking seems to be complementary rather than a substitute for physical and personal banking services. Goddard, McKillop, and Wilson (2009) find that U.S. credit unions that do not provide Internet banking services to their members are more likely to fail or to be acquired by another institution that provides online banking. Lately, D'Andrea and Limodio (2020) examine the impact of the staggered arrival of submarine cables in Africa and find that high-speed Internet can lead banks to lower liquidity hoarding, increase interbank transactions, and increase private-sector lending.

More recently, advances in financial technology also improved digitization in payments — both retail and wholesale payments. The international experience shows that the relationship between the traditional banking sector and fintech companies could be a mix of cooperation and competition (Kowalewski and Pisany (2020)). Rysman and Schuh (2016) summarize recent developments in mobile payments and a faster payments system. Technology firms, rather than banking firms, have been leaders in providing mobile payments in the U.S., suggesting potential benefits from partnerships between banks and fintech firms. Several fintech firms have also been providing white-label technological services for their bank partners. Partnership alliance between banking firms and technology companies would also help banks to digitalize their credit decision process and their risk management.[4] Klus, Lohwasser, Hornuf, and Schwienbacher (2020) investigate the drivers and the extent to which banks interact with fintech start-ups, using detailed information on strategic alliance made by the 100 largest banks in Canada, France, Germany, and the UK. They find that larger banks are better able to integrate start-ups into their own business model and strategy than smaller banks. They also find significantly positive market reactions in response to announcements of alliance formation between digital banks and fintech firms.

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[4] Partnership arrangements between banks and fintech firms may take on various forms, from simple joint ventures, to more advanced technology-based ways of integrating new business models or services (e.g., Enriques and Ringe, 2020; Klus, Lohwasser, Holotiuk, and Moormann, 2019). As an example, China Construction Bank (CCB), one of the Big-4 state-owned banks, announced a strategic pact with Alibaba in 2017, which allowed Alibaba to sell CCB's financial products through its Ant Financial platforms (https://www.spglobal.com/marketintelligence/en/news-insights/trending/hsmye-hebytelrkvaqiqtg2).

Parlour, Rajan, and Zhu (2020) study the impact of fintech competition in payment services when banks rely on consumers' payment data to obtain information about their credit quality. They assume three specific regimes in which payment information flows back into the credit market: fintech lending, data sales, and consumer data portability. They argue that payment data generate information externality and can be useful in predicting consumer default. Fintech competition benefits consumers with weak banking relationships; thus, financial inclusion improves. They also point out a complex tradeoff between consumer welfare and the stability of banks following fintech competition in payment — competition from fintech payment providers could reduce bank profitability.

Technological innovations in recent years have allowed for the rapid adoption of mobile payment and fast payment systems around the globe, especially in China. The adoption has been slower in the U.S.[5] Crowe, Rysman, and Stavins (2010) find that standard concerns such as the cost of adoption and network effects could play a critical role in the speed of adoption. The cost of adoption would be higher in the U.S. because of the fragmented nature of the telecommunications system and the banking industry and the legacy payments system in the U.S. To implement a single national mobile payment mechanism would require an agreement between all the mobile carriers and the banks that issue cards to consumers. Greene, Rysman, Schuh, and Shy (2014) and Rysman and Schuh (2016) discuss the pros and cons of implementing a faster payments system in the U.S., suggesting that the net potential benefits could be large and could extend beyond faster speed. It would, however, be more expensive to build a completely new payments system in the U.S. than in countries that did not have an established legacy payments system. There are also related questions about how such a new system should be managed and funded, the fee structure, and new regulatory regimes associated with the new payments systems. The Federal Reserve System has been working on building a completely new payment rail for fast payment (with uninterrupted 24x7x365 processing), so called FedNow, which is expected to be fully implemented in 2023. The service is intended to be a flexible, neutral platform that supports a broad variety of instant payments and will be made available to all depository institutions.[6] Conti-Brown and Wishnick (2020) argue the plan of the new system might achieve three objectives at the heart of the payment policy in the U.S.:

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[5] While consumers perceive debit and credit card payments as being fast and immediate, the settlement step often takes several business days to complete. Payments through the automated clearing house (ACH) can also take several business days to complete.

[6] See https://www.federalreserve.gov/paymentsystems/fednow_about.htm Federal Reserve Board - FedNow℠ Service for more details.

to catalyze innovation, enhance access to developing payments networks, and shore up financial stability.

2.3 Peer-to-Peer (P2P) Lending

Marketplace lending (MPL), or peer-to-peer (P2P) lending, has emerged as an appealing new channel of financing for consumers and small businesses over the last decade. P2P lending platforms are designed to match lenders and borrowers and to eliminate the intermediary middleman. The platforms connect investors (funding supply) and borrowers (funding demand) directly to facilitate the transaction. The patterns showing that new traditional bank loans are trending downward, while new P2P lending are trending upward, raise a natural question whether these two types of lenders complement or substitute each other in the credit market. Balyuk (2018) explores the effect of P2P lending on consumers' access to credit and finds that fintech lenders have improved credit access to consumers who cannot access credit from traditional banks — see also Chava and Paradkar (2018). Similarly, Jagtiani and Lemieux (2018) find that, using data from the LendingClub consumer platform, fintech lenders have penetrated areas that may be underserved by traditional banks, such as in highly concentrated markets and areas that have fewer bank branches per capita. And Jagtiani, Lambie-Hanson, and Lambie-Hanson (2021) find consistent evidence of this when focusing on mortgage loans originated by fintech versus nonfintech lenders. Other studies, such as Tang (2018) and de Roure, Pelizon, and Thakor (2020), show that P2P lending could be a substitute for or a complement to bank lending, depending on the situation. If assuming banks face an exogenous regulatory shock, P2P lending could act as a substitute for bank lending for serving inframarginal borrowers; however, on small-scale loans, P2P lending would be more likely to complement bank lending.

There have also been questions whether the P2P lending platform could uncover the "correct" pricing for the transactions. There are two market mechanisms to pricing: through an auction or through posted prices, which is a more common approach. An auction process typically relies on the relative strength of lenders and borrowers to determine the price; whereas, posted prices are predetermined by complex algorithms used by the lending platforms.[7] Wei and Lin (2017) show that under posted prices, borrowers are more likely to obtain credit, but the default probability is also higher. Franks, Serrano-Velarde, and Sussman (2018) use a peer-to-business lending platform and find that a 1 percent increase in the interest rate corresponds to a less than a

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[7] One of the lending platforms, Prosper, switched from the auctions approach to the posted prices approach in December 2010 (see Prosper.com).

half percent increase in the default probability, implying that information efficiency was not reached in the pricing process. Cumming and Hornuf (2020) find that individual lenders of peer-to-business lending platforms (online platforms facilitating loans from individuals to small businesses) tend to rely mostly on the ratings of the businesses, which are assigned by the lending platform — they pay little attention to other detailed financial information. Participation of sophisticated investors could potentially improve the screening outcomes but also could create adverse selection among investors (Hildebrandt, Puri, and Rocholl (2017)). Vallee and Zeng (2019) and Liskovich and Shaton (2017) find that sophisticated investors tend to outperform less experienced ones, especially when platforms provide more sufficient information to investors through websites or application programming interfaces (API).

Loan pricing seems to be affected by soft information about borrowers. Butler, Cornaggia, and Gurun (2017) and Crowe and Ramcharan (2012) show that in addition to standard financial variables (such as credit scores, employment history, homeownership), P2P platforms also provide nonstandard soft information about the borrowers that is useful for lenders to make credit decisions. Previous research shows that borrowers' soft information, including personal characteristics such as race, age, and beauty (Ravina, 2018), social capital (Lin and Pusianinen, 2018; Hasan, He, and Lu, 2019), characteristics of listing text (Iyer, Khwaja, Luttmer, and Shue, 2016), hometown (Lin and Viswanathan, 2016), social network (e.g., friend endorsements as in Lin, Prabhala, and Viswanathan, 2013; Freedman and Jin, 2017) affects lenders' decisions in terms of ex-ante loan pricing and loan amount. These factors also improve the ex-post lending outcomes. Many of these factors, however, are prohibited in credit decisions, according to the fair lending and consumer privacy regulations. Jagtiani, Vermilyea, and Wall (2018a) describe how big data and complex algorithms from AI/ML could be used appropriately by lenders and other market participants and how regulators are adapting their supervisory approach accordingly. A similar finding has also been documented in Li, Lu, and Hasan (2020).

3. Fintech and Financial Inclusion

3.1 Digital Wallet and Credit Access for Unbanked Individuals

Financial inclusion, typically defined as the use of formal financial services, especially by the disadvantaged, has become a subject of growing interest. Indeed, the positive relationship between financial development and economic development, documented by literature on financial-growth nexus, is suggestive of a positive association between finance and poverty alleviation (Beck, Demirguc-Kunt, and Levine, 2007). A central question is how to promote financial inclusion for

regions endowed with asymmetric information, weak institutions, and lack of basic infrastructure necessary for banking. According to the Global Findex database by the World Bank, 31 percent of adults do not have a bank account as of 2017, a decline from 38 percent in 2014 and 49 percent in 2011 (Demirguc-Kunt et al., 2018). The numbers also show large disparities between males and females and between rich and poor.[8] Kendall, Mylenko, and Ponce (2010) make a rough estimation of banked and unbanked individuals around the world using a new set of financial access indicators for 139 countries as of 2009. They estimate that people have on average 3.2 financial accounts per adult, and 81 percent of the adults have at least one bank account in developed countries. In contrast, people have on average less than one account (specifically only 0.9 account) in developing countries, and only 28 percent of the adults in developing countries have a bank account.[9]

What are important factors that determine the level of financial access? Beck, Demirguc-Kunt, and Levine (2007) show that the overall level of economic development, the quality of the institutional environment, the degree of credit information sharing, the level of initial endowments, and the development of physical infrastructure are positively associated with financial outreach and depth; whereas, the cost of enforcing contracts and the degree of government ownership of banks are negatively associated with the financial outreach and depth. Kendall, Mylenko, and Ponce (2010) also suggest a similar conclusion. In addition, legal origin and religion have a less consistent impact on financial inclusion. Allen et al. (2016) explore the factors underpinning financial inclusion; they show that policies to promote financial inclusion are especially effective among the most commonly excluded groups of individuals from access to finance: the poor, those living in rural areas, females, and young individuals.

Fintech can promote financial inclusion in different ways. Allen et al. (2021) examine bank branch penetration and financial access in Kenya, a country that has made significant strides in financial inclusion. The emergence of Equity Bank, a pioneering and private institution that devised a banking service targeting low-income and less-educated customers and underserved regions, has had a positive and significant impact on households' use of bank accounts and credit access in Kenya during 2006 to 2010. The number of deposit and loan accounts of Equity Bank represents around 50 percent and 30 percent of the total number of deposit and loan accounts in Kenya, respectively. Their finding suggests that the successful business model of Equity Bank in Kenya

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[8] For more details, see the article "Financial Inclusion on the Rise, But Gaps Remain, Global Findex Database Shows" by the World Bank, https://www.worldbank.org/en/news/press-release/2018/04/19/financial-inclusion-on-the-rise-but-gaps-remain-global-findex-database-shows.

[9] The detailed description of the data on financial inclusion can be found in the report of *Financial Access: 2009*, https://www.cgap.org/sites/default/files/CGAP-Financial-Access-2009.pdf.

provides a solution to the financial access problem that has hindered real growth in many African countries. Similarly, Hau, Huang, Shan, and Shen (2019a) and Hau, Huang, Shan, and Shen (2019b), using a comprehensive loan data set from Alibaba, a lending online ecommerce platform, show that fintech credit promotes financial inclusion in China. Fintech helps to mitigate local credit supply frictions in the credit market and extend the "frontier" of credit availability to small businesses with low credit scores. In addition, these online ecommerce platforms have promoted a self-selection process in which more funding tends to be channeled to those online merchants that receive better rating by their customers; see Huang, Li, and Shan (2019). Dolson and Jagtiani (2021) explore credit supply to underserved consumers, using data on credit offers that were made by fintech versus traditional lenders. They find evidence suggesting that fintech lenders attempt to reach those consumers with lower credit scores and lower income relative to traditional lenders.

Using the evidence from a fintech platform, Basten and Ongena (2020) find that online banking has allowed banks to extend mortgage loans to clients in regions where banks lack branches, reputation, staff, or local expertise. Banks tend to prefer to lend to faraway regions where collateral prices are less correlated with those at home. Breza, Kanz, and Klapper (2020) find that their experiment that introduced new financial technology via payroll accounts for unbanked population in Bangladesh (so that wage payments would go to their mobile money account) resulted in increased savings and increased savings and improvements in their ability to cope with unanticipated economic shocks. Erel and Liebersohn (2020) use data on the Paycheck Protection Program (PPP), the fiscal policy program to support the U.S. economy during the COVID-19 pandemic, to explore if the loans have gone to the targeted recipients. They find that fintech is disproportionately used in counties with fewer banking services, lower incomes, and a larger minority share of the population as well as in industries with little ex-ante small-business lending. In addition, its role in PPP provision is greater in areas where the economic effects of the COVID-19 pandemic were more severe. Overall, the core functions of financial intermediation are impacted by fintech (Crouhy, Galai, and Wiener, 2020).

3.2 The Roles of Alternative Data in Improving Credit Access and Risk Pricing

The recent rapid development in fintech and use of alternative data in evaluating credit risk have also raised questions about whether the use of alternative data and advanced algorithms has improved credit assessment and enhanced access for the underbanked. A related issue is whether these innovations carry a risk of disparate treatment and violate fair lending and consumer privacy regulations. Schweitzer and Barkley (2017) examine the characteristics of online small business

borrowers using the Federal Reserve's 2015 Small Business Credit Survey data and find supportive results that businesses that were denied access to credit by banks turned to fintech lenders to arrange credit for their business. Similarly, Jagtiani, Lambie-Hanson, and Lambie-Hanson (2021) explore the mortgage market and find evidence suggesting that more borrowers turned to mortgage fintech lenders in areas where there were higher denial rates by traditional lenders.

Consistent findings have been documented by other studies. Ahmed et al. (2016) find that borrowers would have been unable to secure external financing without the fintech online lending platform, despite being creditworthy. Jagtiani and Lemieux (2019), using account-level data from LendingClub and Y-14M bank stress test data, find that for the same risk of default, consumers pay smaller spreads on personal installment loans from a fintech platform than from (traditional) credit card borrowing. Berg, Burg, Gombovic, and Puri (2020) suggest that digital footprints can help boost financial inclusion, allowing unbanked consumers to have better access to finance. Eccles et al. (2020) find that the usage of big data can improve the screening of risky borrowers and therefore can improve credit access to small business entities. Similarly, Frost et al. (2019) show that fintech firms often start as payment platforms and later use consumer data to expand into some provisions of credit, insurance, and savings and investment products. These firms lend more in countries with less competitive banking systems and less stringent regulations. In the case of Argentina, fintech lenders have information advantages in credit assessment using alternative data and advanced algorithms. Buchak et al. (2018) find that fintech lenders use different information than traditional lenders to set interest rates; furthermore, the authors also show that regulatory arbitrage and technological advantages together have contributed to the growth of shadow banking and fintech lending since the 2008 global financial crisis.[10]

The use of alternative data has also raised issues related to fair lending. As mentioned earlier, previous studies show that soft information such as applicants' look, relationship, and network has been widely used in evaluating credit availability and pricing. Fu, Huang, and Singh (2018) find that, despite the great benefits that big data and complex ML algorithms can bring, these predictions of creditworthiness could be subject to bias, and lenders may unknowingly make credit decisions based on factors that are related to protected class (such as race and gender), even though these sensitive attributes are not used as inputs to the model. Using over 1.3 million credit card offers, Ru and Schoar (2019) show that credit card companies weigh short-term rent

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[10] Consistently, Cumming and Schwienbacher (2018) find that fintech venture capital investments are relatively more common in countries with weaker regulatory enforcement and without a major financial center since the global financial crisis in 2008.

maximization against increased credit risk when targeting consumers' behavior biases. Padhi (2017) show that the discrimination and competition in online alternative lending could result in a riskier pool of potential borrowers for banks and, thus, could impact safety and soundness in the banking system and threaten the financial stability overall. Jagtiani and John (2018) and Branzoli and Supino (2020) provide an overview of how alternative data and other fintech innovations have changed the entire financial landscape.

