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An Introduction to Blockchain

I love this stuff—bitcoin, blockchain technology—and what the future holds…huge new markets and products will be built on these platforms.

Abby Johnson, CEO of Fidelity[1]

Introduction

For more than 7,000 years, humankind has used ledgers (see **Exhibit 1** for a glossary) to record economic transactions.[2] Clay tablets in ancient Mesopotamia recorded simple purchases and sales of basic goods, growth of herd sizes, and so on.[3] Even the concept of counting was impacted[4] by developments of ledger keeping in antiquity. Maintaining a record of transactions appears to be a common denominator of all human life.

The world has come a long way since clay tablets. Modern computing has transformed basic financial ledgers into lightning-fast, highly automated, and precisely accurate relational databases (**Exhibit 1**). Today, as cybersecurity and transparency emerge as paramount priorities during a digital transaction, blockchain has the potential to be the next generational improvement in how parties record the exchange of value.

However, while commercial enterprise has moved from pen-and-ink ledger keeping to digital databases, it appears unclear whether there will be widespread adoption of blockchain technology.[5] This may be in part due to a lack of understanding of the technology and an opaque regulatory environment.[6] Recent qualitative surveys across senior executives in different industries revealed that, while many believe the impact of blockchain will be profound, nearly 40% have little or no knowledge of what it is.[7]

This note introduces blockchain, its potential uses and limitations, and includes additional considerations for current and future leaders in financial services.

[1] Joe Morris, "Abby Johnson: 'I Love Bitcoin'," *Ignites*, May 24, 2017.
[2] George T. Friedlob and Franklin J. Plewa, *Understanding Balance Sheets*, New York: John Wiley, 1996; Beverley Milton-Edwards, "Iraq, Past, Present and Future: A Thoroughly-Modern Mandate?" *History & Policy*, May 8, 2003.
[3] Friedlob and Plewa, *Understanding Balance Sheets*.
[4] Keith Robson, "Accounting Numbers as 'Inscription': Action at a Distance and the Development of Accounting," *Accounting, Organizations and Society* 17, no. 7 (1992): 685–708.
[5] "Blockchain Reaches beyond Financial Services with Some Industries Moving Faster," Deloitte, December 13, 2016.
[6] "Blockchain Reaches beyond Financial Services;" Stan Higgins, "New York Reveals BitLicense Framework for Bitcoin Businesses," CoinDesk, July 17, 2014.
[7] "Blockchain Reaches beyond Financial Services."

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What is Blockchain?

In its most abstract sense, blockchain is a new platform technology enabling an improved ability to verify and record the exchange of value among an interconnected set of users; it is a secure and transparent way to track the ownership of assets before, during, and after any transaction. Each transaction between parties in the network is a "block," and the cumulative set of transactions across the entire network is the "chain:" blockchain.

Blockchain technology enables any network of users to track and trade virtually anything of value.

Broadly speaking, there are currently two types of blockchains: public and private. The bitcoin blockchain is an example of a public—or "permissionless"—blockchain (**Exhibit 1**). These networks—these blockchains—are open to anyone, and each use their own digital, native currencies (**Exhibit 1**), for example, bitcoin and Ethereum. These native currencies are the required mediums of exchange for using public blockchains to exchange value. Public blockchains allow for unlimited, anonymous or pseudonymous participation. On public blockchains, native currencies are needed for two reasons: (1) to compensate network members who verify their transactions (called "miners"), and (2) given the anonymous or pseudonymous nature of network members, it is the medium required to claim an underlying asset from its issuer.

Exhibit 2 represents a simple example of trading assets using a digital currency on a public blockchain: using bitcoin to pay monthly rent for an apartment. To trade and claim the underlying assets, in this example, rent in U.S. dollars and an apartment to live in for one month, the property owner and tenant both exchange their assets using bitcoin as the common currency. From the perspective of the tenant, the benefits include permanence and tamper-resistance of the record of transaction (i.e., it is auditable), increased security (e.g., checks can be lost in the mail, destroyed or counterfeited), and increased privacy (e.g., a stranger would not be able to see the routing number and account number on the checks). See the bulleted list below for a more complete list of blockchain transaction benefits. From the perspective of the property owner, though, the **Exhibit 2** transaction may bring unwanted exchange rate risk. The price of bitcoin is highly volatile (**Exhibit 3**), and it may decrease in value versus the U.S. dollar in the time it takes to exchange bitcoins for dollars, which has also been historically volatile (**Exhibit 4**). Additionally, there is a fee miners require to verify transactions, which is also volatile (**Exhibit 5**). It is worthwhile to consider whether these benefits and challenges will benefit certain types of digital currency transactions and hinder others.

A private—or "enterprise" or "permissioned"—blockchain (**Exhibit 1**) also records the exchange of value between parties in a network, but access to the network is permissioned because not everyone can join it. Private (i.e., enterprise) and public blockchains are not mutually exclusive either. In practice, and in general, organizations that are piloting proof-of-concept blockchain projects can build on public blockchain infrastructure and design additional bespoke, internally developed technology in order to use it for their own private network's purposes. JPMorgan Chase's Quorum is an archetypical example of this for financial institutions.[8]

In general, while specific applications of blockchain technology are still developing, there appears to be consensus[9] that enterprise blockchains have the following benefits versus legacy ledger technologies:

[8] As of August 13, 2017, JP Morgan Chase offered an enterprise blockchain platform called Quorum, specifically for and marketed to financial institutions.

