Bachelor Thesis

Blockchain for Development

An exploration of the possibilities of blockchain in Kenya.

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Abstract

Blockchain is said to disrupt and transform the world economy and society through its revolutionary way of creating a trustworthy distributed ledger without relying on a third party to provide this trust. Most research on blockchain is focussed on the west and on large corporations operating in finance, but blockchain offers possibilities beyond that, also in developing countries, where it can be used to leapfrog ICT development. These possibilities are even larger because blockchain can function to reduce fraud and corruption, which is more prevalent in developing countries. This thesis explores the possibilities of blockchain applications in developing countries by examining the case of Kenya. Even though Kenya is not as able as western countries to adopt blockchain, the aim of the Kenyan government to use digital innovations for development offers potential. Subsequently the possibilities of blockchain applications in financial services, trade & aid networks, property registration, elections, and identity management are explored, concluding with the potential of smart contracts in the more distant future. Blockchain applications in these sectors would be comparatively more secure, trustworthy, efficient and less prone to corruption and fraud. Crucial obstacles in blockchain adoption are the divide in access to and education in digital technologies, the perceived complexity of blockchain and the people in power benefiting from the corruption blockchain can prevent.

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1. Introduction

Blockchain is a hype. Blockchain is in the news practically every day and cryptocurrencies like Bitcoin have soared in value. Many people have an opinion on blockchain and cryptocurrencies, but few understand what it is exactly. Large numbers of videos and tutorials are shared on what blockchain is in essence, but for many, its possibilities remain murky. Experts boast the advantages and possibilities of blockchain, the World Economic forum has named blockchain the second generation of the internet which could be ''even more disruptive and transformative than the current one'' (Tapscott and Tapscott, 2017). Books titled 'Blockchain Revolution' are best-sellers. It is safe to say that blockchain is a topic that requires academic attention.

The banking and insurance sector are investing heavily in research & development of blockchain to gain short-term benefits. Large corporations like Walmart and Google are researching its use in their companies. Some academic research on blockchain is conducted to find its potential applications in the economy and our society. Lawmakers are finding ways to fit blockchain into existing legal frameworks or changing the law to facilitate blockchain development. However, there is an important caveat. Little attention is paid to the possibilities blockchain could have in developing countries. Almost all research is focussed on western countries and on big corporations. The possibly even larger potential of blockchain in developing countries, enabling them to leapfrog past current technologies to a higher level of economic development, is largely ignored. Conversely, the possibility of developing countries missing out on this progress is also overlooked. The digital divide between the rich and the poor might grow larger through the introduction of blockchain. The possibilities and obstacles for blockchain adoption in developing countries is therefore a very important matter and hence the subject of this research.

This thesis will explore blockchain in developing countries by focussing on possible adoption of various blockchain applications that currently exist or are in development, by examining the case of Kenya. Kenya has been chosen as the subject for this research because in the past decade it has embraced digital technologies, most notably mobile phones, which has had a transformative effect on Kenyan society and shows potential for blockchain adoption. Since research on blockchain in developing countries is scarce, this thesis will be of exploratory nature. First, an explanation of blockchain and its innovative features will be presented in order to give more insight into this hard-to-pin-down concept. Secondly, a framework of technology adoption is presented, with an insight into what the various stages of blockchain development are, including its status as a potentially disruptive technology that enables leapfrogging. This framework will then be applied to the most important practical applications of blockchain adoption in Kenya, namely in financial services, value chains, property titles, voting, identity management and lastly smart contracts. Lastly general obstacles and considerations regarding blockchain adoption in Kenya will be discussed.

The primary research method of this thesis is literature review. Since blockchain is a young technology, peer-reviewed academic articles on blockchain are scarce, but various academics have written papers on blockchain and its applications. Besides this, I have contacted many blockchain experts and blockchain start-ups for an interview, unfortunately only a few were available. Of the various blockchain start-ups I contacted only one, Ripple, replied to my questions, regrettably none of the Kenyan blockchain start-ups I contacted replied. Furthermore I used statistics from various sources like the World Bank and the Kenya National Bureau of Statistics, combined with various theories and frameworks on (blockchain) technology adoption as a basis for analysis.