4. Distributed Ledger Technology (DLT), Blockchain, and Smart Contracts

Distributed ledger technology (DLT) is a term widely used to describe various record-keeping technologies, such as decentralized data architecture and cryptography, which allow the keeping and sharing records in a synchronized way while ensuring their integrity through the use of consensus-based validation protocols. Blockchain is typically used in conjunction with DLT, containing blocks of records that are linked using cryptography.[11] Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data. By design, a blockchain is intended to be resistant to modification of the data; however, there have been concerns around cybersecurity related to blockchain.[12] In general, blockchain is designed to be an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way. Blockchain has become a buzzword mainly because it is the main technology underlying bitcoin transactions. Since late 2015, blockchains in general (not bitcoin blockchains) have attracted explosive interest from the industry as a new way to create, exchange, and track ownership of financial assets on P2P platforms. Blockchain technology has also facilitated the creation of smart contracts; these are computerized protocols allowing terms contingent on decentralized consensus that are tamperproof and self-enforcing via automated execution; see Szabo (1994) and Cong and He (2018).

The idea of blockchain was initially introduced by Haber and Stornetta (1991) to authenticate authorship of intellectual property. Much later in 2008, Nakamoto (2008) reintroduced it as a method of validating ownership of the cryptocurrency bitcoin. It is viewed as a potential mainstream financial technology of the future to eliminate a trusted third party in financial

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[11] Arner et al. (2019) demystify key aspects of blockchain systems and disentangle concepts that are often (incorrectly) used interchangeably, such as distributed ledgers and blockchains.

[12] Gervais et al. (2016) study the security issues existing in blockchains, focusing on how to defend against "double-spend" attacks or other types of attacks that could be undertaken by entity control over a large portion of the computing power of the network. Budish (2018) shows that attacking proof of work blockchains, such as bitcoin, would become profitable if such a blockchain became sufficiently economically important.

intermediation. Szabo (2005) proposes a similar idea to overcome the problem of the dependence on a trusted third party. The proposed "bit gold" was a protocol whereby costly bits could be created online with minimal dependence on trusted third parties and then securely stored, transferred, and assayed with similar minimal trust. The creation of such bit gold would be based on various functions including "client puzzle function," "proof of work function," or "secure benchmark function."

There are three main types of blockchain. The first type, a private blockchain, comes originally from the chain proposed by Haber and Stornetta (1991). In this chain, there needs to be an entity with authority, identified as sponsor or gatekeeper, taking complete control over what is written on the ledger. Such sponsors or gatekeepers can restrict entry into a market, access monopolistic user fees, edit incoming data, or limit users' access to market data. The second type, a permissioned blockchain, is one in which the "write" privilege is granted to a consortium of entities. These entities govern the policies of the blockchain and take control of propagating and verifying transactions. The third type is a public blockchain, in which the write privilege is completely unrestricted. Because the writers are allowed to be anonymous in the public blockchain, there needs to be an efficient, fair, and real-time mechanism to ensure that all participants agree on a consensus on the status of the ledger. Yermack (2017) and Abadi and Brunnermeier (2019) offer an introduction of the development and different types of blockchain. Wall (2018b) notes that there are some critical issues related to the governance of blockchains protocol (code) before they can become a critical part of the financial infrastructure.

So far, well-known types of consensus mechanism algorithms include: 1) proof of work (POW), which is used by major cryptocurrency networks such as bitcoin and Litecoin; and 2) proof of stake (POS), which is used by Peercoin.[13] Biais, Bisiere, Bouvard, and Casamatta (2019) model the POW blockchain protocol as a stochastic game and analyze the equilibrium strategies of rational, strategic miners, and identify negative externalities, implying that equilibrium investment in computing capacity is excessive. Saleh (2020) provides a first formal economic model of the POS blockchain protocol and establishes two design choices that POS developers may employ to

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[13] The proof of work (POW) requires a participant node to prove that it has accomplished a computationally difficult task before getting the rights to write on the ledger. Therefore, one disadvantage of POW is that it needs high-energy consumption and longer processing time. The proof of stake (POS) emerges and evolves as a low-cost and low-energy consuming alternative to POW algorithm, attributing mining power to the proportion of coins held by each miner. It is reported that one of the major networks, Ethereum, is transiting to adopt the POS blockchain instead of POW soon (see, e.g., https://www.coindesk.com/testnet-gorli-ethereum-serenity). Other types of consensus algorithms include proof of capacity (POC), allowing the sharing of memory space of the contributing nodes on the blockchain network.

generate consensus: a minimum stake threshold for validators and a modest block reward schedule. Thus far, the usage of POS blockchain outpaces that of POW blockchain even though POS had a negligible presence before 2015 (Irresberger, John, and Saleh, 2020). Such transition to POS in recent years is partly driven by the limitations of POW (i.e., the limited adoption (Hinzen, John, and Saleh, 2020)). To better understand the public blockchain ecosystem, Irresberger, John, and Saleh (2020) offer an empirical framework. In their framework, the public blockchain ecosystem characterizes three key economic attributes: scale, security, and adoption. Their analysis further shows that POW blockchains dominate in adoption, delegated POS blockchains dominate in scale, and blockchains using nonstandard protocols dominate in security. Pagnotta (2020) documents that the security of any open blockchain should be seen as an economic outcome rather than an embedded property of its blockchain technology. Compared with the POS protocol, the agent updating the blockchain in the POW protocol receives a coin reward. This rewarding feature has led to discussions on whether POS induces wealth concentration. For example, Rosu and Saleh (2020) document that, without trading, the investor shares in the cryptocurrency that uses a POS protocol are martingales that converge to a well-defined limiting distribution; hence, they are stable in the long run.[14]

Major central banks and stock exchanges have been exploring the usage of DLT in payments, clearing and settlements; see Mills et al. (2016) and Benos, Garratt, and Gurrola-Perez (2017). The driving force behind the efforts in deploying DLT in financial transactions and settlement is an expectation that this technology will reduce (or even eliminate) inefficiencies and related frictions that currently exist for storing, recording, transferring, and exchanging digital assets through financial markets. Decentralization, which is the core concept of the DLT, has both pros and cons. A growing literature discusses the advantages that a blockchain can offer compared with the traditional ledgers. The blockchain-based smart contract is encoded to assure one party that its counterparty will fulfill the promise with certainty; therefore, it can eliminate some contracting frictions like the need for costly verification or enforcement in an automated and conflict-free way; see Cong and He (2018) and Harvey (2016). However, Wall (2016) observes that such smart contracts must specify what happens in every state of the world, whereas most real-world contracts are intentionally left incomplete for economic reasons. Meanwhile, through decentralized consensus, blockchain improves the ability to bootstrap and operate a marketplace without the need for a traditional intermediary, which further lowers the cost of networking and improves the

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[14] Some other studies (e.g., Fanti et al., 2019) argue that POS system leads to a rich-get-richer effect because of its rewarding feature.

competition. Overall, participants can make investments to support and operate a shared infrastructure without assigning market power to a platform authority; see, for example, Catalini and Gans (2018) and Abadi and Brunnermeier (2019). More specifically, Yermack (2017) overviews the impact of blockchain on corporate governance and argues that, in addition to resulting in lower cost and more accurate record keeping, a blockchain could bring greater liquidity and improve transparency of ownership. Similarly, Ma, Gans, and Tourky (2018) argue that regulation of bitcoin mining can reduce the overall costs of the system and improve welfare.

Despite these benefits, there are also potential negative features around blockchain technology. For example, Cong and He (2018) argue that, through distributing all transaction information, business privacy can be an issue when pushing for real-world blockchain application. Similar findings are also documented in Malinova and Park (2017), as traders want to hide their identities to prevent front running. Lack of full transparency, the net aggregate welfare is believed to be weakly higher if investors are allowed to split their holdings among many identifiers. Abadi and Brunnermeier (2019) document a Blockchain Trilemma, suggesting that no record-keeping system can satisfy the three properties simultaneously: self-sufficiency, no rent extraction, and cost efficiency. Distributed ledgers promote competition but eliminate rents through "fork competition," engendering instability and miscoordination.[15] Tinn (2018) documents that blockchain technology facilitates faster learning and more frequent effort decisions, which in turn changes the type of financing contracts that are the most efficient or could even make traditional debt and equity contracts more costly. Easley, O'Hara, and Basu (2019) theoretically analyze how equilibrium transaction fees evolve in the bitcoin blockchain, from a mining-based structure to a market-based ecology, and they demonstrate that transaction fees are not welfare improving. Lehar and Parlour (2020) find large variation of bitcoin transaction fees, not only over time, but also within blocks; furthermore, the bitcoin blockchain rarely operates at full capacity even in the presence of fees. There might also be risks associated with DLT, documented by legal scholars, including liability risks from increased transparency, cyber risks, and other operational risks such as insufficient coding, key person risks, and negligent performance (Zetzsche, Buckley, and Arner, 2017).

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[15] The Blockchain Trilemma was originally proposed by Vitalik Buterin, the founder of Ethereum (ETH). Other articles mentioning the Blockchain Trilemma include "The DCS Triangle" by McConaghy in 2016 and "The DCS Theorem" by Slepak and Petrova in 2018. For more details, see https://blog.bigchaindb.com/the-dcs-triangle-5ce0e9e0f1dc.

5. Cryptocurrencies, Initial Coin Offerings, and Central Bank Digital Currencies

In recent years, the initial coin offerings (ICOs) have exponentially grown as a new form of financing for start-ups. There are 4,844 cryptocurrencies in existence as of August 2020, with the total market capitalization of $368.2 billion USD.[16] This number does not include many that have failed. One of the most successful ICOs was from Ethereum in July 2014 that collected in total $18.4 million USD in 42 days.[17] The market capitalization of Ethereum reached more than $30 billion in 2017.[18] These successes led to great excitement about cryptocurrencies as a new form of financing for innovations in the upcoming digital age;[19] but in the meantime, they created concerns about rampant speculation and financial instability.

Given the extreme volatility of cryptocurrencies,[20] stablecoins have been developed in the crypto world. The central feature of stablecoins is that they are pegged to another asset, like the U.S. dollar, national currencies, or commodities, and their issuers back up the value of coins through holding sufficient reserves to support the value of the stablecoins.[21] In June 2019, Facebook announced its Libra 1.0, which would be built upon a "permissioned" blockchain platform: the Libra Association. Unlike some other types of stablecoins (e.g., Tether, True USD), Libra's value would be backed 1:1 by a basket of fiat currency bank deposits, including the U.S. dollar, Euro, Pound Sterling, Japanese Yen, and government securities, rather than any single physical currency. There have been serious criticisms and concerns around Libra, and several of the initial 28 members of the Libra

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[16] See website https://www.coinlore.com/.

[17] Antonio Madeira, "What Is an ICO and How Does It Work," CryptoCompare (January 2018), https://www.cryptocompare.com/coins/guides/how-does-an-ico-work/.

[18] For developments in pricing information, market caps, and coin issuance, see "Top 100 Cryptocurrencies by Market Capitalization," CoinMarketCap, http://coinmarketcap.com/ (last accessed December 19, 2018). See also "ICO Tracker," Coindesk, https://www.coindesk.com/ico-tracker.

[19] In a recent working paper, Kamepalli, Rajan, and Zingales (2020) document that there is a growing concern that digital platforms might acquire any potential competitor, dissuade others from entering, and therefore slow innovations. They build a model of platform competition and show that the economics of digital platforms differ significantly from the neoclassical economics of firms: Digital platforms are two-sided in that one side faces advertisers while the other side faces customers for services (and there isn't any price competition on the customer side; on the other hand, there are important network externalities on the side of customers who face switching costs. They show that the prospect of an acquisition by the incumbent platform undermines early adoption by customers, reducing prospective payoffs to new entrants.

[20] For example, bitcoin once dropped from nearly $20,000 in December 2017 to around $3,600 in January 2019 and reached a new peak of over $50,000 in February 2021.

[21] Cheng (2020) analyzes the legal issues behind stablecoins and how to build a legal basis by leveraging the core principles of U.S. commercial law (i.e., focusing on the principles of settlement finality, rules for adverse claims, discharge of the underlying obligation, and the concept of a security entitlement) to help stablecoin developers and market participants manage their risk exposures.

Association withdrew themselves, including PayPal, Visa, Mastercard, Stripe, and eBay. Major financial institutions such as JPMorgan Chase and Goldman Sachs had also announced they did not plan to join the Libra Association.[22] On April 16, 2020, the Libra Association published a revised version of its 2019 white paper. The revisions attempt to address major concerns raised by the international regulatory community. The updated Libra 2.0 white paper makes several key changes to address the concerns raised by financial regulators.[23] The Libra Association was transitioned into the new Diem Association in November 2020 to continue to pursue its goals. These are evidence of the importance of trust in the payment system; thus, there may be a role for the central banks, "trusted institutions," to play a role in issuing stable digital currencies.[24]

5.1 Cryptocurrencies: Pricing, Impact on Central Banking and Regulations

As a new form of electronic money, cryptocurrency is part of the latest innovations in the financial system. However, the idea of virtual money is not new; electronic payment systems have been growing steadily for decades. Online fantasy games provided a platform for issuing virtual currencies in the 1980s, which have been regarded as predecessors for the current cryptocurrencies such as bitcoin. Later, the M-pesa, a currency denominated in mobile phone minutes, was introduced in Kenya by Safaricom in 2007 (Raskin and Yermack, 2016). M-pesa greatly facilitates money transfers between individuals and therefore increases the probability of being banked for the poor (Allen et al., 2021). Bitcoin, originally proposed by Nakamoto (2008) and introduced into circulation in 2009, is the most successful cryptocurrency so far in terms of volume

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[22] Zetzsche, Buckley, and Arner (2020) discuss the regulatory concerns of Libra 1.0, including licensing, risk management, identity and data protection, etc.

[23] The changes in Libra 2.0 include: 1) offering single-currency stablecoins in addition to the multicurrency coin (Libra Coins). Specifically, the design of the Libra payment system is envisioned to start with single-currency (USD, EUR, GBP, and SGD) coins in addition to the basket currency version; 2) enhancing the safety of the Libra payment system with a robust compliance framework. The association plans to develop strong Anti-Money Laundering and Combating the Financing of Terrorism (AML/CFT) standards and establish a Financial Intelligence Function to help support and uphold operating standards for network participants; 3) forgoing the future transition to a permissionless system, while maintaining its key economic properties. Regulators have been concerned about the risk in such an open system of unknown participants taking control of the system and removing key compliance provisions. Instead, network participants (service providers) will be selected through a competitive process based on a set of published criteria; and 4) building strong protections into the design of the Libra Reserve. Libra will still be fully backed by reserves, of which 80 percent will be invested in liquid short-term government securities, and the remainder will be held in cash. In addition, with input from regulators, the association will develop a regulatory capital framework to ensure it maintains an appropriately sized, loss-absorbing capital buffer.

[24] If stablecoins are adopted globally, referred to as *global stablecoins* (GSCs), there might be additional risks. BIS investigates the adverse effects of GSCs both domestically and internationally in its report: https://www.bis.org/cpmi/publ/d187.pdf.

but with high price volatility. The price peaked at almost $20,000 per bitcoin in November 2017 and then declined by 82 percent in 2018 (a 38 percent decline in November alone) to a price of around $3,500 as of December 2018, then rose to about $58,000 per bitcoin in February 2021.[25] The major difference between bitcoin and M-pesa is that bitcoin has been used all around the world and is circulated over an open Internet network, rather than tied to any traditional banking system.

It has remained unclear what type of asset cryptocurrency is — whether it should be treated as a currency, a commodity, or a security. Another related concept is that of a token. The Securities and Exchange Commission (SEC) classifies the tokens into three categories: cryptocurrency tokens, security tokens, and utility tokens.[26] Cryptocurrency tokens (or coins) are a means of exchange and a store of value; security tokens, determined by the Howey test, represent a conventional security that is recorded and exchanged on a blockchain; and utility tokens give the holder the right to access a product or services on platforms.[27] Proponents of cryptocurrencies highlight various potential benefits, which can improve overall welfare; critics note that those features may facilitate illicit financial activities.