[9] Morris; "Blockchain Reaches beyond Financial Services;" "Simple Introduction to Smart Contracts on a Blockchain," YouTube video, 5:07, uploaded by "Chainthat," December 6, 2015, https://www.youtube.com/watch?v=FkeLDPZ-v8g (accessed Aug. 31, 2017); Matthew Hancock and Ed Vaizey, "Distributed Ledger Technology: Beyond Block Chain. A Report by the UK Government Chief Scientific Adviser," UK Government Chief Scientific Adviser, January 19, 2016; "The Blockchain Practice," Deloitte UK, 2017; Christian Cachin, "Blockchain, Cryptography, and Consensus," IBM (Zurich), October 2016; "Blockchain Innovation in Wealth and Asset Management," EY, 2017; Accenture Digital, "Blockchain Technology. How Banks Are Building a Real Time Global Payment Network;" Accenture, 2016; Matt Higginson, "How Blockchain Could Disrupt Cross-Border Payments," The Clearing House, 2017; "Leading Global Transaction Banks Kick off Blockchain Proof of Concept with SWIFT Gpi," SWIFT, April 25, 2017; He Dong,

- Consistent. A blockchain records a history of all transactions within it, and all users in the network have an identical copy of the record/ledger.
- Democratic. The network using the blockchain agrees on and governs the rules for its use.
- Secure and accurate. Cryptography (ref. Glossary) protects all data and information, and the use of digital keys and digital signatures is required to access data in the ledger.
- Segmented and private. Based on pre-defined rules, users' digital keys and digital signatures (**Exhibit 1**) can access the entire ledger, a particular transaction, a set of transactions, and so forth.
- Permanent and tamper resistant. The ledger does not require a centralized point of control (**Exhibit 1**), and the details of all recorded transactions cannot be altered retroactively without the full agreement of the network.
- Quickly updated. The ledger reflects any changes (e.g., a new transaction) in near real time, every user's copy within the network reflects these changes in the same time frame, and records of transactions can be maintained and updated securely by the users themselves.
- Intelligent. Blockchain enables the creation of "smart contracts" (**Exhibit 1**).

These benefits enable the development of many potential products and applications for industry.

What Blockchain Can Do

With an understanding of the potential benefits of blockchain, we can now begin to develop visibility into possible ways to deploy blockchain technology. In practice today, it appears that most current blockchain products and applications fall into three buckets: (1) the clearing, payments, and settlement functions in financial services companies (e.g., banks, asset managers), (2) creation and use of a digital identity within an enterprise, and (3) smart contracts. Before exploring applications, though, we need to understand digital identities and smart contracts.

Blockchain enables the creation of a secure, private and tamper-resistant "single source of truth" for each customer within an enterprise—a customer's digital identity. Digital identities have the potential to affect the customer onboarding process, which can be cumbersome and time consuming. Recall the last time you bought insurance, opened a checking or savings account, opened an account at a brokerage or investment firm, or applied for a mortgage or a bank loan. We refer to this broadly as customer onboarding. The purpose of customer onboarding is to provide personal information and verify your identity to an enterprise, and for the enterprise to meet compliance requirements for onboarding new customers (e.g., know your customer [KYC] and antimony laundering [AML]). Customer onboarding has the potential to be a cumbersome process for both the customer and the enterprise and can include waiting in line, holding on the phone, meeting face-to-face with an agent or salesperson, signing many documents, filling out long forms, sending documents back and forth, making deposits, or paying premiums, and so forth. Using a diversified financial institution as an example, a customer who has checking and savings products, investment management products, and a mortgage all within that same enterprise more than likely had to do an onboarding process for each one of these products even though these products exist within the same enterprise…and even though the individual was already a customer.

"Fintech and Financial Services: Initial Considerations. Staff Discussion Notes," IMF, June 19, 2017; and Lucy Burton, "Bank of England Trials Artificial Intelligence and Blockchain in Bid to Stay Ahead of the Pack," *Telegraph*, March 17, 2017.

Referencing the benefits of blockchain from the previous section, the digital identity is:

- Consistent: the record is the same across the organization(s);
- Secure, accurate, and private: only those with the necessary digital keys can access the record;
- Tamper-resistant: others in the network cannot alter the record; and
- Quickly updated: everyone that has access to a customer's digital identity receives any updates the customer makes to their record immediately (e.g., mortgage broker, consumer banker, investment manager, insurance agent).

Smart contracts[10] are a type of blockchain transaction that can be thought of as event-triggered automated pieces of computer code. They can be as simple as "ship the product when we receive the payment" or "distribute dividends to shareholders upon their declaration." All smart contract transactions are stored on a blockchain, which provides both an audit trail (ref. Glossary) of events and assurance of fulfillment of contract terms. Further, if any party/user fails or does not fulfill their obligation, the blockchain continues to function with no loss of data or integrity.[11]

Including digital identity and smart contract applications, the following are examples of possible ways for asset managers to use blockchain technology in a product or application:[12]

- Client onboarding
- Trade order generation
- Regulatory reporting
- Clearing and settling securities transactions
- Cross border payments
- Compliance reporting (e.g., KYC)
- Management of model portfolios
- Voting of any kind (e.g., proxy)
- Dividend distribution
- Real asset transactions (e.g., property)
- Data storage
- Contracts (e.g., rollovers, estates)

Potential blockchain applications touch other industries, too. There are also potential applications across enterprises in CPG, government, and technology industries:[13]