2. What is blockchain and why is it revolutionary?

This chapter provides an introduction to the concept of blockchain. It will provide an insight into why the blockchain concept is innovative, important and possibly revolutionary. However, it is important to note that this chapter will only delve into the aspects of blockchain that are necessary to understand with regards to the larger aims of this paper. Technical details concerning the maths, cryptography and computer science behind blockchain will therefore be omitted. First some background information will be provided, subsequently an explanation of blockchain technology and its main features will be given. Lastly the drawbacks surrounding blockchain technology will be discussed.

The concept of blockchain has only existed since it was put forward in the widely cited white paper *'Bitcoin: A Peer-to-Peer Electronic Cash System'* by the unknown entity Satoshi Nakamoto in 2008 (Nakamoto, 2008). In 2009 the open-source software called Bitcoin was released and became the first cryptocurrency in existence (Swan, 2015). In the following years the interest in both Bitcoin and blockchain slowly increased. However, in the past three years the interest in Bitcoin and the associated blockchain has surged, indicated by the large increase in value of the bitcoin currency, currently at 13,000 US Dollars, with the total stock of value being worth 250 billion US Dollars in January 2018 (Nasdaq, 2017). Although the current total value of Bitcoin is large, it is still relatively small compared to other currencies. Its real value is to be found in the new possibilities that the blockchain concept offers. Many businesses, mainly financial institutions, have already recognized its potential and are researching the possibilities blockchain could provide for them (PwC, 2017). Governments and NGO's are also exploring the potential of blockchain. This begs the question: what is blockchain and why is it revolutionary?

The most recurring definition of the blockchain is: a decentralized, public, digital ledger recorded chronologically in blocks (Nakamoto, 2008; Swan, 2015; Swanson, 2015; Baptiste, 2017). This ledger functions on a peer-to-peer consent based network without an owner, with cryptography hiding specific parts of the data, with the rules of the network written down in the protocol. The most well-known and widely used blockchain, the Bitcoin blockchain, is a helpful example to understand how blockchain technology works.

Bitcoin

In the Bitcoin network, many so called peers are connected with each other. A person can send bitcoins to another person through their public address, much like you can send emails to someone through their email address. This transaction and all other transactions in the network are then recorded by all nodes in the network and stored in a block of data which is timestamped and spans a particular amount of time. To create this block, a particular cryptographical code, called hash, needs to be discovered, which requires large amounts of processing power of the nodes in the network (Swanson, 2015). The difficulty of this hashing varies over time and depends on the computing power of the network. This variation is to ensure that the hash for every consecutive block is discovered approximately every 10 minutes (Swan, 2015). Once the hash problem is solved, this is the so called proof-of-work in the case of Bitcoin, the solution is broadcast to all nodes in the network. The nodes in the network can easily check whether the hash is correct or not and can check if all the transactions within the block are valid and not already spent. The network expresses its acceptance of the new block by building onto it by using the hash of the block as starting point for the new hash (Nakamoto, 2008). These linkages of transaction blocks is what blockchain gave its name.

The individual nodes always consider the longest chain of blocks to be the valid chain and will use that as a basis for their hashing operations. The reason for this is that the longest chain has required the most computing power to be created, which means it is the most secure. It is possible that two blocks are created and broadcasted at the same time. If this happens the network might function with two versions of the last block. However when a new block is built on one of these old blocks, the longest chain will be accepted again and so over time a dominant chain will occur (Nakamoto, 2008).

This network is supported by nodes using their computer processing power to find the new hash proof-of-work to validate the transactions in the block. This 'mining' requires large amounts of investment in processing power and significant amounts of electricity. The reward these 'miners' receive is some bitcoins when they are the first to write the new block. This creation of extra bitcoins is written into the Bitcoin protocol and simultaneously functions as a way of increasing the supply of bitcoins. The creation of bitcoins to reward the miners is being phased out in the coming years and will be gradually replaced by transaction fees (Swanson, 2015). This will result in Bitcoin having a steady money supply, theoretically being inflationless.