An important question raised by the recent literature on cryptocurrencies is what determines the fundamental value. In addition to being an alternative to traditional currency as a means of exchange, bitcoin and other digital currencies have also been treated as investment vehicles, and the price has been extremely volatile, further leading to potential risks in financial markets. Several recent studies provide theoretical pricing models of cryptocurrencies.

Schilling and Uhlig (2019) develop a pricing model of bitcoin in a simple endowment economy, in which they assume there are two types of monies for transactions: bitcoin and dollars. They show that in the "fundamental" cases, in which bitcoin is used in transactions, the price of bitcoin follows a martingale pattern, meaning that today's price is the best forecast for tomorrow's price; while in the "speculative" cases, in which the buyers hold bitcoin for speculative purposes, the dollar price of bitcoin is expected to rise, and the agents start hoarding bitcoin with the expectation of a price increase. In equilibrium, if the bitcoin prices and marginal utility of consumption are

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[25] See Coinbase website, https://www.coinbase.com/.

[26] See the SEC statement on cryptocurrencies and initial coin offerings by Chairman Jay Clayton at https://www.sec.gov/news/public-statement/statement-clayton-2017-12-11; see also an investigative report on the DAO (decentralized autonomous organization) hack at https://www.sec.gov/litigation/investreport/34-81207.pdf.

[27] The SEC has jurisdiction over securities pursuant to the Securities Act and Exchange Act. A token is a "security" if it meets the definition of an investment contract as outlined in *SEC v. W.J. Howey Co.* Under the Howey test, an investment contract exists when it is: (1) an investment of money; (2) in a common enterprise; (3) with a reasonable expectation of profits; (4) from the managerial or entrepreneurial efforts of others. *Securities and Exchange Commission v. W. J. Howey Co.,* 328 U.S. 293, 301 (1946).

negatively correlated, then agents are willing to hold bitcoin with an expectation of bitcoin price appreciation. Garratt and Wallace (2018) suggest that the best theory of the value of bitcoin is that it rests on self-fulfilling beliefs and that the set of beliefs that can be self-fulfilling is huge.

Sockin and Xiong (2020) propose a pricing model for cryptocurrencies. In their model, a cryptocurrency serves two functions — one as membership in a platform with access to goods and services provided by the platform — and the other as the initial pricing for the platform. In their model, when the demand for the platform is publicly observable, there exists either two or no cutoff equilibria, suggesting that one may observe two entirely different dynamics of cryptocurrencies in practice. And the cryptocurrency price would be volatile in this case unless there is government intervention/regulations. On the other hand, when the transaction demand for the platform is unobservable, the trading price of the cryptocurrency would serve as an important channel for aggregating private information and serve to facilitate coordination between the two equilibria (the high- and low-price equilibria). As the high- and low-price equilibria are disparate, it would be difficult for outsiders to diagnose the health of the cryptocurrency simply based on its observed price.

Cong, Li, and Wang (2018) provide a dynamic asset pricing model for cryptocurrencies/tokens on blockchain platforms. Their model allows for both user-based externality and endogenous user adoption. The expected price appreciation makes tokens attractive to early users, allowing them to capitalize future prospects of the platform and hence accelerating adoption. They find a positive but nonlinear relationship among token price and platform productivity, users' heterogeneous transaction needs, and network size. Cong, Li, and Wang (2020) further develop a dynamic model of platform economy, where tokens are used as means of payment among users and issued by the platform to finance investment. Platform owners maximize their seigniorage by managing token supply, subject to the condition that users optimally decide on token demand and rationally form expectations of token price dynamics. They argue that the financial constraints of the platform generate an endogenous token issuance cost that causes underinvestment and conflicts of interest between the owners and users.

Pagnotta and Buraschi (2018) provide an equilibrium model of the bitcoin market in a decentralized network. They show that the overall production (capacity) and the price of bitcoin are jointly determined. Their calibration shows that bitcoin price is very susceptible to the fundamental properties of its demand and supply. Tripling the current network size raises the equilibrium price of bitcoin from $14,200 to $77,627 (a 546 percent increase). Pagnotta (2020) further models the interactions between users and miners, which give rise to multiple self-fulfilling equilibria with

distinct price-security levels. In his model, the price-security feedback effects can amplify the volatility impact of fundamental shocks and lead to boom-bust cycles not driven by fundamentals.

In addition to these theories, empirical studies also document the volatility of cryptocurrency prices. Griffin and Shams (2020) investigate whether the largest stablecoin, Tether, influenced bitcoin and other cryptocurrency prices during the 2017 boom of cryptocurrency markets, and they find that purchases with Tether were timed following market downturns and resulted in sizable increases in bitcoin prices. Put differently, Tether was printed regardless of the demand from cash investors and the additional supply of Tether in the market created inflation in the price of bitcoin and other cryptocurrencies.

Kroeger and Sarkar (2017) show that the price of bitcoin varies significantly in the various exchanges around the globe. For example, the maximum absolute price difference ranges between 17 percent for the Coinbase-BTC-e exchange pair and as high as 41 percent for the Bitstamp-BTC-e pair during the same time period 2013–2016. They attribute such violation of the Law of One Price to two main reasons: One is the microstructure frictions such as bid-ask spread, order book depth, and volatility; the other is the use of bitcoin to avoid foreign exchange restrictions, money laundering, and so on. Similarly, Makarov and Schoar (2019) construct an arbitrage index and calculate the arbitrage profits from bitcoin trading across different exchanges and regions. They show that the arbitrage profits from December 2017 to February 2019 was more than $1 billion. In addition, the recurrent arbitrage opportunities in cryptocurrency prices relative to fiat currencies are much larger across regions (the U.S., Japan, and Korea) than within the same region. Liu and Tsyvinski (2018) show that cryptocurrency returns can be predicted by factors specific to the cryptocurrency markets, their finding suggests there is a strong time-series momentum effect and proxies for investor attention strongly forecast cryptocurrency returns. Corbet et al. (2020) examine the recent cybercriminality in cryptocurrency markets and find that cryptocurrency hacking events tend to increase both the price volatility of the targeted cryptocurrency and broad cross-cryptocurrency correlations.

The sudden rise of cryptocurrencies may pose challenges to central banks at many levels. Fernández-Villaverde and Sanches (2019) analyze the impact of cryptocurrencies on monetary policy effectiveness. Their game theory model shows that there exist several equilibria, in which only one of the several equilibria would be stationary, such that the value of all privately issued cryptocurrencies would be stable over time, while other equilibria may be undesirable. Even the best equilibrium (stationary) cannot deliver the socially optimum amount of money supply. Therefore, if the cryptocurrencies become widespread, central banks would have difficulty finding

appropriate intermediate targets for the monetary policy. Unless central banks could find ways to stabilize the supply of cryptocurrencies as individuals, corporations, and financial institutions increase their holdings of cryptocurrencies, the financial system might be less stable. Benigno, Schilling, and Uhlig (2019) examine the scope for global cryptocurrencies to impose restrictions on monetary policies and exchange rates in an international context. They consider a minimalistic two-country setting, encompassing many monetary models in the literature. Under the assumption that the global cryptocurrency is used as a medium of exchange alongside the national currencies in both countries, they show that the short-term nominal interest rate set by the two central banks must be equalized and that the exchange rate between the two national currencies becomes a risk-adjusted martingale. The authors call this Crypto-Enforced Monetary Policy Synchronization (CEMPS), and they argue that it is a sharpened version of the classic Mundell-Fleming Impossible Trinity. They show that even sharper restrictions arise, if the global currency is asset backed, as was planned for the original Libra 1.0 launch. As an option, central banks could consider creating their own central bank digital currencies (CBDCs) to retain control of money supply. We discuss CBDC in greater detail in Section 5.3.

5.2 Initial Coin Offering: Structure, Valuation, and Regulation

Initial coin offerings (ICOs) are mechanisms to raise funds by selling coins or tokens, using blockchain technology, to support a product launch or a new virtual currency. ICOs are a conjunction of crowdfunding and blockchain. Tokens purchased in an ICO give the participant certain rights, most frequently the right to use the platform services that are being developed or ownership rights. The coins can also be exchanged for other cryptocurrencies (and even potentially fiat currencies) on secondary markets. They operate similarly to initial public offerings (IPOs) but typically skirt the usual regulations and restrictions on IPOs. While start-ups have traditionally relied on venture capital to raise funds and grow, ICOs present a more decentralized and democratic alternative. Allen (2020) reviews the development of ICOs in recent years as well as the recent studies on ICOs and documents the advantages of ICOs compared with traditional IPOs. Allen, Fatas, and Weder di Mauro (2020) discuss the rationale for ICOs and the associated regulatory issues. The total capital raised through ICOs was only $16 million across two deals in 2014 and only $6.1

million (USD) across three deals in 2015, but this spiked exponentially in the following two years.[28] The biggest ICO until mid-2018 was priced by EOS (a tech start-up) and raised $4.1 billion (USD).[29]

Reaching a consensus on a formal and complete definition of ICOs is challenging, given a large number of different forms that current ICOs take. Through an ICO, an individual or group of founders can offer a stock of specialized crypto-tokens for sale, usually promising that those tokens would operate as the only medium of exchange when assessing the venture's future products to avoid running afoul of securities laws. The structure of ICOs is based on the offer of digital tokens or coins that use blockchain technology. A typical ICO process starts with a white paper, similar to a prospectus, which describes the financing project and the rights given to the investors. Very often the white paper determines a minimum and a maximum amount of coins that need to be subscribed for the financing project to go live.

The startling growth of ICOs has raised concerns about irrational exuberance. Two central questions are related to how ICOs could be accurately evaluated and priced, and what would be appropriate regulatory responses. A growing literature studies the structure of ICOs. One consistent finding is that the ICO structure could help to solve the coordination problems among investors; see Li and Mann (2018); Cong, Li, and Wang (2018); Bakos and Halaburda (2018); and Catalini and Gans (2018). For example, Li and Mann (2018) present an economic mechanism through which token and ICO structures create values for both entrepreneurs and platform users. In their model, by transparently distributing tokens before the launch of the platform, an ICO can overcome coordination failures during platform operations, in which each user of the platform cares about the activities of his transaction counterparty on the other side. Put differently, in the typical structure of an ICO, when a user purchases a token, the volume of the subscription is publicly observable, given the transparency of the smart contract implementing the ICO. This allows platform users to communicate with other users and in turn motivate them to participate as well.

Sockin and Xiong (2020) document the dual roles of cryptocurrency in the platform: as a member for the transactions and as an initial financing for the platform, which makes ICOs different from traditional project financing mechanisms in the way that investors and business customers are not separated. The outcome is that the trading price and volume of the cryptocurrency not only provide financing of the cryptocurrency, but also directly impact the business operations of the platform. In addition, Bakos and Halaburda (2018) find that token issuance could serve as a low-

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[28] For more data, see the ICODATA website, https://www.icodata.io/stats/2014.

[29] See this report from PricewaterhouseCoopers, https://cryptovalley.swiss/wp-content/uploads/20180628_PwC-S-CVA-ICO-Report_EN.pdf.

cost alternative of financing when the platform faces credit constraints, as its cost of capital increases over time. In doing so, the platform trades off its future revenue for the present. On the other hand, an agency conflict might exist between entrepreneurs and investors, as documented in Chod and Lyandres (2020). When compared with traditional equity or debt financing, an ICO may lead to a better or worse alignment of the incentives with the interests of investors, depending on the characteristics of the venture (Garratt and Oordt, 2019) as well as the tradability of tokens (Bakos and Halaburda, 2019).

The overall empirical evidence on valuation and pricing of ICOs so far suggests that the success of ICOs is determined by an assortment of characteristics of the tokens, entrepreneurs, and underlying projects, but these findings are far from conclusive. Initially there is ex-ante information asymmetry between an entrepreneur and outside investors, resulting in an adverse selection process that could potentially hamper a successful fundraising through ICOs. Howell, Niessner, and Yermack (2019) use a sample of 453 completed ICOs and find that the failure rate is lower for tokens that offer voluntary disclosure via a white paper and provide a signal of quality and potential value of the project. The following factors are also strongly associated with ICO success: professional background of the CEO or the founder, funding experience of the venture capitalist, ICO design choices (e.g., whether using dynamic pricing mechanisms), and social media promotion. In addition to these determinants, Amsden and Schweizer (2018) document that the tradability of tokens or coins as well as the uncertainty and quality of venture (e.g., whether being on Github or Telegram, the length of white papers) also matter. Lee, Li, and Shin (2019) use a sample of 3,400 ICOs and find that the diverse opinions from a number of online analysts form an aggregate signal that predicts the quality of the underlying projects as well as the subsequent token sales. Lyandres, Palazzo, and Rabetti (2020) perform the first systematic analysis of ICO data quality by compiling a comprehensive data set of ICOs from no fewer than 11 ICO aggregators and overturn some findings in prior studies. For example, they find the presence of a bonus is positively associated with funding success, while the length of white papers has only marginally significant impact on ICO funding success. Akyildirim et al. (2020) find that stock prices of companies that announce interest in cryptocurrencies earn a significant premium, suggesting that crypto announcements can be used to manipulate the associated company's stock price. Other related studies on the returns and success of ICOs include Adhami, Giudici, and Martinazzi (2017); Hu, Parlour, and Rajan (2018); Fisch and Momtaz (2020); Momtaz (2020); and Benedetti and Kostovetsky (2018).

Given the nature of entrepreneurs financing through ICOs, particular risks of an ICO include potential fraud such as issuance of scam coins. Scam coins usually establish a Ponzi scheme and rob

investors of their currencies.[30] Some smart contracts for ICOs are artifactual, which does not match the description in the white papers. Cohney et al. (2019) compare smart contracts with the associated white papers for 50 ICOs and find that some popular ICOs have retained the power to modify their tokens' rights in the smart contract but failed to disclose this possibility in the white papers. In addition to the potential fraud issue, price manipulation also exists in the cryptocurrency market. Li, Shin, and Wang (2020) study the "pump-and-dump schemes," a form of price manipulation that involves artificially inflating an asset price before selling cheaply purchased assets at a higher price in the cryptocurrency market and find such manipulations are detrimental to the liquidity and pricing of cryptocurrencies.

More frequent risky events surrounding ICOs are cyberattacks. For instance, the DAO (Decentralized Autonomous Organization) was hacked one month after it was launched.[31] The DAO, built on Ethereum, was an investment entity that aims to raise money through the DAO ICO to fund projects. The DAO was so popular that it raised over $150 million and was the largest crowdfunding project in history.[32] The holders of DAO tokens had the power to select which project to invest in by voting, which was administered by the DAO codes. However, one of the flaws is how the DAO acted as a factory for creating child "smart contracts" that split off from the main DAO to a "child DAO." Shortly after the DAO was launched, a hacker drained a total of 3.6 million Ether (worth around $70 million) into a child DAO that was in the same structure as the parent DAO in a few hours by exploiting the codes repeatedly. Other potential risks of ICOs are associated with the institutional and legal environment in different countries where the ICOs are launched as well as the potential systemic risks (Zetzsche et al., 2019).

In the U.S., the SEC has classified nearly all ICOs as securities, within their competency and authority.[33] Although the SEC has carved out the "utility token" from the security category, certain

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[30] According to *The Economist*, in Vietnam, police are investigating two ICOs (Pincoin and Ifan) run by a firm named Modern tech that are accused of duping investors out of $660 million. See "Initial Coin Offerings Have Become Big Business," *The Economist,* https://www.economist.com/technology-quarterly/2018/09/01/initial-coin-offerings-have-become-big-business. See also Kai Sedgwick, "46% of Last Year's ICOs Have Failed Already," Bitcoin (February 23, 2018), https://news.bitcoin.com/46-last-years-icos-failed-already/; Nathaniel Popper, "S.E.C. Issues Warning on Initial Coin Offerings," *New York Times* (July 25, 2017), https://www.nytimes.com/2017/07/25/business/sec-issues-warning-on-initial-coin-offerings.html.

[31] Shendra Kumar Sharma, "Details of the Dao Hacking in Ethereum in 2016," Blockchain Council (August 2017), https://www.blockchain-council.org/blockchain/details-of-the-dao-hacking-in-ethereum-in-2016/.

[32] See DAO White Paper, https://daostack.io/wp/DAOstack-White-Paper-en.pdf.