- Customer loyalty programs
- Medical recordkeeping
- Supply chain management
- Passport and customs controls
- Tax collection/payment
- Customer payments
- Government benefit distribution
- Inventory controls

Many of the applications listed above are expected to reduce many forms of operational waste. While the quantifiable impacts remain unproven given the stage of implementation of blockchain technology industry-

[10] https://www.youtube.com/watch?v=FkeLDPZ-v8g.
[11] Hancock and Vaziey.
[12] Morris; "Blockchain Reaches beyond Financial Services;" https://www.youtube.com/watch?v=FkeLDPZ-v8g; Hancock and Vaizey; "Distributed Ledger Technology;" "The Blockchain Practice;" Cachin; "Blockchain Innovation in Wealth and Asset Management;" Accenture Digital; Higginson; "Blockchain Proof of Concept with SWIFT Gpi;" Dong; and Burton.
[13] "Blockchain Reaches beyond Financial Services;" Cachin; "Blockchain Innovation in Wealth and Asset Management."

wide, financial services institutions specifically expect blockchain to yield benefits in the following areas in the short term:[14]

- Intrabank cross border payments
- Interbank cross border transactions
- Cross border payments
- Cross border remittances
- Corporate payments
- Person-to-person transactions

Financial services institutions expect these benefits to accrue due to:[15]

- Lower transaction costs
- Lower administrative costs
- Shorter settlement times
- Fewer errors and exceptions
- Lower capital costs

Blockchain has the potential to deliver cost savings to financial services institutions, better customer experiences, and more seamless interactions between enterprises and customers—as well as capturing the benefits of blockchain listed in the previous section.

Use Case Example: Cross Border Payments

Whether it is at the household level or between *Fortune* 100 enterprises, sending payments across a border is, at present, a highly intermediated, cumbersome, somewhat opaque, costly, and slow process. Global financial services institutions with retail bank businesses appear particularly interested in using blockchain to simplify, hasten, and reduce the cost of cross border payments.[16] For the sake of illustration, **Exhibit 6** is a simplified description of how blockchain can potentially improve a straightforward cross border payment.

Sender wants to send money to receiver, and sender and receiver are in different countries using different currencies. Sender goes to their bank (or the bank's website) and initiates the transfer. Sender and receiver's banks then work with networks of domestic and cross border banks, each of which add incremental cost and additional processing time. Fees that sender's bank are charged during the transfer are not always known at its initiation, and it is not always clear when costs will also be charged to receiver.[17] Fees are high, too, running an average of 2% to 3% when volumes of payments and payment values are high, and can exceed 10% if they are low. Sender and receiver are not typically able to track the transfer while it is taking place, either, creating additional uncertainty regarding delivery and final payment amount; as of 2015, the average time to complete a cross border payment was from three to five business days. Finally, total pricing, fees, and foreign exchange rates for the cross border payment are not actually finalized until the funds arrive in the receiver's account.

In this case, if global financial services companies with retail and/or commercial banking businesses set up an enterprise blockchain, this cross border payment could occur in near real time, require no additional intermediaries other than the sender and receiver's banks (i.e., no third parties are needed to verify transactions), and cost a negligible fee (**Exhibit 7**). Additionally, in this case, foreign exchange providers could compete to offer the lowest rate to these global financial institutions for these transactions, and banks in the network could search for and select the best rate offered in the market. Additionally, the transaction would be secure, private,

[14] Accenture Digital.
[15] Accenture Digital.
[16] Hancock and Vaizey; "The Blockchain Practice;" Cachin; Accenture Digital; Higginson; "Blockchain Proof of Concept with SWIFT Gpi."
[17] The remainder of this paragraph is drawn from Higginson.

and verifiable. This could potentially both drive cost savings for the banks as well as the customers and immediately improve the customer experience.

There is evidence that global financial services companies have come to the realization that blockchain technology can be applied to cross border payments. Some of the largest banks in the world, including the Bank of England, [18] are currently piloting applications like this,[19] and the IMF is evaluating it independently for this purpose as well.[20]

But…Is What We Have Already Good Enough?

There appears to be a lot of interest in blockchain across diverse industries,[21] and industry-leading technology companies and financial institutions have deployed teams of experts to work on how to use it.[22] There also appears to be a consensus that blockchain offers a host of new features and benefits versus legacy methods for exchanging value.[23]

Does this mean companies should invest in developing blockchain-driven products or applications? Some experts are skeptical that blockchain technology will find a broader home in industry.[24] The basic argument against investing in a blockchain project appears to be that financial ledgers can be easily expressed as tables (i.e., relational databases), and current best-in-class database tools are more proven tools that are typically sufficient for many needs. More precisely, as Gideon Greenspan argues:

> If your requirements are fulfilled by today's relational databases, you'd be insane to use a blockchain. Why? Because products like Oracle have decades of development behind them. They have been deployed on millions of servers running trillions of queries. They contain some of the most thoroughly tested, debugged and optimized code on the planet, processing thousands of transactions per second without breaking a sweat…[Blockchain] is still in its diapers.[25]

Bill Gates wrote in his 1995 book *The Road Ahead*, "We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten."[26] Applying that concept to blockchain invites reflection regarding whether or not relational databases will be sufficient today but blockchain might be preferred tomorrow.

An Introduction to Network Effects[27]

All other things being equal, blockchain technology becomes more valuable as more people use it to do different things. However, while many large, multinational organizations have carefully studied blockchain and its possible uses, there does not appear to be unified agreement regarding blockchain usage and deployment.