The blockchain concept proposed by Nakamoto is revolutionary because it gives a solution to the so-called double-spend problem (Nakamoto, 2008). The problem that digital cash could in principle be copied and sent to multiple people at once, just like one can copy a text document multiple times and send it to multiple people (Swan, 2015). Historically a central authority, a bank, would check all the transactions for double-spending since they have the ledger with all the accounts of their clients. The blockchain technology replaces the bank as a central authority by making the whole network responsible for checking all the transfers for the double-spend problem. Since the whole network has a copy of the public ledger, fraud is easily detectable and will be rejected by the network (Nakamoto, 2008). This blockchain network has various qualities that are crucial in understanding the usefulness and possibilities of this technology.

Features of Bitcoin/blockchain
Decentralized

The blockchain network is decentralized, as opposed to centralized or distributed. This means that in theory every node in the network is equal to any other node. Hence, unlike the traditional online banking network which has one or multiple central servers containing all the information, Bitcoin was designed to have all information stored on all nodes (Nakamoto, 2008). This makes the system less vulnerable to attackers because if one node gets taken out by an attack, the other nodes in the system will have the same information and nothing is lost. In reality, the miners in the Bitcoin network have congregated to pool computing power together in so called ''mining pools''. The four biggest mining pools provide more than half of the votes in the network. This pooling does not mean there are less nodes in the network, the pooling is mainly aimed at sharing the benefits of all miners equally. The pools are still divided in separate nodes. However, this does mean that network participants must now trust a small amount of pools to provide the security of the network, which is not how Nakamoto originally designed the Bitcoin network (Swanson, 2015).

Public & encoded

All transactions made within the Bitcoin network are public, on a website like www.blockchain.com you can easily find all transactions ordered chronologically in the blocks. The transactions show the sender, receiver and the amount transferred. The sender and receiver are however, identified by their public address, not their private key. This means that individuals are still completely anonymous, unlike our conventional banking system, where an authority can gain access to people's transactions. This is the reason the Bitcoin network is often perceived as a means for illicit activity (Swan, 2015).

Immutable
In a blockchain network, the data stored through cryptography in the ledger are immutable, not alterable (Tapscott and Tapscott, 2017). Because every node in the network has a copy of the ledger, if one illicit node changes their copy of the ledger and broadcasts it, the network will not accept it. In the case that two new blocks are broadcast at the same time, the one that the network builds upon will be accepted as the correct block. This means that after a few blocks, less than an hour, the transactions are safely stored behind a large ever-growing computational puzzle, almost impossible to change (Swan, 2015). Changing this would require so much computing power that it would be more economical to utilize this computing power to mine new blocks and earn newly minted bitcoins and a transaction fee (Swanson, 2015).

Types of blockchain

As the largest, oldest and most researched blockchain, the Bitcoin blockchain is a good way of understanding the novel concept of blockchain and is the blockchain protocol discussed thus far. However various other kinds of blockchain exist, all with different attributes and protocols. The most important other blockchains are Ethereum, Ripple and Everledger. These variations in blockchains have various properties that can be mutually exclusive (Peters and Panayi, 2016). Important distinctions between the differing blockchain architectures are the rules regarding who can be a node in the system: permissioned versus permissionless, and who can view the blockchain data: public versus private (Peters and Panayi, 2016). These distinctions are displayed as two axes in figure 1. It is important to note that one type is not necessarily better than the other, the blockchain architecture needs to suit its use.