[33] The key documents that provide guidance on how the SEC will likely classify any ICO are "The DAO Investigative Report," released in July 2017 (DAO Report) and "Cease and the Desist Order Against Munchee," issued on December 11, 2017 (Munchee Order).

definitions and requirements for utility tokens remain vague and need clarification. Zetzsche et al. (2019) review financial law and regulations on ICOs and crowdfunding in different jurisdictions and explore an appropriate approach to regulate ICOs. In other jurisdictions, China and Korea have both banned ICOs outright, while Switzerland has provided an ICO-friendly model. Singapore, Hong Kong, the UK, and Australia have proposed regulatory warning for ICOs. Bellavitis, Cumming, and Vanacker (2020) show that a regulatory ban of ICOs in one country causes a short-term increase in the number of low-rated ICOs in other countries and a long-term drop in the number of ICOs, suggesting that regulatory cross-border spillovers can occur among countries.

The overall results from the literature (theoretical studies) are consistent with an argument that, while it may be necessary for ICO activities to be regulated, it would not be desirable to completely ban all ICO activities (an approach adopted in China and Korea). Regulators and academics have been working to design the appropriate regulatory framework for ICOs — to curtail ICO scams while continue to encourage fintech innovations. One possible approach to reducing ICO scams is to follow a protocol similar to the Rule 144A restrictions on private placements — ensuring that only qualified investors can participate in ICOs.

5.3 Central Bank Digital Currency (CBDC)

The recent advances in cryptographic and distributed ledger technologies, along with extreme volatility in private digital currencies, have led to a discussion around the possibility of central banks issuing their own CBDCs; see Mancini-Griffoli et al. (2018); Jagtiani et al. (2021); Engert and Fung (2017); Bech and Garratt (2017); Bordo and Levin (2017); Ali et al. (2014). The threats to financial stability by private cryptocurrencies have led to intensive debates among policymakers and monetary economists about whether and how central banks play a role in CBDCs — whether to issue the CBDC or play a supporting role in issuing CBDCs. Based on a BIS survey of central banks, with 63 central bank respondents representing jurisdictions covering close to 80 percent of the world population, Barontini and Holden (2019) show that many central banks are progressing from conceptual work on CBDCs into experimentation and proofs of concept, including cooperating with other central banks. Jagtiani, Papaioannou, and Tsetsekos (2019); Jagtiani et al. (2021); Boar, Holden, and Wadsworth (2020); and Arner, Buckley, Zetzsche, and Didenko (2020) provide a review of CBDCs and highlight several important country experiences with CBDCs.

One of the concerns among central banks in issuing CBDCs is the impact on the banking sector (the risk of a bank run as people would prefer an account with a central bank) and the stability of the financial systems overall. Andolfatto (2018) develops models in which the

introduction of CBDCs would lead to an expansion of bank deposits if CBDCs compel banks to raise their deposit rates. They find that interest-bearing CBDCs generally promote financial inclusion as they diminish the demand for cash. Brunnermeier and Niepelt (2019) model the relationship between bank panics and CBDCs and suggest that whether CBDCs would undermine financial stability depends on the monetary policy accompanying the issuance of CBDCs and on the strength of a central bank's commitment to serve as a lender of last resort. They show that with a strong commitment, the issuance of CBDCs, which are assumed to be the equivalent of a transfer of funds from deposit to CBDC accounts, would give rise to an automatic substitution of deposits by central bank funding (the "pass-through" mechanism). Furthermore, in this case, the issuance of CBDCs would not undermine but rather strengthen financial stability because a depositor run into CBDCs would trigger a pass-through funding automatically and turn the central bank into a large depositor (see also Niepelt, 2020a). Niepelt (2020b) further analyzes a two-tiered monetary system with noncompetitive banks that issue deposits and central banks that issue reserves and (retail) CBDC and derives optimal policy rules: Spreads stratify modified Friedman rules, and deposits must be taxed or subsidized. Similarly, Keister and Sanches (2019) find that issuing CBDCs would enhance efficiency in exchange at the expense of crowding out deposits. The theoretical models in Chiu, Davoodalhosseini, Jiang, and Zhu (2020) and Williamson (2019) suggest that the introduction of CBDCs can enhance competition, expand intermediation, and mitigate crime associated with physical cash. Agur, Ari, and Dell'Ariccia (2020) point out that CBDCs could be designed with attributes similar to either cash or bank deposits, with varying impacts on financial systems. If the CBDC closely competes with bank deposits, it would likely depress bank credit. If the CBDC is designed to be cash-like currency, it could lead to the disappearance of cash. The optimal CBDC design involves a tradeoff between bank intermediation and the social value of maintaining diverse payment instruments. Interest-bearing CBDCs could potentially help alleviate this tradeoff.

Raskin and Yermack (2016) explore the impact of digital currency on the future of central banking and argue that CBDCs could narrow the relationship between retail consumers and the central banks and remove the need for the public to keep deposits in fractional reserve at commercial banks. According to Fernández-Villaverde, Sanches, Schilling, and Uhlig (2020a), assuming that competition among commercial banks is allowed and that depositors do not panic, account-based CBDCs would give consumers the possibility of holding a bank account with the central bank directly. Fernández-Villaverde, Sanches, Schilling, and Uhlig (2020b) provide a richer and nominal version, analyzing an account-based version of CBDCs. Similar to the traditional banking literature, issues of maturity transformation and spending decisions of currency holders

arise. The authors argue that a "run" on the central bank can arise, when more than just the impatient agents seek to spend in the intermediate period. While the central bank can always satisfy the nominal spending requests (akin to deposit withdrawals in the traditional literature), the price level may be affected. The authors show that central banks face an unresolvable conflict among the three objectives of price stability, allocational efficiency, and financial stability, suggesting that the traditional concerns in banking and maturity transformation would be present (but in a slightly altered form) when traditional banking is replaced or complemented by CBDCs. Mehl, Stracca, and Ferrari (2020) examine open-economy implications of the introduction of CBDCs and find that the presence of CBDCs could amplify the cross-border spillovers of shocks in a significant way; for example, risk-free rates in foreign economy would move more strongly and could lead to tighter financial conditions in foreign countries. The magnitude of such effects depends crucially on the design of the CBDC, including whether there are tight restrictions on CBDC transactions by foreigners.

Brunnermeier, James, and Landau (2019) review the ongoing digital revolution as well as its impact on the traditional model of monetary exchange. They suggest that in a digital economy in which most activities are conducted through networks with their own monetary instruments, CBDCs would open up a direct channel by which monetary policy could be transmitted to the public and permit the central bank's unit of account to remain relevant in a fast-changing digital economy. Overall, CBDC proponents highlight that CBDCs would improve the safety and efficiency of the financial and payment systems as well as increase central banks' controlling power over monetary policy. Critics, however, raise concerns about the significant risks that CBDCs might bring to the rest of the financial system.

6. Fintech, Trading, and Algorithmic Investment Strategies

6.1 High-Frequency Trading

Over the last decade, the forces of technology have increasingly shaped the market structure and trading behavior. One type of computerized trading that attracted the most attention is high-frequency trading, which was largely absent in 2001 but participated in about 50 percent of the trading activities by 2010 (Securities and Exchange Commission, 2010). In the meantime, liquidity has improved, and transaction costs to end users have declined substantially in this period. The bid-ask spread that investors paid on market orders, which is a measure of trading costs for retail investors, was reduced. And the implementation shortfall, which is a measure of transaction cost

for large institutional investors, was also largely reduced from 2001 to 2011; see Menkveld (2016), Jones (2013), and Linton and Mahmoodzadeh (2018).

While there is no formal definition for high-frequency trading (HFT), the SEC (2010) identifies some features that often are attributed to HFT, such as the use of extraordinarily high-speed and sophisticated algorithms, the use of co-location services and individual data feeds, the very small and short-lived positions in margin accounts, and the submission of numerous orders and cancelling quickly. HFT represents a large subset but not all of algorithmic trading, which is generally defined as the use of computer programming to make decisions about order submissions and cancellations.[34] Menkveld (2016), Jones (2013), O'Hara (2015), and Kirilenko and Lo (2013) provide a review of the types of high-frequency traders and trading strategies.

O'Hara (2015) makes a point about the complexity of information in a high-frequency age. In a high-speed and co-located world, information is not just asset related but also order related. Being informed is multidimensional, meaning that informed traders can be seeing and acting on market prices faster than competitors or know more about the assets or the markets. A key question is whether HFT can benefit market quality or hurt it. If HFT is a faster-acting agent as it can trade on new information instantly before it becomes available to others, adverse selection is more severe and market quality decreases (Biais, Foucault, and Moinas, 2015; Foucault, Hombert, and Rosu, 2016; Du and Zhu, 2017). However, if HFT is a better-informed agent, then liquidity improves (Ait-Sahalia and Saglam, 2013; Goettler, Parlour, and Rajan, 2009).

In theory, this tradeoff is documented in Jovanovic and Menkveld (2016) that, if HFT is both an informed and fast agent, it can update limit orders quickly based on new information as it has both information and speed; therefore, HFT can avoid some adverse selection and further provide benefits to uninformed traders who need to trade. An implication is that we need to be careful when interpreting lower bid-ask spreads as better market quality because this may be driven by other traders who are not able to earn the spread through posting limit orders.

Empirically, there has also been evidence on the effects of HFT. Some researchers use specific market structure changes to identify the causal and positive effects of HFT on market quality. For example, Hendershott, Jones, and Menkveld (2011) employ the implementation of an automated quote at the New York Stock Exchange in 2003 and show that at least for large-cap

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[34] In SEC (2010) and SEC (2014), algorithmic trading (AT) encompasses a broad range of activity that includes particularly large-order execution algorithms often used by or on behalf of institutional investors. These algorithms slice large orders into many small pieces that are fed into the marketplace over time. This type of algorithmic trading is not classified as HFT; the time horizon of trading is far beyond the short time frame of HFT. Li, Wang, and Ye (2020) study the competition for liquidity provision between higher-frequency traders and slower execution algorithms designed to minimize investors' transaction costs.

stocks in that period, an increase in algorithmic trading resulted in an improvement in stock market liquidity. Using the September 2008 short-sale ban, Brogaard, Hendershott, and Riordan (2017) find that HFT's short selling is detrimental to liquidity, driven by HFTs adversely selecting limit orders and by a decrease in competition for liquidity provision. Menkveld (2013) examines the entry of high-frequency market makers into the trading of Dutch stocks in July 2007 and find that because of the higher degree of competition, compared with untreated Belgian stocks, the bid-ask spreads of Dutch stocks are about 15 percent narrower, and adverse selection is also less. Aitken, Cumming, and Zhan (2015) show the presence of HFT significantly mitigated the frequency and severity of end-of-day price dislocation. Gai, Yao, and Ye (2014) use data from two Nasdaq technology upgrades in 2010 and find that there is little change in bid-ask spreads and market depths, suggesting there could be diminishing liquidity benefits. Using evidence on the London Stock Exchange and NYSE Euronext Paris over the period 2004 to 2011, Aitken et al. (2018) show that greater algorithm trading is associated with increased transactional efficiency and reduced information leakage in top quintile stocks, and that there is a tradeoff between fairness and efficiency in the process. The effect of HFTs on price discovery is also documented in Brogaard, Hendershott, and Riordan (2014) and Brogaard, Hendershott, and Riordan (2019).

One of the most salient trends in securities markets has been the fragmentation in the trading system (Menkveld, 2016). Without a central market, traders need to search for liquidity across different venues, in which the high-frequency traders are specialized. Existing studies find that an increase in trading fragmentation is associated with lower costs and faster execution speed in a given asset class (Foucault and Menkveld, 2008; O'Hara and Ye, 2011; Degryse, De Jong, and van Kervel, 2015). Pagnotta and Philippon (2018) find that competition among venues increase investor participation, trading volumes, and allocative efficiency; but in the meantime, there could be excessive fragmentation and inefficient execution speed, suggesting that the welfare consequences depend critically on the ability to impact entry decisions and that sound regulations would be important. Baron, Brogaard, Hagstromer, and Kirilenko (2019) find empirical evidence that differences in relative latency account for large differences in HFT firms' trading performance.

Overall, evidence strongly indicates that HFT is good for average market quality. However, its impact on market quality in stressed conditions is a concern to both regulators and investors. On May 6, 2010, in the course of 33 minutes, starting from 2:32 p.m. EST, the U.S. stock market experienced one of the most turbulent periods in the history known as the Flash Crash. Kirilenko, Kyle, Samadi, and Tuzun (2017) analyze the Flash Crash using the audit trail data for all 15,000 accounts that traded the E-mini that day. They find that HFT did not trigger the Flash Crash, but

their responses to the extreme selling pressure exacerbated the price decline. Basically, what high frequency traders did was buy contracts from fundamental sellers in the E-mini during the price decline and then sold contracts and competed for liquidity with fundamental sellers. Kirilenko, Kyle, Samadi, and Tuzun (2018) further find that the trading activity of high-frequency traders is distinct from that of a traditional market maker. The direction of HFT precedes price changes, while the activity of market makers does not. However, the SEC (2014) points out that Kirilenko, Kyle, Samadi, and Tuzun (2017) did not capture more than one-third of the total HFT activities in the E-mini during the Flash Crash. Easley, Lopez de Prado, and O'Hara (2011, 2012) use intraday data and find that order imbalance was severe in the minutes just before the Flash Crash, confirming that HFT and other trading intermediaries were overwhelmed by selling pressure. Another recent market glitch associated with HFT occurred with trading errors by Knight Capital, one of the largest market makers for U.S. equities on August 1, 2012. A new trading algorithm introduced by this HFT firm rushed into service without sufficient testing and caused a large accumulation of stock positions over about 45 minutes at the start of the trading day. Knight Capital lost $456.7 million from liquidating the positions in the end, wiping out its capital.

These types of trading errors and extreme events call for more HFT regulations. The benefits of automation and other new technology in financial markets are indisputable, but they need to be evaluated and sufficiently tested. Several initiatives have been proposed by regulators and academics, including a real-time consolidated order-level audit trail (Jones, 2013), a required minimum time-in-force for orders (SEC, 2010), and small securities transaction taxes; see Mehta (2013) and Kirilenko and Lo (2013). Kirilenko and Lo (2013) further propose some principles for an advanced financial regulatory framework in the Digital Age that they refer to as Financial Regulation 2.0. We will discuss the regulatory issues further in Section 8.

6.2 Quantitative Investment Strategies

In recent years, there has been considerable hype concerning the use of sophisticated computer-based and AI/ML techniques for quantitative investment strategies. Many have argued that this would be the future of investment management. We have been here before. Allen and Karjalainen (1999) use a genetic ML algorithm to learn technical trading rules for the S&P 500 Index using daily prices from 1928 to 1995, and they confirm that the stock markets are efficient in the sense that it is not possible to make money after transaction costs when using technical AI/ML trading rules. The rules were useful in identifying periods to be in the market when returns were high and

volatility was low and out of the market when the reverse was true, consistent with Brock, Lakonishok, and LeBaron (1992).

Empirical evidence so far suggests that quantitative investment management strategies tend to work well in stable market environments[35] but often work poorly during a crisis or unforeseen shocks. An example is the Quant Meltdown during the week of August 6, 2007 (see Khandani and Lo, 2007; Kirilenko and Lo, 2013), when some of the most successful hedge funds suffered unprecedented losses. It appeared that the losses were concentrated among "quantitative equity market neutral" or "statistical arbitrage" hedge funds (Khandani and Lo, 2011). More recently, more computer resources, big data, and statistical tools such as the AI/ML algorithms have been applied in investments. Ozik and Sadka (2014) show how hedge funds and other investors use big data to improve their information advantage. However, there is a dark side of these powerful techniques. When misapplied, these techniques can lead to false discovery and disappointment. For example, Arnott, Harvey, and Markowitz (2019) point out that, unlike in physical and biological sciences, data are much more limited in scope in investment finance, which might be too small for most AI/ML applications and impossibly small for advanced deep learning approaches. Dugast and Foucault (2018) document that new data providers for unstructured data can reduce price informativeness eventually because it reduces the demand for more precise signals (e.g., fundamental analysis). Information processing can filter out the noise in data, but it takes time. Low-precision signals are available before high-precision signals, and therefore, the cost of low-precision signals decline. Lopez de Prado (2018) raises 10 pitfalls and proposes solutions to the concerns around the application of AI/ML in investment and finance.