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[18] Burton.
[19] "Blockchain Proof of Concept with SWIFT Gpi."
[20] Dong.
[21] "Blockchain Reaches beyond Financial Services."
[22] "Linux Foundation Unites Industry Leaders to Advance Blockchain Technology," Linux Foundation, December 17, 2015.
[23] "Blockchain Reaches beyond Financial Services;" Cachin; Accenture Digital; "Linux Foundation Unites Industry Leaders."
[24] Gideon Greenspan, "Avoiding the Pointless Blockchain Project," LinkedIn, November 24, 2015.
[25] Greenspan.
[26] Bill Gates, Nathan Myhrvold, and Peter Rinearson, *The Road Ahead* (New York: Viking, 1995).
[27] Richard Johnson, Paul Farris, and Paul Pfeifer, "The Value of Networks," UVA-M-0645 (Charlottesville, VA: Darden Business Publishing, 2001); Anu Hariharan, et al., "All about Network Effects," Andreessen Horowitz, March 26, 2017, https://a16z.com/2016/03/07/all-about-network-effects/ (accessed Aug. 10, 2017).

Why? The answer may be in that blockchain is a "network effect" technology. A network effect describes anything that becomes more valuable to its users as more users use it.

There are several types of networks, and each has a corresponding valuation concept that help explain their value relative to one another. The most straightforward example of the most basic network type is the broadcast, for example, when a group of people consumes the same material at the same time broadcast from a single source. In a broadcast network, none of the viewers are connected with one another and the connection is unidirectional (i.e., information flows in one direction). From a valuation perspective, it has been suggested that the value of a broadcast network is described by Sarnoff's Law,[28] which says that the value of this type of network is proportional to the number of viewers, or *N*.

A step beyond the broadcast network is the homogenous network, in which the same type of user uses a platform or product for a similar purpose. A good example of this type of network is Skype (**Exhibit 8**). To illustrate the value of a network effect within a homogenous network, Skype has more limited value if only two people use it to call each other, but becomes more valuable with tens of millions of users using it for calls, texts, videoconferencing, and so on. From a valuation perspective, the value of networks in which users are connected is described by Metcalfe's Law,[29] which says that the value of this type of network is proportional to the square of number of connected users, or N^2.

A step beyond the homogenous network is the heterogeneous network, in which diverse sets of users use a platform or product for varying purposes. A simple example of this type of network is OpenTable, in which two distinct categories of participants—diners and restaurants—interact with one another (**Exhibit 9**). The value of OpenTable, though, would still be described by Metcalfe's Law. However, one of the features that makes heterogeneous networks so valuable is that groups can form within it. In this case, Facebook may be the ultimate example of a heterogeneous network, as it has a large user base and a large number of self-forming groups. From a valuation perspective, the value of networks capable of generating user groups is explained by Reed's Law,[30] which says that value grows exponentially with the size of the network, or 2^N.

However, as Peter Thiel wrote in 2015, "Network effects can be powerful, but you will never reap them unless your product is valuable to its very first users when the network is small."[31] If blockchain technology attracts diverse users doing different things with it, its value will be described by Reed's Law, and it will become increasingly more valuable as engagement increases (measured by an increasing number of transactions across an increasing number of users occurring at an increased frequency).[32]

Regulatory and Governance Considerations

When novel technologies in the financial services industry gather—or appear to gather—critical mass, regulation follows. Blockchain does not appear to be an exception to this rule. Legislators and central banks started publically talking and wondering about blockchain in 2015 and 2016, and most of the focus appears around payments, clearing, and settlements—"a core element of the financial infrastructure at the national and international level."[33]

[28] Johnson, Ferris, and Pfeifer.
[29] Johnson, Ferris, and Pfeifer.
[30] Johnson, Ferris, and Pfeifer.
[31] Peter A. Thiel and Blake Masters, *Zero to One: Notes on Startups, or How to Build the Future* (London: Virgin Books, 2015).
[32] Hariharan et al.
[33] "Payment, Clearing and Settlement Statistics," Bank for International Settlements, December 11, 2015.

The U.S. House of Representatives is exploring the regulatory and legislative implications of blockchain on payments, clearing, and settlement systems, specifically the irreversibility of a transaction on a blockchain, and that criminals are able to transfer assets and extract bitcoin-denominated ransoms.[34] The Federal Reserve System in the United States is also focusing on payments, clearing, and settlements, believing that "[blockchain] may represent the most significant development in many years in payments, clearing, and settlement."[35] This focus appears to makes sense, too: U.S. payment, clearing, and settlement systems process approximately 600 million transactions per day, valued at over $12.6 trillion.[36] While the Federal Reserve and the U.S. legislature have provided some indication on their respective foci, as of 2017 it is unclear what plans the SEC has to address the regulatory implications of blockchain within the financial services industry.