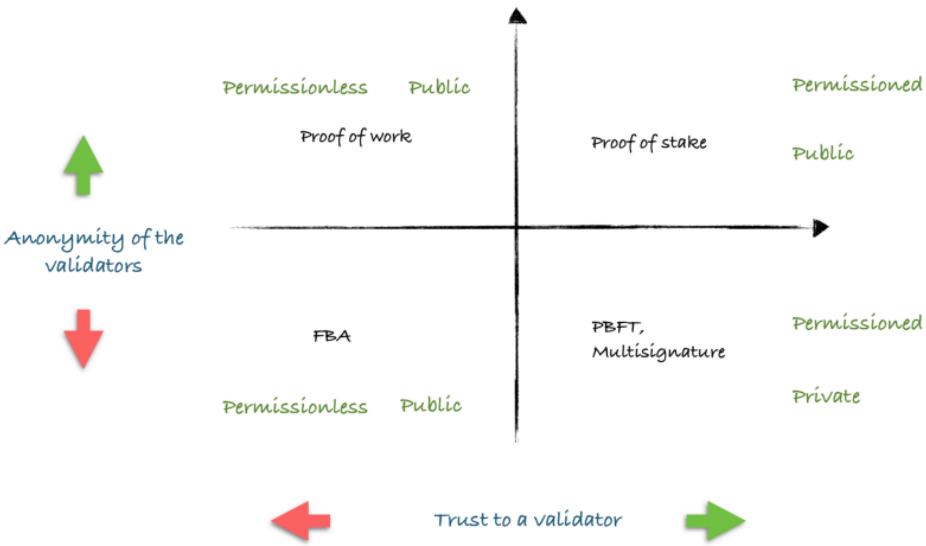

Figure 1 Model by Kravchenko (Kravchenko, 2016)

The X-axis in the model represents the level of trust in a validator, in the Bitcoin network this is called a miner. On the left side, trust in the validator is low because the blockchain is completely permissionless, this means that the blockchain is open-access to anyone and no permission from any authority is required to become a node in the network. On the right side trust in validators is high, because the participants in the network need to be permissioned to become a node by some authority. This means that only trustworthy, known validators are admitted into the network, which means incentive mechanisms are not required to foster cooperation and consensus, as is the case with Bitcoin (Mattila, 2016). On the Y-axis in the model the anonymity of the validator is represented, with complete anonymity at the top and the level of anonymity decreasing when going down.

The top left quadrant is permissionless and public blockchains. An example of this is the Bitcoin blockchain which would exist in the far top left corner of the quadrant, being fully anonymous and exhibiting a high level of distrust in validators since it is completely permissionless, needing an incentive mechanism to prevent malicious activity (Swan, 2015). Security is provided through the proof-of-work consensus and all validators are theoretically equal and can only distinguish themselves through their computing power. There is no authority and changes in the protocol can only be created through consensus of the majority of the network (Kravchenko, 2016). Various problems including scalability issues arise, more on this in the section on drawbacks of blockchain.

In the top right quadrant permissioned public blockchains are situated. Permission often takes the form of Proof-of-Stake. This means that a certain amount of coins need to be held by a validator, which then will be taken away in the case the validator conducts malicious activity. This is all still determined by an algorithm, thus there is still no central authority, the rules are determined by the protocol which is determined by the nodes in the network. The Proof-of-Stake allows for policing the validators' behaviour without knowing their identity, allowing for full anonymity still. An application of this concept is Ethereum in the future.

The bottom left quadrant is for largely permissionless, public blockchains. The permissionless aspect means something different than it does with Bitcoin however. In this case it means anyone that fulfils certain small requirements can become a validator. Since the validators in this quadrant are not anonymous a good example of a requirement can be that the validators need to identify themselves as citizens of a certain country (Kravchenko, 2016). Attacks by validators can then be prevented through a Federated Byzantine Agreement, as successfully applied by Stellar, for more information on this see Mazières (2015).

The bottom right quadrant of figure 1 applies to permissioned, private blockchains. This means that validators need to receive permission from the authority over the blockchain to become a node. The data in the blockchain is private which means that it is not accessible to outside parties. Because of its high trust in validators, the consensus mechanism can be simple, allowing for high scalability. A successful application of this is Ripple (Peters and Panayi, 2016). In theory, a traditional single-owner database is in the far right bottom corner, with the permission to be a node is only granted to the owner and the identity of this owner is completely known (Rafiee, 2018). To reiterate from a different perspective what is revolutionary about blockchain, it is the fact that a trustworthy database can be created without a single authority giving permission to validators to be part of the network while ensuring full anonymity of these validators. This has been enabled by the proof-of-work mechanism designed with Bitcoin, although various other mechanisms are possible, however they compromise anonymity, decentralization and possibly security and might reinstate the need for an authority of some sorts (Swan, 2015; Swanson, 2015; Kravchenko, 2016).