One interesting question regarding the application of computer and advanced technologies in investment is why quantitative investment strategies produce a better alpha (a measure of excess returns). One of the most important aspects of such investment strategies for both buyers

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[35] There has been a growing literature on machine learning (ML) and asset pricing. For example, to deal with high-dimensional data, some studies use penalized regressions, such as LASSO, to predict stock returns (e.g., Freyberger, Neuhierl, and Weber, 2020; Feng, Giglio, and Xiu, 2020; Kozak, Nagel, and Santosh, 2020; Chinco, Clark-Joseph, and Ye, 2019). Dessaint, Foucault, and Fresard (2020) find that the usage of big data can impair the quality of analysts' long-term forecasts. Apart from this, ML has also been applied in corporate finance studies. Techniques (e.g., natural language processing) have allowed scholars to use unstructured data to capture the features missing in traditional measures. For example, Kelly, Manela, and Moreira (2019) develop an economically motivated high-dimensional selection model that improves learning from text. Loughran and McDonald (2020) provide an updated review of the literature in finance using textual analysis (related to social media, political bias and detecting fraud). Cao et al. (2020) show that increasing the ML/AI readership, proxied by Machine Downloads, leads firms to prepare their disclosures and filings that are more friendly to machine readability. In addition to textual analysis, some work has been conducted on voice processing (e.g., Mayew and Venkatachalam, 2012).

and sellers of the products is to understand whether and how they produce excess returns. Are they simply reallocating returns across states of outcome so the returns look good most of the time but melt down occasionally? Are there missing risk factors that are not modeled properly so it seems there is an excess return but in fact there is not? Financial crises, which have low probability but high impact, are another possible form of this type of risk. Risks can also be endogenous if a new strategy appears promising and is simultaneously adopted by many investment firms so that the environment changes and new types of risk arise. When these firms all try to exit together, prices change in unexpected ways. Are there market imperfections that the strategy is helping to get around so excess returns come from increased efficiency? Quantitative investment strategies using AI/ML could help to overcome market imperfections through reduced transaction costs and improved diversification or carry trades.

6.3 Investment Advisors, Wealth Management, and InsurTech

Online wealth management platforms providing investment advice driven by algorithms (more commonly called *robo-advisors*) have emerged to replace or complement traditional (human) investment advisors. Robo-advisors leverage data provided by investors to construct and manage a tailored appropriate investment portfolio for them. Since the first major service launched by Betterment in 2010, this market has grown rapidly, accumulating nearly $45 billion in assets under management (AUM).[36] Later, witnessing the success of independent robo-advisors, traditional money managers have also started launching services that work in tandem with the products they conventionally offer.[37] A typical robo-advisor platform consists of three phases: (1) the initial investor screening, (2) investment strategy implementation, and (3) monitoring and rebalancing the strategy.

For the initial client intake and screening, robo-advisors provide automated in-app or online questionnaires, including general questions about clients' financial preferences and goals; the robo-advisors could then build a profile of the client's financial goals, investment strategies, and risk tolerance on that information. Then robo-advisors will select targeted assets and curate a

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[36] Since it launched, Betterman has raised over $200 million in equity funding and has over $9 billion in AUM. Wealthfront, the second-largest independent robo-advisor to date, has raised about $130 million in equity and has over $6 billion in AUM. It is widely expected that the robo-advice market will continue to skyrocket. A particularly aggressive projection predicts that robo-advisors will have $5.0 trillion to $7.0 trillion in AUM by the year 2025 (https://hbr.org/2018/01/robo-advisers-are-coming-to-consulting-and-corporate-strategy).

[37] For example, Charles Schwab and Vanguard were the two pioneers in providing robo-advising services in line with their other advising products (see, e.g., https://smartasset.com/retirement/the-top-10-robo-advisors).

personalized portfolio based on the client profile. Currently, most robo-advisors implement passive investment strategies, including strategies using exchange-traded funds (ETFs) as baseline investments.[38] Finally, robo-advisors would monitor and rebalance a client's investment portfolio to ensure the portfolio risk does not exceed clients' preferences while simultaneously taking advantage of price changes in the market. Compared with traditional human financial advising, the key promise of robo-advising is evident: delivering convenient and unbiased financial advice at significantly lower cost.[39]

Based on an automated portfolio optimizer introduced by a brokerage firm to its clients in India, D'Acunto, Prabhala, and Rossi (2019) examine the determinants of using robo-advising and the effects. While users and nonusers are indistinguishable along several demographic characteristics, including gender, age, and trading experience, users are generally more sophisticated and usually have a larger amount of investment funds than nonusers. In addition, undiversified investors could benefit more from robo-advising, and their market-adjusted investment performance could improve significantly. Robo-advisors can reduce pervasive behavioral bias and cognitive litigations that traditional human financial advisors might have (Linnainmaa, Melzer, and Previtero, 2017), such as the disposition effect, trend chasing, and the rank effect. Rossi and Utkus (2020) examine the effects of the largest U.S. robo-advisor, Vanguard Personal Advisor Services (PAS), on investment performance and find that, on average, it reduces holding in money market mutual funds and increases bond holdings, while it increases investors' international exposure and mean risk-adjusted performance. Investors with little investment experience seem to benefit the most from robo-advising. Hodge, Mendoza, and Sinha (2018) examine the investment judgment of humanizing robo-advisors and find that investors are more likely to follow the advice of a robo-advisor when the advisor exhibits fewer human features. Moreover, investors are more likely to follow the advice of a named human advisor compared with an unnamed human advisor; while investors are less likely to follow the advice of a named robo-advisor compared with an unnamed robo-advisor. Overall, advisors' credibility will mediate how likely investors are to follow their recommendations.

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[38] It is reported that active management robo-advising strategies (typically hybrid solutions) have a growing presence in the marketplace (see, e.g., https://money.usnews.com/investing/investing-101/articles/2018-10-17/should-i-use-an-actively-managed-robo-advisor).

[39] According to Ringe and Ruof (2019), with comparative advantage through economies of scale, robo-advisors charge lower fees on average between 0.4 percent (mainly in the U.S.) and 0.8 percent (mainly in Europe), whereas the fee for human financial advice usually amounts to 1 percent to 2 percent.

Robo-advising makes access to financial advice available at a lower cost, mitigates under-diversification, and improves investment performance; however, it might be subject to conflict of interests and other potential risks. Baker and Dellaert (2018) argue that because robo-advisors are designed and implemented by humans, we cannot always expect an ideal robo-advisor in terms of honesty, competence, and suitability. Despite the difference between robo-advisors and human advisors, they are currently regulated under the same statutory framework — under the Investment Advisers Act of 1940 (in the U.S.) and the Market in Financial Instruments Directive (MiFID) framework (for the EU). A narrative, driven by academia and lawyers, argues that robo-advisors are inherently incapable of meeting the Investment Advisers Act standards; i.e., the fiduciary duty (duty of care and duty of loyalty obligations).[40] For example, some critics argue that using an electronic questionnaire to gather information from clients without further confirming its accuracy are not enough to satisfy the investment advisor duty of care (e.g., Fein, 2015). Others criticize that robo-advisors lack human perceptions and are not equipped to address market failures (Fein, 2015).[41]

Ji (2018) argues that concerns about conflicts of interest associated with robo-advising could be quite severe because of bias in the algorithms that reflects a firm's existing conflicts of interest. However, traditional human advisors may also be influenced by outside incentives. Recently, both the SEC and the Financial Industry Regulatory Authority (FINRA) have directly addressed some of the ambiguity, with respect to how robo-advisors fit into the current regulatory structure through a series of guidelines. For example, the SEC recommends that robo-advisors provide a concise explanation of their business model (because of the unique nature of their business) and fully disclose all fees and other charges.[42] It remains unclear whether the current rules are effective in dealing with the risks and challenges of robo-advising. Ringe and Ruof (2019) and Financial Conduct Authority (2017) propose a regulatory sandbox, an experimentation space, which would allow market participants to test robo-advising services in the real market, with real

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[40] The fiduciary duty required by the Investment Advisers Act of 1940 means that advisors must (1) take the reasonably necessary steps to avoid misleading clients, (2) provide full and fair disclosures to their clients and prospective clients of all material information, and (3) eliminate, or at least disclose, all conflicts. See https://www.sec.gov/investment/im-guidance-2017-02.pdf.

[41] See also Samantha Sharf, "Can Robo-Advisors Survive a Bear Market?" available at https://www.forbes.com/sites/samanthasharf/2015/01/28/can-robo-advisors-survive-a-bear-market/#243f981ce7ec; Michael Wursthorn and Anne Tergesen, "Robo Advisor Betterment Suspended Trading During 'Brexit' Market Turmoil," available at https://www.wsj.com/articles/robo-adviser-betterment-suspended-trading-during-brexit-market-turmoil-1466811073.

[42] See SEC, *Investment Management Guidance*: *Guidance Update*, No. 2017-02 (February 2017), https://www.sec.gov/investment/im-guidance-2017-02.pdf.

consumers, but under close scrutiny of supervisors. Such a sandbox can allow for mutual learning for both the firms and regulators and reduce regulatory uncertainty for all market participants.[43]

Insurance technology, manifested as InsurTech, is a subset of fintech dedicated to the insurance industry. The insurance industry has access to a large amount of data, which would be critical for the application of complex algorithms like AI/ML methods. With big data and advanced techniques, more precise measurements of underlying insurance risk can be estimated. Insurers could have better protection against operational risks, such as preventing insurance fraud or money laundering. Customers can also have a wider range of better tailored products and services. Massive investment funding in the form of mergers and acquisitions, venture capital, and private equities have flowed into the InsurTech industry. Over $35 billion was raised by InsurTech companies from 2016 to 2019 through 852 deals.[44] Geographically, the InsurTech industry has been dominated by the U.S. since 2012. China, Germany, the UK, and France are the other top InsurTech markets.[45]

Lin and Chen (2019) examine the potential risks associated with the application of InsurTech as well as the possible regulatory solutions. The risks come from the general use of technology, such as cybersecurity, data protection, consumer privacy issues, and other special features related to the insurance industry. Addressing fraud risk is key to online business models for InsurTech providers. They propose a "meta-regulation" approach: Regulated firms write a set of rules tailored to the firms themselves, and these rules are subject to further scrutiny and approval by a regulatory agency. Thakor (2020) briefly discusses the development of InsurTech. By applying the new methods, overall, InsurTech firms are believed to be able to provide better calibrated risk assessment and pricing, with less pooling across customers with heterogeneous but ex-ante indistinguishable risk profiles.

7. Cybersecurity

Cyber-risk has become one of the most important sources of risks for corporations. Recent surveys by PricewaterhouseCoopers (PwC) from 2017 to 2019 show that more than half of the CEOs expect

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[43] See Section 8 for more about the regulatory sandbox.

[44] See Willis Towers Watson, 2020, Quarterly InsurTech Briefing Q4 2019, https://www.willistowerswatson.com/en-GB/Insights/2020/01/quarterly-insurtech-briefing-q4-2019.

[45] In the third quarter of 2019, China contributed 13 percent of the total InsurTech deal activity, driven by an increased interest from start-ups contributing to the growth of China's health insurance industry. See Willis Towers Watson, 2019, Quarterly InsurTech Briefing Q3 2019, October, https://www.willistowerswatson.com/en-US/Insights/2019/10/quarterly-insurtech-briefing-q3-2019.

cybersecurity and data breach incidents to threaten stakeholder trust in their industries in the near future.[46] On top of that, the financial industry has witnessed the most incidents with data losses.[47] As documented in previous sections, while the advanced financial technology brings efficiency gains for financial institutions and improves financial inclusion, it has also increased the sophistication of attacks, making it harder and more complex to prevent. The increased cyber-risks because of the advanced financial technology can take multiple forms, including cyber-risks related to the data-sharing process such as data aggregation through an open API. This allows third-party vendors to access consumer data directly from their bank account. There has been increased vulnerability, especially when the interfaces between the two systems are not compatible (e.g., not designed around the same time period and often because of limitations of the banks' legacy technology). It is increasingly difficult to thoroughly identify all potential sources of vulnerability in the systems as the processes are usually more time consuming and expensive.

The various financial applications that allow consumers to transfer funds and make payments through voice or facial recognition also increase cyber-risk. There have been several incidences of successful cyberattacks, including an incident in February 2016 when hackers stole $81 million from the Central Bank of Bangladesh, through a transfer fraud via compromised SWIFT servers.[48] The SEC's EDGAR system was also hacked by a Ukrainian hacker using deceptive hacking techniques in 2016. The extracted EDGAR files that contain nonpublic earnings information was passed to individuals who used it to trade in the narrow window before the companies released the news to the public, resulting in at least $4.1 million of illegal profits.[49]

Another well-known cyber incident is the Equifax hack in September 2017, in which the hackers exploited a vulnerability in the software that Equifax uses to build its websites to steal customer names, Social Security numbers, birthdates, and addresses, affecting 147.7 million Americans. Later in July 2019, the Amazon Alexa and CapOne data breach exposed credit card application data for those who applied for cards between 2005 and 2019, affecting roughly 100 million individuals in the U.S., and 6 million customers in Canada. Many cryptocurrency exchanges

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[46] For more details, please see "Risk in Review Study" by PwC from 2017 to 2019.

[47] See Verizon, 2019, *Data Breach Investigations Report 2019*, Verizon, https://enterprise.verizon.com/resources/reports/dbir/.

[48] For more details, see https://www.ft.com/content/39ec1e84-ec45-11e5-bb79-2303682345c8 and https://www.reuters.com/investigates/special-report/cyber-heist-federal/.

[49] In January 2019, the SEC charged the nine defendants in the EDGAR hacking case: a Ukrainian hacker, six individual traders in California, Ukraine, and Russia, and two entities. For more details, see https://www.sec.gov/news/press-release/2019-1.

have also been shut down because hackers were able to steal assets from the exchange systems. Finally, cloud computing, which is an enabler of the fintech ecosystem (payment gateways, digital wallets, secured online payments rely on cloud-computing services) also resulted in new types of risk, especially cyber-risks.

Most direct costs related to cyber incidents, such as the cost of forensic investigation, legal assistance, customer notification and post-breach customer protection, and other measures, are relatively well understood and easy to measure. However, some of the *indirect* costs, such as the reputation risks of brand names, negative shock to existing customer relationships, or depreciation of intellectual property value are often far less visible, more long term, and more difficult to quantify. Therefore, there can be significant uncertainty surrounding the potential impact of cyber incidents, as documented in Kopp, Kaffenberger, and Wilson (2017).

Who are more likely to be targets of cyberattacks? Using the data breach events caused by cyberattacks reported to the Privacy Rights Clearinghouse (PRC) over the period 2005 to 2017, Kamiya et al. (2018) find that firms are more likely to be attacked when they are larger, less financially constrained, more highly valued, have more intangible assets, and operate in less competitive industries. Firm-level corporate governance characteristics, such as features of the board, are not found to predict the likelihood of cyberattacks.

Conventional wisdom suggests that hacking events would have some negative and sticky influence on firms' reputations and henceforth on growth prospects. Recent studies confirm this prediction and find that a firm's stock price drops upon the announcement of a serious cybersecurity breach. Lin, Sapp, Rees-Ulmer, and Parsa (2019) show that there is an abnormal return of -1.44 percent in the five-day window surrounding the public announcement of a data breach, and such price decline does not reverse over the following month. Amir, Levi, and Livne (2018) document that firms may underreport the cyberattacks, and investors cannot discover most attacks independently. For the withheld attacks, the negative abnormal return in the stock market (3.6 percent) in the month when the attack is discovered is higher than that of the disclosed attacks (0.7 percent). Tosun (2020) find that upon corporate announcements on a cybersecurity breach, daily excess returns drop, and trading volume increases in the short run. Kamiya et al. (2018) document a significant mean cumulative abnormal return of -0.84 percent during the three-day window around cyberattack announcements, which can be translated into an average value loss of $495 million per attack. Lin, Sapp, Rees-Ulmer, and Parsa (2019) find significant evidence of opportunistic insider trading in the three months prior to cybersecurity breach announcements.

In a relative long-run scenario, existing studies find that firms adjust their investment and financial policies in response to cyberattacks. Kamiya et al. (2018) document that attacks in which personal financial information is appropriated are associated with a decrease in sales growth for large firms and retail firms, with an increase in leverage and debt maturity, but with a weak deterioration in financial deficit and capital expenditure. Firms also further respond by reducing CEO risk-taking incentives and strengthening their risk management. Consistently, Tosun (2020) also finds weak evidence of a negative impact on cash flows and operating performance upon cybersecurity incidents.