There is also the question of whether or how digital currency regulations will trickle down to affect blockchain use, and there appears to be regulatory interest connected to how people will ultimately use digital currencies.[37] For example, if people use digital currencies to pay for goods and services, then it is important to remember that bitcoin transactions on the blockchain are permanent and tamper-resistant; transactions cannot be altered retroactively without the full agreement of the network. This presents a possible challenge for merchants and retail customers, for example, in refunding a purchase. If digital currencies are issued to raise money for an enterprise (e.g., an initial coin offering or ICO), the SEC has indicated that it will regulate digital currencies as securities, making them subject to federal securities law.[38] Additionally, product developers are trying to create marketable securities (e.g., exchange-traded funds [ETFs]) that track the value of digital currencies; in March 2017, the SEC denied a bid to list a bitcoin-tied ETF (though this decision appears to be an ETF structure–related decision rather than a blockchain-related one).[39]

From a governance standpoint, public blockchains are decentralized, open-source technologies with no single set of leaders or owners. Industry observers have commented that, for public blockchains and digital currencies, establishing a governance structure—establishing underlying reliability and accountability of public blockchains—will be critical to their continued development and adoption.[40]

Considerations for the Future

At present, blockchain is a relatively nascent technology that appears to offer possibly valuable product and service applications. All practitioners whose businesses might evolve from technological advances need to decide: should they determine how to use this and pursue those opportunities, or should they wait until others try it, see how they do, and learn from their mistakes. The urgency of this decision will vary depending on industry; the financial services industry may undergo a greater degree of evolution sooner than other industries. Industries that feature complicated global supply chains, have high degrees of intermediated global payments, require high levels of data security, and whose transactions face strong degrees of regulatory scrutiny may be motivated to adopt and deploy blockchain within individual enterprises.

For example, blockchain has the potential to improve investment and asset managers' operating businesses, as each one uses retail and wholesale payment systems, trading platforms, clearinghouses, and settlement

[34] "Disrupter Series: Digital Currency and Blockchain Technology," Public Hearing before the Energy and Commerce Committee of the U.S. House of Representatives, March 16, 2016.

[35] "Speech by Governor Brainard on Distributed Ledger Technology: Implications for Payments, Clearing, and Settlement," Board of Governors of the Federal Reserve System, October 7, 2016.

[36] David Mills, "Distributed Ledger Technology in Payments, Clearing, and Settlement," Federal Reserve Board Divisions of Research & Statistics and Monetary Affairs Finance and Economics Discussion Series, 2016.

[37] Higgins; "Digital Currency and Blockchain Technology;" "Speech by Governor Brainard."

[38] Connie Loizos, "In the Murky World of ICOs, this Young Founder Aims to Lead the Way," TechCrunch, July 26, 2017.

[39] Stan Higgins, "SEC Rejects Winklevoss Bitcoin ETF Bid," CoinDesk, March 10, 2017.

[40] Nathaniel Popper, "Some Bitcoin Backers are Defecting to Create a Rival Currency," *New York Times*, July 25, 2017.

systems for securities. However, at present, there is less clarity surrounding financial services industry regulators and what regulations will ultimately govern blockchain use.[41] Will blockchain be the underlying technology that transforms how an asset manager runs core parts of its business? In a vacuum, one could make a strong argument that this is at least possible. Yet as a network effect technology, the ultimate utility in any industry will be a function of who uses it and how.

JPMorgan Chase perhaps offers some directional guidance for financial services; it invested in and built an enterprise blockchain specifically for the financial services industry and are giving it away for free. It believes that its blockchain platform, Quorum, balances data privacy with regulatory transparency, and offers high speed and high throughput processing. Further, JPMorgan Chase is piloting Quorum as an underpinning of the global payments function of their enterprise.

If blockchain can deliver products and services that improve the customer experience and the profitability of an enterprise, the organizations that use it may capture a larger, more profitable share of a competitive marketplace moving forward.

[41] Higgins, "Bitlicense Framework for Bitcoin Business;" "Digital Currency and Blockchain Technology;" "Speech by Governor Brainard;" and Mills.

Exhibit 1

An Introduction to Blockchain

Glossary of Terms

Audit trail: A chronological record, set of records, and/or destination and source of records that provide documentary evidence of the sequence of activities that have affected at any time a specific operation, procedure, or event.[1]

Centralized point of control: The single storage and maintenance location of a database.[2]

Cryptography: The computerized encoding and decoding of information.[3]

Digital identity: Information used by a computer system to represent an external agent.[4]

Digital key/signature: Cryptographic technique used to validate the authenticity and integrity of an identity, message, software, or digital document.[5]

Ledger: A complete record of financial transactions over the life of the company.[6]

Native currency: The "currency" (e.g., bitcoin) required to claim an underlying asset traded on a blockchain from its issuer. This currency is also the form of compensation network members receive that verify public blockchain transactions (called miners).

Permissioned blockchain: Restricts the actors who can contribute to the consensus of the system state. In a permissioned blockchain, only a restricted set of users have the rights to validate transactions and create smart contracts.[7]

Permissionless blockchain: Anyone can join the network, trade assets, validate transactions, and/or create smart contracts.[8]

Relational database: A database that presents information in tables with rows and columns, with the ability to retrieve data from the table based on searchable keys and concepts or commands.[9]

Smart contract: Event-triggered, automated pieces of computer code intended to facilitate, verify, or enforce the negotiation or performance of a contract.[10]

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[1] *Merriam Webster Unabridged Online*, s.v. "audit trail," http://unabridged.merriam-webster.com/unabridged/audit%20trail (accessed Aug. 31, 2017).

[2] "Centralised Database," Internet Archive, https://web.archive.org/web/20140827182930/http://ict.stmargaretsacademy.org.uk/isint2/infosystems/centraldb.html (accessed Sept. 27, 2017).

[3] *Merriam Webster Unabridged Online,* s.v., "cryptography," http://unabridged.merriam-webster.com/unabridged/cryptography (accessed Aug. 31, 2017).

[4] "ISO/IEC 24760-1:2011 - Information Technology -- Security Techniques -- A Framework for Identity Management -- Part 1: Terminology and Concepts." International Organization for Standardization, 2011–2012, http://standards.iso.org/ittf/PubliclyAvailableStandards/c057914_ISO_IEC_24760-1_2011.zip (accessed July 19, 2017).