The true costs of a cybersecurity breach could be huge, yet the market could fail to provide a socially optimal level of security because of information asymmetries, externalities, coordination failures, and barriers to entry (Kopp, Kaffenberger, and Wilson, 2017). It remains unclear what the best policy response to cyber-risk should be, including how to design ex-ante regulation and assign ex-post liability. Moreover, cyberattacks raise issues about jurisdiction as warfare in cyberspace pays little regard to national boundaries. So far, there remains neither clear nor meaningful international consensus on the sovereignty and jurisdiction issues relating to cyberattacks nor on the governance of cyberattacks (Lin, 2016).[50]

8. Cloud Computing and the Roles of BigTech

A key driver behind the recent explosion of data is the concomitant growth of computing power as well as cloud servicing. Cloud storage and cloud computing have allowed a large volume of information to be stored cheaply on external, third-party, Internet-based servers. By using cloud services, incumbent systems are increasingly open and operate on a shared rather than closed basis. The Financial Conduct Authority (FCA) in the UK issued guidance on financial institutions' use of cloud storage facilities in 2016.[51] The UK challenger bank, OakNorth, became the first bank in the UK to transfer its core systems into the cloud by using Amazon's Web Services (AWS) in 2016.[52]

Fintech was previously defined by the Financial Stability Board (FSB) as a "technologically enabled financial innovation that could result in new business models, applications, processes, or

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[50] For example, the U.S. generally prefers a multiple stakeholder model of cybergovernance in which states, international organizations, and private actors all play a role in governance, while China and Russia generally prefer a sovereign-oriented model that gives individual states most of the power.

[51] See Financial Conduct Authority (FCA), *Finalized Guidance for Firms Outsourcing to the "Cloud" and Other Third-Party in IT Services*, July 2016.

[52] See E. Dunkley, "OakNorth Takes UK Banking into the Cloud," *Financial Times*, May 26, 2016, https://www.ft.com/content/36c4eba2-2280-11e6-9d4d-c11776a5124d.

products with an associated material effect on financial markets and institutions and the provision of financial services."[53] After 2008, a new era of fintech has been marked by the arrival of a wave of the new fintech start-ups, including LendingClub, Prosper, PayPal, Venmo, Square, Plaid, and Credit Karma. A new term, *BigTech*, created later, refers to large existing firms with the primary business in providing digital services rather than mainly in financial services (Frost et al., 2019). In other words, fintech companies operate primarily in the financial sector, while BigTech firms offer financial products only as a subsector of their main businesses. Amazon, Google, Microsoft, Uber, Tencent, and Alibaba are examples of BigTech firms that offer various forms of payment, lending, or other financial services. The activities of BigTech firms in credit provision are so far the most pronounced in China and have been growing in other jurisdictions as well, though on a smaller scale. Frost et al. (2019) show that BigTech firms usually start with payments and then expand into credit provision, insurance, and savings and investment products.

        Stulz (2019) reviews the recent development in fintech and BigTech and compare them with traditional banks. He defines fintech as the use of digital technologies and big data to enhance existing financial services. Given this definition, fintech firms compete with banks for specific financial services; fintech firms are relatively lightly regulated, not part of inflexible organizations, and not saddled with legacy IT systems. BigTech firms are technology companies whose business model is focused on exploiting digital technologies. They have potential big advantages compared with banks and fintech firms; they not only have all the technical knowhow and up-to-date systems that fintech companies aspire to, but also the scale that large banks have. Other than these benefits, they also have access to a wide range of data that banks and fintech firms do not have access to, but they do not have the legacy or the organizational issues. All these advantages might allow BigTech firms to replace traditional banks (see also Frost et al., 2019). Cornelli et al. (2020) show that the flow of capital raised through fintech and BigTech reached $223 billion USD and $572 billion USD in 2019, respectively. China, the U.S., and the UK are leading countries in fintech credit, while BigTech credit is growing quickly in Asia (including China, Japan, Korea) and some African and Latin American countries.

        Other than competing with incumbent financial institutions, there are also other forms of interactions between BigTechs and traditional banks. In many cases, BigTech firms are important third-party service providers to financial institutions. Amazon AWS, Microsoft, and Google are all large providers of cloud services to many financial institutions. Ali Cloud, an affiliated firm of Ant

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[53] See Financial Stability Board, 2017. *Financial Stability Implications from FinTech*, https://www.fsb.org/wp-content/uploads/R270617.pdf.

Financial, is a dominant player in the Asian market. Pierri and Timmer (2020) shows that the IT budget and the usage of cloud computing in banking before the financial crisis can lead to 10 percent fewer nonperforming loans during the global financial crisis and help improve financial stability. There has also been evidence that BigTech firms have helped to promote financial inclusion. For example, using proprietary (alternative) data on small businesses' credit and payment activities through BigTech firms (BigTech Credit) in Argentina and China, Frost et al. (2019) find that firms with access to credit through BigTech firms were able to expand their product offering, resulting in significant growth. There have been, however, concerns around the impact on financial stability and consumer welfare as a large number of financial institutions rely more on a few large cloud-service providers.[54] Efforts have been devoted to building infrastructure in a more coordinated fashion (for compatible systems), allowing firms to switch instantaneously from one cloud-service provider to another without major interruption to the financial and payment systems. However, the future remains uncertain regarding the overall impact — much depending on the regulatory design to protect financial stability and consumers while also promoting efficiency through fintech innovations.

9. Regulation of Fintech

Prior to the global financial crisis in 2008, financial innovation was viewed very positively, resulting in a laissez-faire and deregulatory approach to financial regulations. After the crisis, fintech and data-driven financial services providers profoundly challenged the current regulatory paradigm. Financial regulators are seeking to balance the competing objectives of promoting innovations, financial stability, and consumer protection. In this section, we review recent development in regulating fintech, especially how technology is playing an ever-increasing role in financial regulation itself.

9.1 RegTech

RegTech, a contracted term of *regulation*s and *technology*, describes the use of technology in the context of regulatory monitoring, reporting, and compliance (e.g., Zetzsche et al., 2017; Arner,

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[54] For example, Mano and Padilla (2019) propose that, in the long run, the entry of BigTech platforms may monopolize the origination and distribution of loans to consumers and small/medium-sized enterprises, forcing traditional banks to become "low cost manufacturers," which merely fund the loans intermediated by BigTechs — this situation could potentially harm competition and consumer welfare.

Barberis, and Buckley, 2016b).[55] A defining feature of RegTech is that it shifts supervision by humans to supervision by machines and analysis of data. After the 2008 global financial crisis, the cost of regulatory obligations has dramatically increased, providing a strong economic incentive for more efficient reporting and compliance systems to better control risks and reduce compliance costs. For example, in 2009, the SEC created the division of Economic and Risk Analysis, to use data insights for better regulation. The Bank of England highlighted some specific technologies currently used in financial regulations, such as pattern analysis, which can be used to identify unusual patterns of activity such as "spoofing," front running, and wash trades; big data analysis, which typically uses a much larger set of inputs than standard surveillance techniques; predictive coding, which looks to identify patterns of activity; or digitalization of voice communications, which could be more effective than written communications.[56] Nasdaq also uses data-driven approaches via SMARTS trade surveillance system to monitor trading.[57]

Looking forward, the next stage of the development of RegTech is likely to be driven by regulators' efforts to increase their supervisory capacity, using techniques such as AI/ML and deep learning (Arner, Barberis, and Buckley, 2016b). For instance, a close to real-time surveillance system is proposed by the Bank of England when discussing the future of regulation.[58] Auer (2019) proposes a new concept called Embedded Supervision (ES) and shows that DLT could be used to ensure high-quality and low-cost compliance. The ES would allow supervisors to verify compliance with regulatory goals by reading the market's distributed ledger without the need for businesses to actively collect, verify, and deliver the data, therefore, reducing the costs of regulations. In the DLT-based market, data credibility is assured by economic incentives, whereas in today's compliance process, trustworthiness is guaranteed by relevant authorities and the threat of legal penalties.

RegTech has also been developed within major financial institutions and fintech firms. Recent leading examples include compliance requirements in the financial industry, such as for AML and KYC. The AML regulations are a legislative attempt to prevent the practice of generating

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[55] Wall (2018a) discusses some of the benefits and limitations of applying machine learning to supervisory issues.

[56] See C. Roxburgh, M. Shafik, and M. Wheatley, 2015. *Fair and Effective Market Review: Final Report, Bank of England*, June 10, 2015, https://www.bankofengland.co.uk/report/2015/fair-and-effective-markets-review---final-report.

[57] For more details, see https://www.nasdaq.com/solutions/nasdaq-trade-surveillance.

[58] See A. Haldane, 2014. *Managing Global Finance as a System*, Bank of England, October 29, 2014, https://www.bankofengland.co.uk/-/media/boe/files/speech/2014/managing-global-finance-as-a-system.pdf?la=en&hash=93BF6D650AAE5D055618D2D2DBC5870DC0580FA7.

income through illegal actions or to conceal criminal origin and true ownership. While not mentioning money laundering specifically, the Bank Secrecy Act of 1970 essentially laid the groundwork for what would become the "anti-money laundering complex" that governs a substantial portion of financial law enforcement today. For example, for insured banks and financial institutions, the act imposed a duty to maintain records of "the identity of each person having an account in the U.S. with the bank and of each individual authorized to sign checks, make withdrawals, or otherwise act with respect to any such account." The decades afterward saw the Money Laundering Control Act of 1986, Annunzio-Wylie Anti-Money Laundering Act of 1992, the Money Laundering and Financial Crimes Strategy Act of 1998, and the USA PATRIOT Act of 2001. Internationally, an intergovernmental organization called the Financial Action Task Force (FATF) on Money Laundering was launched in 1989, establishing international soft law standards that address money laundering and terrorist financing.[59] The FATF rules were implemented by financial institutions in most jurisdictions as well as infrastructure providers such as SWIFT and CLS.

From a standpoint of compliance, AML requires that every client or potential client of a financial institution must be reviewed under the KYC due diligence. Hence, KYC is an intensive process that requires documentation of clients' identity, income, and sources of funds at a deeper-than-surface level. Identity today can be analogue (paper documents), digitized (e.g., a scan of an ID document), or digital (e.g., online footprint). Identity verification, both on the acceptance of a new customer (onboarding) and on an ongoing basis, is essential to protect against fraud and crime, and henceforth is fundamental to market integrity as well. At the same time, identification and KYC rules can be major barriers to accessing financial services for millions of individuals and small businesses.

Arner, Zetzsche, Buckley, and Barneris (2018) argue that technology can present an opportunity to solve this challenge and ensure the objectives of financial inclusion and market integrity through the development of digital identity infrastructure and electronic KYC (e-KYC) infrastructure, but not at the cost of financial stability. A good example is India Stack, a collection of open application programming interfaces (APIs) that provides a paperless e-KYC service to instantly establish the identify of prospective banking customers in India.[60] An estimation by the

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[59] The 40 Recommendations of the FAFT, originally drawn up in 1990, revised in 1996, and again reviewed and updated in 2003, are universally recognized as the international standards for AML.

[60] India Stack is an idea originated by a group of Indian IT entrepreneurs and supported by the government and the Reserve Bank of India. The e-KYC service allows customers to electronically provide their demographic and personal information, including proof of identity, address, date of birth, and gender, to

Ministry of Finance of India shows that moving from paper-based KYC to e-KYC in India reduced the average cost of verifying customers from roughly $15 to $0.50. Indian banks that make the shift can shorten the time spent on verifying customers from more than five days to seconds.[61]

In the age of cryptocurrency and blockchain, while financial institutions gradually developed tools to combat money laundering over the last decades, AML and KYC have become more intricate and complex because of the difficulty to verify identity and IP addresses, as well as the growing theft of cryptocurrencies.[62] Lawmakers around the world in 2018 added a broader scope to AML, such as the adoption of the European Union's Fifth Anti-Money Laundering Directive (AMLD5) that includes cryptocurrency exchanges. In February 2019, the FATF published a draft of an Interpretive Note to Recommendation 15, which was formally adopted as part of the FATF Standards in June 2019, to guide regulatory authorities in member countries when identifying risk, sharing information, and monitoring virtual asset service providers. Virtual asset service providers will need to be registered or licensed and monitored by authorities.[63]

In the U.S., to identify and address the risk of identity theft, the SEC and the Commodity Futures Trading Commission (CFTC) jointly issued rules (SEC's Regulation S-ID and CFTC's Subpart C) requiring certain regulated entities that qualify as either financial institutions or creditors to adopt, implement, and update periodically a written program on identity safety known as the Red Flag Rules in 2013. In September 2018, the SEC brought its first enforcement action under the Identity Theft Red Flag Rules against a registrant, Voya Financial Advisor, because it failed to adequately protect customer information following a six-day cyberattack in 2016.[64]

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financial providers, who can verify it in real time. For more information about India Stack, see https://indiastack.org/about/.

[61] For more details, see https://www.cgdev.org/blog/overcoming-know-your-customer-hurdle-e-kyc.

[62] In virtual money laundering, the first step of the cleaning process is called *layering*; the criminals move money into the cryptocurrency system and move it around by using mixers, tumblers, and chain hopping. The pseudo-anonymous nature of virtual currencies makes it exponentially difficult to trace funds. The second step is burst-out integration; criminals can obtain fiat currency through withdrawing a basic currency to a connected bank account or transferring to real estate (see the KPMG report, *Anti-Money Laundering in Times of Cryptocurrencies*, June 2018, https://assets.kpmg/content/dam/kpmg/ch/pdf/anti-money-laundering-in-times-of-cryptocurrency.pdf).

[63] See FATF, *Public Statement: Mitigating Risks from Virtual Assets*, February 22, 2019, http://www.fatf-gafi.org/publications/fatfrecommendations/documents/regulation-virtual-assets-interpretive-note.html.

[64] See SEC, Advisers Act Rel. 5048 (September 26, 2018), https://www.sec.gov/litigation/admin/2018/34-84288.pdf.

9.2 Regulation of Fintech

The goal in fintech regulation has been to design a policy framework that would encourage and support disruptive innovation to enhance financial inclusion and economic growth while at the same time provide protection to the safety and soundness of the banking system and financial stability overall.[65] Brummer and Yadav (2019) summarize market integrity, rules simplicity, and financial innovations as the three-legged foundation to accomplish these goals. They point out the tradeoffs and the potential interplay that could interfere with one another. In designing fintech regulations, regulators seek to provide clear rules, maintain market integrity, and encourage fintech innovations, but they are likely to achieve only two of the three objectives. For example, if regulators prioritize market safety, financial stability, and simple and transparent rulemaking, the rules would likely impose broad prohibitions, which can largely inhibit fintech innovations. Alternatively, if regulators wish to prioritize encouraging fintech innovations and provide clarity of rules, they might have to use a simple and low-intensity regulatory framework that may not ensure safety, soundness, and stability in the financial system. Finally, if regulators look to enable innovations and promote market integrity, they would likely impose a set of more complex rules (and with specific cases of exemptions), which are less transparent and not easy to understand.

With rapid growth in usage of big data and AI/ML, the current wave of fintech has created informational and regulatory gaps and loopholes that need to be closed. Rapid advance in the technologies have also increased the uncertainties and difficulty in evaluating the impact of new technologies on consumers, the market, and financial systems overall. Jagtiani and John (2018) provide an overview of fintech innovations and regulatory considerations, especially discussion around consumer protection in response to fintech growth. Liu, Sockin, and Xiong (2020) discuss consumer privacy issues associated with personal data collection by digital platforms such as Google, Amazon, and Facebook, as well as current regulations on data privacy. The General Data Privacy Regulation (GDPR) was enacted by the European Union in 2018, and the California Consumer Privacy Act (CCPA) was enacted by the State of California in 2020.[66] Both the GDPR and

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[65] The findings from existing studies seem to show that legal regulations can improve fintech activities. For example, using a sample of crowdfunding volume obtained by surveying crowdfunding platforms globally, Rau (2020) shows that the introduction of explicit legal regulation appears to significantly increase crowdfunding volume, and more importantly, such an effect appears to be at least partly causal.