[5] "Digital Signature," TechTarget, http://searchsecurity.techtarget.com/definition/digital-signature (accessed July 19, 2017).

[6] "General Ledger," Investopedia, http://www.investopedia.com/terms/g/generalledger.asp?ad=dirN&qo=investopediaSiteSearch&qsrc=0&o=40186 (accessed Sept. 27, 2017).

[7] Deva Annamalai, "Blockchain—What Is Permissioned vs Permissionless?" LinkedIn, January 11, 2017.

[8] Annamalai, "Blockchain—What Is Permissioned vs Permissionless?"

[9] "A Relational Database Overview," Oracle https://docs.oracle.com/javase/tutorial/jdbc/overview/database.html (accessed Sept. 27, 2017).

[10] Nick Szabo, "Formalizing and Securing Relationships on Public Networks," *First Monday*, September 1, 1997.

Exhibit 2

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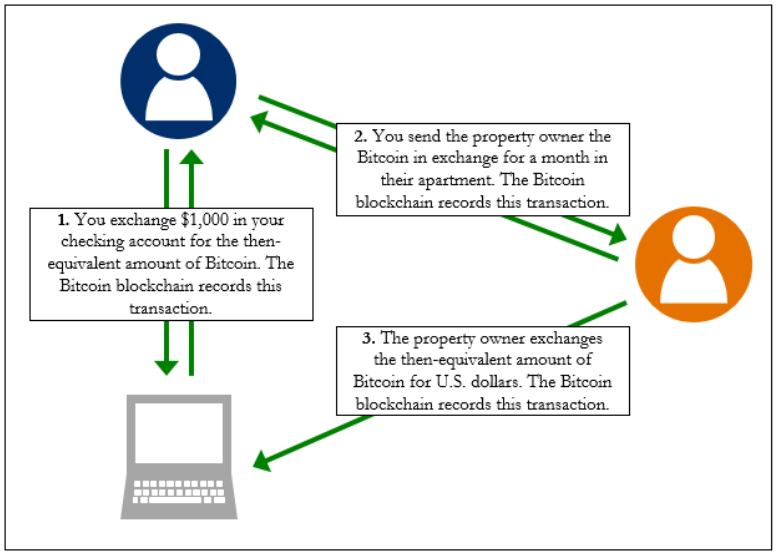
The Lifecycle of Paying Apartment Rent Using Bitcoin

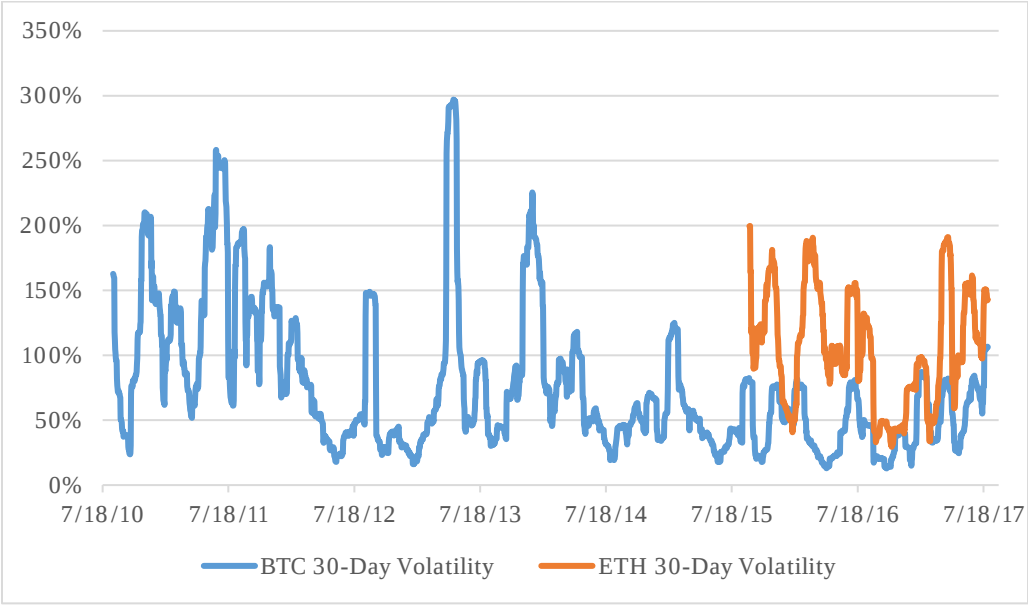


Source: Created by authors.

Exhibit 3

An Introduction to Blockchain

Historical (30-Day) Rolling Volatility (Annualized) for Bitcoin (BTC) and Ethereum (ETH) Since Inception