[66] In the European Union (EU), the GDPR applies to the processing of personal data by businesses established within the EU and businesses outside the EU, if their data collection activities are related to individuals in the EU. In the U.S., absent a comprehensive federal privacy law, the CCPA is currently considered to be one of the most important regulations on data privacy. For more details, see Liu, Sockin, and Xiong (2020).

the CCPA give each consumer the choice to opt-in or opt-out of data sharing. However, these regulations may not provide sufficient protection to consumers because of a negative externality in which the opt-in decision of some consumers could potentially reduce the anonymity of those who opt out. Brummer and Yadav (2019) propose several regulatory strategies in dealing with the potential risks posed by fintech, including informal guidance, no-action letters, regulatory sandboxes, and other pilot programs, and licensing versus chartering forms of organization.[67]

A *fintech regulatory sandbox* is a regulatory, innovative method in fintech, based on informal guidance. Specifically, it is a mechanism for firms to conduct tests of new fintech products and services in a live environment, with regulatory oversight and subject to certain conditions and safeguards. The innovators would be provided with an environment within which they could experiment and try out their new ideas — under a more relaxed regulatory environment but would cause no harm to the general population or the financial system. Ringe and Ruof (2019) propose a regulatory sandbox for robo-advice, with which market participants test robo-advice services in the real market, with real consumers, but under the close scrutiny of the supervisors.

The first fintech regulatory sandbox was proposed and implemented by the UK's Financial Conduct Authority (FCA) in November 2015. The concept was then followed by other countries including Canada, Malaysia, Singapore, and Australia.[68] The FCA accepted applications for its first three cohorts in June and December 2016 and June 2017. For the three cohorts, the FCA received a total of 146 applications and admitted 68 of them. Nine companies, which had been accepted into the first two cohorts, were unable to test their solutions for a variety of reasons.[69]

The benefits of regulatory sandboxes include not only signaling a friendly general regulatory approach to fintech innovations but also reducing fintech regulatory uncertainty and increasing regulatory and supervisory capacity.[70] Cornelli et al. (2020) analyze the effect of entering the FCA's regulatory sandbox and find that firms entering the sandbox see a significant increase (about 15 percent) in capital raised post-entry. Jagtiani and John (2018) point out how the

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[67] Regulators can also design or oversee tests involving new innovations or techniques, observe outcomes, and then tailor rulemaking to its most efficient and effective form. In other words, pilots provide a way for regulators to generate information on the likely effects of particular products or services. As an example, China has been using frequent pilots when making new rules tied to liberalizing financial markets.

[68] The UK's sandbox is one of five initiatives carried out under the umbrella of the FCA's Project Innovate, which include these primary initiatives: Regulatory Sandbox, Direct Support, and Advice Unit.

[69] See FCA, *Regulatory Sandbox Lessons Learned Report*, October 2017, https://www.fca.org.uk/publication/research-and-data/regulatory-sandbox-lessons-learned-report.pdf.

[70] J. Crane, L. Meyer, and E. Fife, 2018. *Thinking Inside the Sandbox: An Analysis of Regulatory Efforts to Facilitate Financial Innovation*, RegTech Lab, https://www.regtechlab.io/report-thinking-inside-the-sandbox.

lack of clarity around which alternative data variables could be used in credit risk modeling has created regulatory uncertainty. The fintech industry seems to be more concerned about fintech regulatory uncertainties and the lack of clarity than regulation itself. In addition, there is evidence that fintech firms are willing to be regulated in a level playing field with traditional lenders; several fintech firms have recently applied to become a bank. For example, LendingClub successfully acquired Radius Bank and became a bank holding company in January 2021; Square also received an approval to become an industrial loan corporation (ILC) March 2020 to start operating as a bank (with FDIC deposit insurance) in 2021.

The U.S. regulatory authorities, including the SEC, Consumer Financial Protection Bureau (CFPB), Office of the Comptroller of the Currency (OCC), and the Federal Deposit Insurance Corporation (FDIC), have also implemented some pilot programs to further understand the various impacts of fintech on consumers and the financial systems.[71] Zetzsche, Buckley, Arner, and Barberis (2017) summarize the current regulatory approaches: doing nothing, case-by-case approach (such as no-action letters in the U.S.) and structured experimentalism (such as sandboxes, testing, and piloting). They propose a new "smart" regulation approach, which comprises regulatory design and implementation in stages as follows: testing and piloting environment, conducting a regulatory sandbox, issuing a restricted licensing or a special charter scheme, and finally, when size and income permits, moving to operating under a full license. From each stage to the next, regulatory complexity and costs increase, as does the scope of fintech innovations.

While traditional firms are increasing investments in technology to keep up with new consumer preferences and to sustain in the new tech landscape, tech start-ups and BigTech firms are rapidly getting involved in payments and providing other financial services. In the long run, traditional financial institutions, fintechs, and BigTechs in financial services may converge, as large international banks may buy big data sets from various sources and compile these with their own proprietary data. In addition, some BigTechs may ultimately apply for full financial services licenses and become global financial conglomerates, as evident in the Chinese financial system with Alibaba BigTech and its Ant Financial that owns one of the largest mutual funds in the world.

The opportunities that BigTechs can provide are obvious in reducing transaction costs, as well as improving risk management and financial inclusion. From the regulatory point of view, both BigTechs and fintechs seek to minimize regulatory constraints and costs. However, they are still different in terms of clients' trust and potential systemic risks. First, BigTechs create trust in a

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[71] The OCC launched an innovation pilot program in April 2019, https://www.occ.gov/news-issuances/news-releases/2019/nr-occ-2019-42.html.

world unrelated to financial services (such as trust in the payment platforms operated by Amazon and PayPal) and leverage clients' trust in the financial sphere (such as Amazon and PayPal using data from their own payment platforms to make loans to small businesses). Second, BigTechs are often significant firms prior to stepping into the financial sector, while fintech firms usually start small as problem-driven firms. Hence, a central regulatory issue is the tradeoff between improving innovation/financial inclusions and reducing systemic risks. One possible way to respond, as proposed in Zetzsche, Buckley, Arner, and Barberis (2018), is requiring authorization for data gathering and analytics when used for financial services, if the firm size exceeds certain thresholds.

10. Concluding Remarks

Fintech has the potential for disrupting the entire financial system, and it has played an important role in rapid digital transformation and how financial products and services are produced, delivered, and consumed in recent years. The current COVID-19 pandemic has also expedited financial and nonfinancial firms to better serve consumers in the new landscape — by using technology and transforming business models to a fully digital lifestyle and potentially bringing us toward a potential cashless economy. Digital banks are seeing increased traffic, while consumers embrace digital and contactless technologies. In this paper, our aim is to provide a comprehensive review of research studies and policy discussion around fintech, covering the various aspects of fintech and its role in each segment of the financial market and the associated impact on consumers, other market participants, and the financial system overall.

So much data has been collected and monetized in recent years, leading to an interesting fintech mantra: "Data is the new currency." The vast amount of data and the fast and complex computing algorithms have become key factors that drive innovations in recent years, and billions of consumers around the globe have benefited from these changes. The new generation of consumers are less tolerant to mediocre quality of services and opaque fine prints in their financial relationship, while BigTech firms are exploring opportunities to serve. Many believe that firms relying on the fine print, such as the various hidden fees (like credit card late fees or bank overdraft fees) will not survive the new landscape. It is important to recognize that these advanced technologies that improve our lives also come with new set of risks, such as risks to consumer privacy and cybersecurity.

Fintech activities have been progressing quickly and penetrating all areas of the financial system. Under the new landscape where financial firms use cloud storage and cloud computing to achieve high speed and efficiency, it is no longer true that larger firms are more efficient, and it is no

longer true that larger firms beat smaller firms (but faster one beat those that are slower). In other words, large firms that do not fully use the technology could potentially fall behind. Cloud computing may also introduce new exposure to cyber-risks that did not exist before, while it has greatly benefited traditional financial institutions in terms of efficiency, resiliency, and flexibility. BigTech firms are playing increasing roles in financial services and real-time payments as well as providing cloud computing services to large and small financial institutions.

It remains unclear, however, how loans originated by fintech firms will perform relative to traditional loans in an extreme environment (severely stressed scenario), and they are going through a real test now during the COVID-19 crisis. It is also unclear how the complex algorithms with alternative data, which worked well earlier, would continue to perform in the new landscape (after the COVID-19 crisis). The AI models may need to be retrained with new data to reflect the "new normal." In the meantime, fintech lenders have a role to play in the background (white label services) to assist small banks in screening and processing a large number of loan applications under the Coronavirus Aid, Relief, and Economic Security Act (CARES Act) to support small businesses.

Blockchain technology and smart contracts have attracted a great deal of interest, with thousands of fintech start-ups around the globe working on ways to resolve blockchain scalability, with the potential of allowing consumers to have control over their own information and rely less on third-party intermediation. Blockchain technology has also made it possible for real-time payment and settlement, eliminating frictions in the current payment system, especially for cross-border payments. The success of stablecoin could potentially contribute to more widespread use of blockchain technology. Central banks around the globe are considering whether to issue central bank digital currency (CBDC) to stabilize the value of digital assets or to take a supporting role for the public sector to operate in the new cash-lite economy. The Chinese government is also experimenting with blockchain technology, introducing the Blockchain-based Services Network (BSN) in April 2020, intended to serve as the backbone technological infrastructure for massive interconnectivity throughout mainland China.

How should fintech firms be regulated? Many tech firms, especially payment platforms, have access to unique data about their customers, and they have the comparative advantage in making small business loans. These nonbank lenders are providing similar financial products and services outside the banking regulatory framework. There have been discussions around activity-focused regulations so that all lenders (banks and nonbanks) would be subject to the same regulations. It is debatable whether the future mainstream financial technology would be blockchain and DLTs,

quantum computing, or something else — and how the industry and policymakers could be best prepared to keep pace with the evolving technologies and the new adoption. While the advanced technology has delivered vast benefits, it has also allowed for more sophisticated cyberattacks. In addition, third-party vendor risk management has become more important than ever as loans that were approved on fintech platforms could end up on banks' balance sheet. Banks also increasingly rely on cloud-computing services provided by nonbank BigTech firms. Given all these innovations and rapid digital transformation, the existing regulations need to adapt to keep up with the new financial landscape — to protect consumers and financial systems while continuing to promote responsible fintech innovations.

Going forward, it's uncertain how fintech as the mainstream technology for the financial services industry will evolve. Economists have been trying to predict what would happen to fintech when the next recession comes. As we are finalizing this draft, the entire fintech industry is facing a real test for the first time under the current COVID-19 crisis. It has been evident that collaboration among fintech firms and traditional lenders have been critical in pushing the funding relief to those targeted recipients (mainly small businesses) in a timely fashion. There may be evidence of potential complementarity leading to a wave of mergers among financial firms and tech firms, thus further reducing the distinction between fintech firms and traditional firms. Once again, this is an opportune time for researchers to further explore the impact of fintech on consumers and the overall financial systems and stability and to design appropriate financial regulations for the new landscape.

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Table 1: Summary of Fintech Literature by Topics

Sections/ Subsections	List of papers	Methodology	Summary of findings
Credit scoring using AI/ML and alternative data	Mester, Nakamura, and Renault (2007) Norden and Weber (2010) Hibbeln, Norden, Usselmann, and Gurtler (2019) Jagtiani and Lemieux (2019) Croux, Jagtiani, Korivi, and Vulanovic (2020) Iyer, Khwaja, Luttmer, and Shue (2016) Hildebrandt, Puri, and Rocholl (2017) Lin, Prabhala, and Viswanathan (2013) Gao, Lin, and Sias (2017) Dorfleitner et al. (2016) Berg, Burg, Gombovic, and Puri (2020) Fuster, Goldsmith-Pinkham, Ramadorai, and Walther (2018) Iyer, Khwaja, Luttmer, and Shue (2016) Jagtiani, Hughes, and Moon (2019) Goldstein, Jagtiani, and Klein (2019)	Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Policy	The rise of fintech helps evaluate credit risks of the unbanked population, and the usage of AI/ML algorithms overcomes the limitations of traditional models/data in estimating borrowers' credit risks and their ability to pay back loans and improves the predictive ability of default risks. Fintech helps use alternative information including borrowers' digital footprints and fills in the information gap for unbanked population or consumers who have thin-credit file.
Internet-based banking and investment services	Hernandez-Murillo, Llobet, and Fuentes (2010) Furst, Lang, and Nolle (2002) Kowalewski and Pisany (2020) DeYoung, Lang, and Nolle (2007) Hernando and Nieto (2007) McKillop and Wilson (2009) D'Andrea and Limodio (2020) Klus, Lohwasser, Hornuf, and Schwienbacher (2020) Parlour, Rajan, and Zhu (2020) Arner, Barberis, and Buckley (2016a) Rysman and Schuh (2016) Crowe, Rysman, and Stavins (2010) Greene, Rysman, Schuh, and Shy (2014) Conti-Brown and Wishnick (2020)	Empirical Empirical Empirical Empirical Empirical Empirical Empirical Empirical Theory Policy/Survey Policy/Survey Policy/Survey Policy/Survey Policy/Survey	The determinants of the adoption of Internet-based banking include profitability, size as well as the organizational structure of banks. Empirical evidences show that the adoption of online banking improves bank performance and reduces banks' operating costs. Recent advances in fintech improves digitization in payments (i.e., mobile payment and fast payment systems around the global, especially in China). Empirical research shows that the cost of adoption and network effect play a critical role in the speed of adoption. In the U.S., the Federal Reserve System has proposed to build and operate an entirely new payment platform, *FedNow*, to speed up payments. Policy research argues that the plan of the new system might achieve important objectives including catalyzing innovation, enhancing access to developing payment networks, and shoring up financial stability.

Peer-to-peer (P2P) lending	Balyuk (2017)	Empirical	Empirical studies find that P2P can be either a substitute or a complement to bank lending, depending on the situation. If assuming that banks face an exogenous regulatory shock, P2P lending could act as a substitute for bank lending to serve inframarginal borrowers, or on small-scale loans, P2P lending would be more likely to complement bank lending. The P2P lending platform can also help uncover the "correct" pricing for transactions by providing nonstandard soft information, which is usually not available in credit decisions, according to the fair lending and consumer privacy regulations.
	Chava and Paradkar (2018)	Empirical	
	Jagtiani and Lemieux (2018)	Empirical	
	Tang (2018)	Empirical	
	de Roure, Pelizzon, and Thakor (2018)	Empirical	
	Wei and Lin (2017)	Empirical	
	Franks, Serrano-Velarde, and Sussman (2018)	Empirical	
	Cumming and Hornuf (2020)	Empirical	
	Hildebrandt, Puri, and Rocholl (2017)	Empirical	
	Vallee and Zeng (2019)	Empirical	
	Liskovich and Shaton (2017)	Empirical	
	Butler, Cornaggia, and Gurun (2017)	Empirical	
	Crowe and Ramcharan (2012)	Empirical	
	Ravina (2018)	Empirical	
	Lin and Pusianinen (2018)	Empirical	
	Hasan, He, and Lu (2019)	Empirical	
	Iyer, Khwaja, Luttmer, and Shue (2016)	Empirical	
	Lin and Viswanathan (2016)	Empirical	
	Lin, Prabhala, and Viswanathan (2013)	Empirical	
	Feedman and Jim (2014)	Empirical	
	Li, Lu, and Hasan (2020)	Empirical	
	Jagtiani, Lambie-Hanson, and Lambie-Hanson (2021)	Empirical	
	Jagtiani, Vermilyea, and Wall (2018a)	Policy	
Financial inclusion, digital wallet, and credit access for unbanked individuals	Beck, Demirguc-Kunt, and Levine (2007)	Empirical	Empirical studies find that the overall level of economic development, legal origin, religion, the quality of institutional environment, the degree of credit information sharing, and the development of physical infrastructure are important determinants of level of financial access. Using evidence from Kenya, China, and other countries, existing literature suggests that fintech can promote financial inclusion via mitigating local credit supply frictions and extending credit availability to individuals/small businesses with low credit scores.
	Demirguc-Kunt et al. (2018)	Empirical	
	Kendall, Mylenko, and Ponce (2010)	Empirical	
	Allen et al. (2016)	Empirical	
	Allen et al. (2021)	Empirical	
	Hau, Huang, Shan, and Shen (2019a)	Empirical	
	Hau, Huang, Shan, and Shen (2019b)	Empirical	
	Huang, Li, and Shan (2019)	Empirical	
	Basten and Ongena (2020)	Empirical	
	Breza, Kanz, and Klapper (2020)	Empirical	
	Erel and Liebersohn (2020)	Empirical	
	Crouhy, Galai, and Wiener (2020)	Empirical	
	Dolson and Jagtiani (2021)	Empirical	

The roles of alternative data in improving credit access and risk pricing	Schweitzer and Barkley (2017)	Empirical	The use of alternative data and advanced algorithms has improved credit assessment, especially for the unbanked consumers and small businesses. Meanwhile, the use of alternative data has also raised issues related to fair lending. Using evidence from different countries, empirical studies suggest that, by using big data and complex ML algorithms, lenders may unknowingly make credit decisions based on factors that are related to sensitive attributes such as race or gender, resulting in discrimination and further a riskier pool of potential borrowers for banks. These might affect safety and soundness in the financial system.
	Jagtiani, Lambie-Hanson, and Lambie-Hanson (2021)	Empirical	
	Ahmed et al. (2016)	Empirical	
	Jagtiani and Lemieux (2019)	Empirical	
	Berg, Burg, Gombovic, and Puri (2020)	Empirical	
	Eccles et al. (2020)	Empirical	
	Frost et al. (2019)	Empirical	
	Buchak et al. (2018)	Empirical	
	Cumming and Schwienbacher (2018)	Empirical	
	Fu, Huang, and Singh (2018)	Empirical	
	Ru and Schoar (2019)	Empirical	
	Padhi (2017)	Policy/Survey	
	Jagtiani and John (2018)	Policy/Survey	
	Branzoli and Supino (2020)		
Distributed ledger technology (DLT), blockchain, and smart contracts	Irresberger, John, and Saleh (2020)	Empirical	Blockchain is viewed as a potential mainstream financial technology of the future to eliminate a trusted third party in financial intermediation. Three main types of blockchain are private blockchain, a permissioned blockchain, and a public blockchain. The current well-known types of consensus mechanism algorithms include proof of work (POW) and proof of stake (POS). Theoretical studies have been exploring the economic models of the blockchain protocol and establishing the design choices that developers may employ to generate consensus. Decentralization, which is the core concept of the DLT, is also under discussion by theoretical studies. A growing literature argues the advantages of a blockchain compared with traditional ledgers, including certainty and reducing costs of verification, enforcement, or networking. Potential negative features also exist, including lack of full transparency, as well as the Blockchain Trilemma. Legal scholars have raised concerns associated with liability risks, cyber-risks, and other operational risks.
	Hinzen, John, and Saleh (2020)	Empirical	
	Budish (2018)	Theory	
	Cong and He (2018)	Theory	
	Abadi and Brunnermeier (2019)	Theory	
	Biais, Bisiere, Bouvard, and Casamatta (2019)	Theory	
	Saleh (2020)	Theory	
	Pagnotta (2020)	Theory	
	Rosu and Saleh (2020)	Theory	
	Catalini and Gans (2018)	Theory	
	Ma, Gans, and Tourky (2018)	Theory	
	Malinova and Park (2017)	Theory	
	Tinn (2018)	Theory	
	Easley, O'Hara, and Basu (2019)	Theory	
	Lehar and Parlour (2020)	Theory	
	Arner et al. (2019)	Policy/Survey	
	Yermack (2017)	Policy/Survey	
	Wall (2018b)	Policy/Survey	
	Mills et al. (2016)	Policy/Survey	
	Benos, Garratt, and Gurrola-Perez (2017)	Policy/Survey	
	Harvey (2016)	Policy/Survey	
	Wall (2016)	Policy/Survey	
	Zetzsche, Buckley, and Arner (2017)	Policy/Survey	

Crypto-currencies: pricing, impact on central banking and regulations	Allen et al. (2020)	Empirical	Theoretical studies develop models to explain what determines the fundamental values of cryptocurrencies. For example, in Schilling and Uhlig (2019), the price of bitcoin follows a martingale pattern; in Garratt and Wallace (2018), the value of bitcoin rests on self-fulfilling beliefs. Cong, Li, and Wang (2018) allows for both user-base externality and endogenous user adoption and develops a dynamic asset pricing model and document a positive but nonlinear relationship among token price and platform productivity. Pagnotta and Buraschi (2018) provide an equilibrium model of the bitcoin market in a decentralized network and show that the overall production and bitcoin price are jointly determined. On the empirical side, existing studies document the volatility of cryptocurrency prices. The sudden rise of cryptocurrencies may pose challenges to central banks in many ways including affecting the monetary policy effectiveness, policies on exchange rates.
	Griffin and Shams (2020)	Empirical	
	Kroeger and Sarkar (2017)	Empirical	
	Makarov and Schoar (2019)	Empirical	
	Liu and Tsyvinski (2018)	Empirical	
	Corbet et al. (2020)	Empirical	
	Schilling and Uhlig (2019)	Theory	
	Garratt and Wallace (2018)	Theory	
	Sockin and Xiong (2020)	Theory	
	Cong, Li, and Wang (2018)	Theory	
	Cong, Li, and Wang (2020)	Theory	
	Pagnotta and Buraschi (2018)	Theory	
	Pagnotta (2020)	Theory	
	Fernández-Villaverde and Sanches (2019)	Theory	
	Benigno, Schilling, and Uhlig (2019)	Theory	
	Raskin and Yermack (2016)	Policy/Survey	
	Zetzsche, Buckley, and Arner (2020)	Policy/Survey	
Initial coin offering: structure, valuation and regulation	Howell, Niessner, and Yermack (2018)	Empirical	The current research on ICOs focuses on how they should be accurately priced and what would be appropriate regulatory responses. A number of theoretical studies examine the structure of ICOs, and a consistent finding is that the ICO structure could help to solve coordination problems among investors. Empirical studies investigate ICOs valuation and pricing and find that the success of ICOs is determined by an assortment of features of the tokens, entrepreneurs, as well as the underlying projects. Given the nature of entrepreneurs financing through ICOs, particular risks of an ICO include potential fraud, such as issuance of scam coins. Legal scholars and policy research examine and compare smart contracts and white papers. Overall, the literature suggests that it may be necessary for ICO activities to be regulated, but it may not be desirable to completely ban ICOs.
	Amsden and Schweizer (2018)	Empirical	
	Lee, Li, and Shin (2018)	Empirical	
	Lyandres, Palazzo, and Rabetti (2020)	Empirical	
	Akyildirim et al. (2020)	Empirical	
	Adhami, Giudici, and Martinazzi (2017)	Empirical	
	Hu, Parlour, and Rajan (2018)	Empirical	
	Fisch and Momtaz (2020)	Empirical	
	Momtaz (2020)	Empirical	
	Benedetti and Kostovetsky (2018)	Empirical	
	Li, Shin, and Wang (2020)	Empirical	
	Bellavitis, Cumming, and Vanacker (2020)	Empirical	
	Li and Mann (2018)	Theory	
	Cong, Li, and Wang (2018)	Theory	
	Bakos and Halaburda (2018)	Theory	
	Catalini and Gans (2018)	Theory	
	Sockin and Xiong (2020)	Theory	
	Bakos and Halaburda (2018)	Theory	
	Chod and Lyandres (2020)	Theory	
	Garratt and Oordt (2019)	Theory	

	Bakos and Halaburda (2019)	Theory	
	Allen (2020)	Policy/Survey	
	Allen, Fatas, and Weder di Mauro (2020)	Policy/Survey	
	Cohney et al. (2019)	Policy/Survey	
	Zetzsche et al. (2019)	Policy/Survey	
Central Bank Digital Currency (CBDC)	Andolfatto (2018)	Theory	The literature so far lies in the benefits and concerns of central banks' issuance of CBDCs and its impact on the banking sector. Theoretical and policy studies suggest that, on one hand, CBDCs can promote financial inclusion, improve the safety and efficiency of the financial and payment system as well as increase central banks' controlling power over monetary policy; on the other hand, digital currencies might also bring significant risks to the rest of the financial systems.
	Brunnermeier and Niepelt (2019)	Theory	
	Niepelt (2020a)	Theory	
	Niepelt (2020b)	Theory	
	Keister and Sanches (2019)	Theory	
	Chiu, Davoodalhosseini, Jiang, and Zhu (2020)	Theory	
	Williamson (2019)	Theory	
	Agur, Ari, and Dell'Ariccia (2020)	Theory	
	Raskin and Yermack (2016)	Theory	
	Fernández-Villaverde, Sanches, Schilling, and Uhlig (2020a)	Theory	
	Fernández-Villaverde, Sanches, Schilling, and Uhlig (2020b)	Theory	
	Mehl, Stracca, and Ferrari (2020)	Theory	
	Brunnermeier, James, and Landau (2019)	Theory	
	Mancini-Griffoli et al. (2018)	Policy/Survey	
	Jagtiani, Papaioannou, Tsetseko, Dolson, and Milo (2021)	Policy/Survey	
	Engert and Fung (2017)	Policy/Survey	
	Bech and Garratt (2017)	Policy/Survey	
	Bordo and Levin (2017)	Policy/Survey	
	Ali et al. (2014)	Policy/Survey	
	Barontini and Holden (2019)	Policy/Survey	
	Jagtiani, Papaioannou, and Tsetsekos (2019)	Policy/Survey	
	Jagtiani et al. (2021)	Policy/Survey	
	Boar, Holden, and Wadsworth (2020)	Policy/Survey	
	Arner, Buckley, Zetzsche, and Didenko (2020)	Policy/Survey	
High-frequency trading	Hendershott, Jones, and Menkveld (2011)	Empirical	Theoretical studies examine a key question that whether high-frequency trading (HFT) can benefit or hurt market quality. On one hand, if HFT is a fast-acting agent as it can
	Brogaard, Hendershott, and Riordan (2017)	Empirical	
	Menkveld (2013)	Empirical	

	Aitken, Cumming, and Zhan (2015)	Empirical	trade on new information instantly before it becomes available to others, adverse selection would be more severe and market quality would decrease; however, if HFT is a better-informed agent, then liquidity would improve. Empirical evidence strongly suggests that HFT is good for average market quality. However, the impact of HFT on market quality in stressed conditions is a particular concern to regulators and investors. The existing trading errors and extreme events call for more HFT regulation.
	Gai, Yao, and Ye (2014)	Empirical	
	Aitken et al. (2018)	Empirical	
	Brogaard, Hendershott, and Riordan (2014)	Empirical	
	Brogaard, Hendershott, and Riordan (2019)	Empirical	
	Kirilenko, Kyle, Samadi, and Tuzun (2017)	Empirical	
	Kirilenko, Kyle, Samadi, and Tuzun (2018)	Empirical	
	Easley, Lopez de Prado, and O'Hara (2011)	Empirical	
	Easley, Lopez de Prado, and O'Hara (2012)	Empirical	
	Biais, Foucault, and Moinas (2015)	Theory	
	Foucault, Hombert, and Rosu (2016)	Theory	
	Du and Zhu (2014)	Theory	
	Ait-Sahalia and Saglam (2013)	Theory	
	Goettler, Parlour, and Rajan (2009)	Theory	
	Jovanovic and Menkveld (2016)	Theory	
	Li, Wang, and Ye (2020)	Theory	
	Menkveld (2016)	Policy/Survey	
	Jones (2013)	Policy/Survey	
	Linton and Mahmoodzadeh (2018)	Policy/Survey	
	O'Hara (2015)	Policy/Survey	
	Kirilenko and Lo (2013)	Policy/Survey	
	Jones (2013)	Policy/Survey	
Quantitative investment strategies	Allen and Karjalainen (1999)	Empirical	Empirical studies suggest that quantitative strategies can work well in stable environments but often work poorly when there is a crisis or other unexpected events. Big data and AI/ML can help improve information advantage, but when misapplied, these techniques can lead to false discovery and disappointments.
	Brock, Lakonishok, and LeBaron (1992)	Empirical	
	Freyberger, Neuhierl, and Weber (2020)	Empirical	
	Feng, Giglio, and Xiu (2020)	Empirical	
	Kozak, Nagel, and Santosh (2020)	Empirical	
	Chinco, Clark-Joseph, and Ye (2019)	Empirical	
	Kelly, Manela, and Moreira (2019)	Empirical	
	Cao et al. (2020)	Empirical	
	Mayew and Venkatachalam (2012)	Empirical	
	Khandani and Lo (2007)	Empirical	
	Ozik and Sadka (2014)	Theory	
	Dugast and Foucault (2018),	Policy/Survey	
	Loughran and McDonald (2020)	Policy/Survey	
	Arnott, Harvey, and Markowitz (2019)	Policy/Survey	
	Lopez de Prado (2018)		

Investment advisors, wealth management, and InsurTech	D'Acunto, Prabhala, and Rossi (2019) Linnainmaa, Melzer, and Previtero (2017) Rossi and Utkus (2020) Hodge, Mendoza, and Sinha (2018) Ringe and Ruof (2019) Baker and Dellaert (2018) Fein (2015) Ji (2018) Lin and Chen (2019) Thakor (2020)	Empirical Empirical Empirical Empirical Policy/Survey Policy/Survey Policy/Survey Policy/Survey Policy/Survey Policy/Survey	Empirical research suggests that determinants of using robo-advising include gender, age, trading experience, sophistication as well as the amount of investment funds. It is also documented that robo-advisors can reduce pervasive behavioral bias and cognitive litigations that a traditional human financial advisor might have. Legal scholars and policy research raise up the conflict-of-interest concerns associated with robo-advising because of the bias in the algorithms that reflect a firm's existing conflicts of interests.
Cybersecurity	Kamiya et al. (2018) Lin, Sapp, Rees-Ulmer, and Parsa (2019) Amir, Levi, and Livne (2018) Tosun (2020) Kopp, Kaffenberger, and Wilson (2017) Lin (2016)	Empirical Empirical Empirical Empirical Policy/Survey Policy/Survey	Using data from different countries, empirical studies find that the probability of being attacked is related to firm size, financial constraints, its intangible assets, as well as the industries to which it belongs. Corporate governance characteristics do not seem to matter for the likelihood of cyberattacks. Hacking events are found to have negative and sticky influence on firms' reputations and henceforth on growth prospects. In the long run, firms adjust their investment and financial policies in response to cyberattacks.
Cloud computing and the roles of BigTech	Frost et al. (2019) Cornelli et al. (2020) Pierri and Timmer (2020) Stulz (2019) Mano and Padilla (2019)	Empirical Empirical Empirical Policy/Survey Policy/Survey	Empirical evidences have shown BigTech firms have helped to promote financial inclusion. In many cases, BigTech firms are also important third-party service providers to financial institutions. The effect on financial stability seems to be quite mixed so far. On one hand, empirical studies have shown that the usage of cloud computing in banking before financial crisis can lead to 10% fewer nonperforming loans during the crisis; on the other hand, concerns remain with a large number of financial institutions that start to rely more and more on a few large cloud-service providers.

Regulation of fintech	Auer (2019),	Empirical	The current wave of fintech has created informational and regulatory gaps and loopholes that need to be closed. Theoretical studies discuss the consumer privacy issues in the collection of personal data by digital platforms and find the current regulations may not provide sufficient protection for severely tempted consumers because of a negative externality in which the opt-in decision of some consumers reduces the anonymity of those who opt out. Possible regulatory strategies in dealing with potential risks include informal guidance, no-action letters, regulatory sandboxes and other pilot programs, and licensing versus chartering forms of organization. In the meantime, regulators are shifting from supervision by humans to supervision by machines using techniques such as AI/ML and analysis of data (RegTech). RegTech has also been developed within major financial institutions and fintech firms for corporate compliance.
	Liu, Sockin, and Xiong (2020)	Empirical	
	Zetzsche et al. (2017)	Theory	
	Arner, Barberis, and Buckley (2016b)	Theory	
	Wall (2018)	Policy/Survey	
	Arner, Zetzsche, Buckley, and Barneris (2018)	Policy/Survey	
	Brummer and Yadav (2019)	Policy/Survey	
	Jagtiani and John (2018)	Policy/Survey	
	Ringe and Ruof (2019)	Policy/Survey	
	Zetzsche et al. (2018)	Policy/Survey	