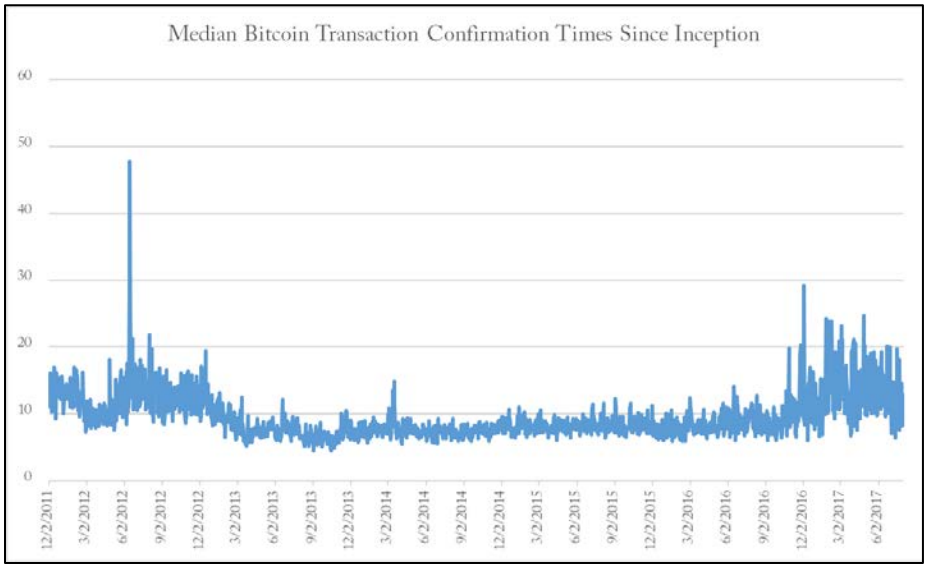


Data source: BraveNewCoin.

Exhibit 4

An Introduction to Blockchain

Median Bitcoin Transaction Confirmation Times Since Inception

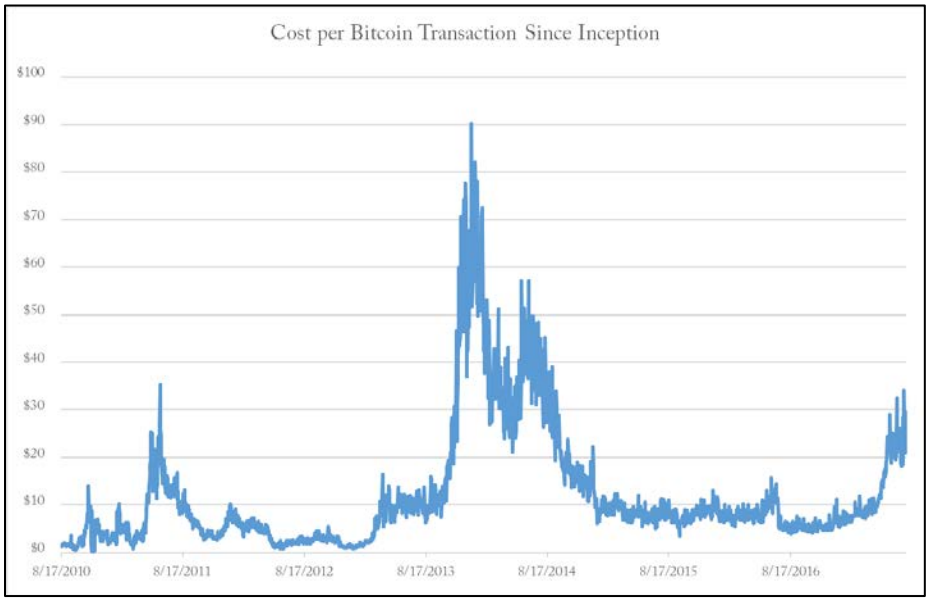


Data source: SpreadStreet.

Exhibit 5

An Introduction to Blockchain

Cost per Bitcoin Transaction Since Inception



Data source: SpreadStreet.

Exhibit 6

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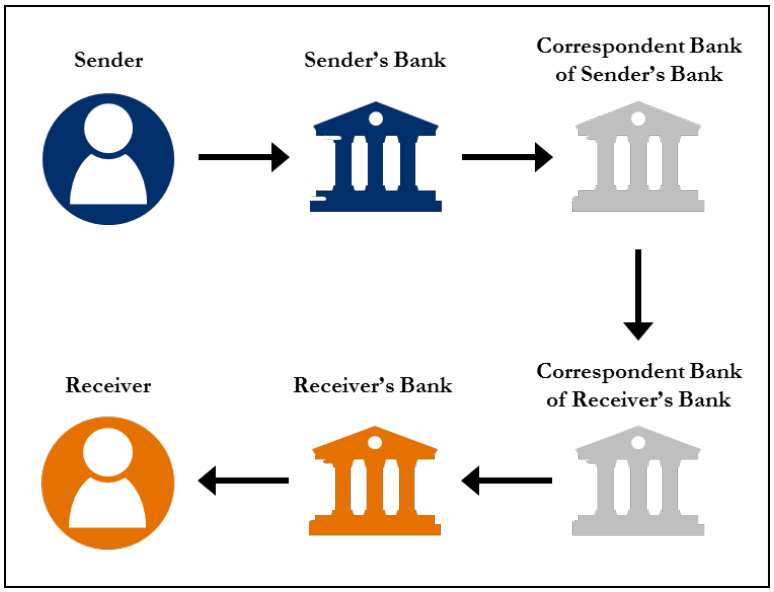
Current Example of a Simple Cross Border Payment



A sender in the United States needs to send money to a receiver in another country in another currency. Sender requests its bank in the United States, sender's bank, send a payment to receiver. Sender's bank requests its correspondent bank facilitate the transfer. Correspondent bank of sender's bank sends the funds to correspondent bank of recipient's bank, which then sends the funds to recipient's bank. At each step, fees and time accumulate. The sender and receiver only know the total amount of fees and the incremental exchange rates once the funds are in receiver's account.

Source: Created by authors.

Exhibit 7

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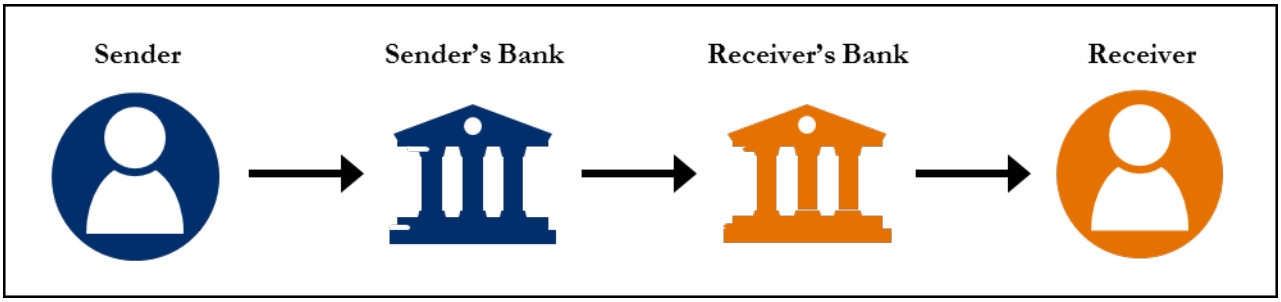
Example of a Simple Cross Border Payment Using an Enterprise Blockchain



Sender in the United States needs to send money to receiver in another country in another currency. Sender requests its bank in the United States to send a payment to receiver. Sender's bank transfers the funds to receiver's bank.

Source: Created by authors.

Exhibit 8

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Example of Homogenous Network

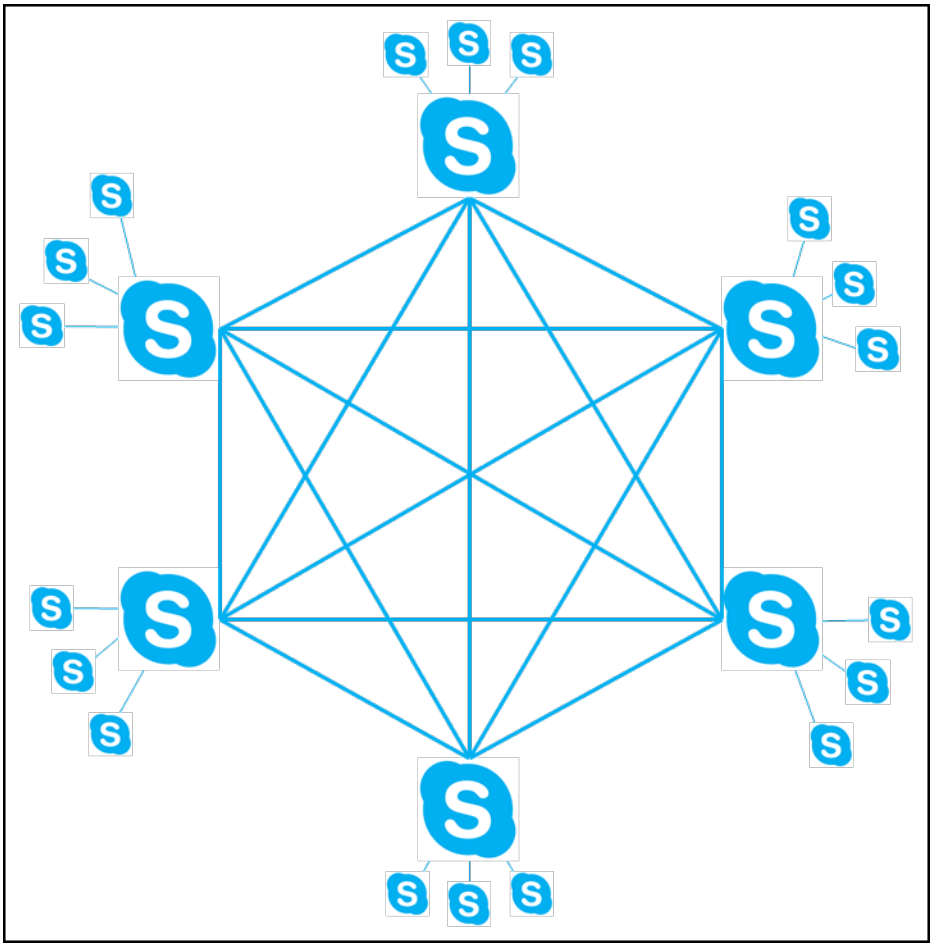

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Exhibit 9

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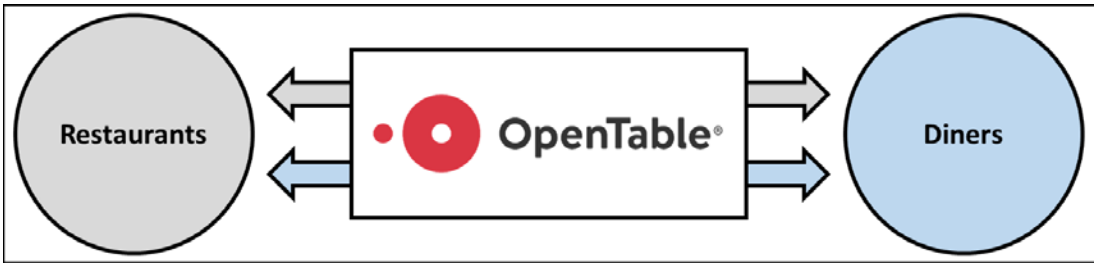
Example of Heterogeneous Network



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