Drawbacks of blockchain

Although the blockchain technology is a promising, revolutionary technology, it has several technical drawbacks. Since Bitcoin is the most researched blockchain, the drawbacks of the Bitcoin blockchain will be discussed. First of all, if Bitcoin were adopted in the mainstream, the current maximum limit of 7 transaction per second would be extremely prohibitive. To compare, the VISA network can accommodate peak volumes of 10,000 transactions per second(Swan, 2015). Simultaneously, another drawback is the fact that bitcoin transactions take at least 10 minutes to be safely confirmed. In the case of a large transaction, it is better to wait more than an hour, to avoid a double-spend attack. To scale up the amount and speed of the transactions two other problems arise, the acceleration of the blockchain bloat and the use of a hard fork:

The current size of the Bitcoin blockchain is approximately 140 GB and it is expanding almost exponentially. This is much larger than expected by Nakamoto and since the blockchain cannot be compressed for security and accessibility reasons, it poses a problem (Nakamoto, 2008). If the network was to facilitate even more transactions, this problem would get worse, this is called the blockchain bloat. The other problem that arises when scaling up the number of transactions is the need for a so-called hard fork. A hard fork is a split in the chain with the new chain ultimately taking over from the old one, which is achieved by changing the rules of the protocol. The technical details of this hard fork are beyond the scope of this thesis, but they imply large security, functioning and immutability problems (Tapscott and Tapscott, 2017).

The electricity use associated with mining bitcoins is another technological drawback of the Bitcoin network. Since the Bitcoin blockchain uses a proof-of-work mechanism, large amounts of computational processing power is necessary to mine the blocks (Malone and O'Dwyer, 2014). The estimates of electricity use of the network vary tremendously because the computing equipment used by miners is unknown and the size of the network changes rapidly. However, estimates provided by digiconomist.net – which are supported by scientific research – indicate that the electricity use of the Bitcoin network is approximately 36 Terrawatthours per year (Digiconomist, 2017). This is similar to a country like Qatar or New Zealand (Central Intelligence Agency, 2017). O'Dwyer and Malone estimated this energy consumption already in 2014 when the Bitcoin network required significantly less processing power (Malone and O'Dwyer, 2014). Figure 2 shows the steady increase of the energy usage of the Bitcoin network, which is closely related to the price of a bitcoin, the higher the price of Bitcoin, the more lucrative it is to be a miner. This increased processing power of the network automatically increases the difficulty of mining the next block, which then requires more energy to be mined (Nakamoto, 2008).

Figure 2 Estimated energy consumption of the Bitcoin network in TerraWatt Hours per year (Digiconomist, 2017).

This large energy consumption is arguably a serious problem with regards to sustainability, system costs and Bitcoin's image. Defendants on the other hand have argued that the total energy costs related to the traditional banking sector are roughly the same (Tapscott and Tapscott, 2017). To cut costs, most mining activity happens where the electricity is cheapest and air is cool enough to provide natural cooling for the CPU's, which is mainly in Tibet and Iceland (Tapscott and Tapscott, 2017). To solve the problem of high energy consumption, Bitcoin could move away from the energy intensive Proof-of-work system to alternative ways for reaching consensus such as the proof-of-stake mechanism of Ethereum. This would only use a fraction of the energy Bitcoin currently uses, though this could jeopardize security (Swanson, 2015). This problem is only applicable to permissionless, public blockchains however, since those blockchains will often rely on a proof-of-work consensus mechanism (see figure 1).

Another technical problem associated with Bitcoin is the possibility of a 51-percent attack. This means that more than half of the network's processing power will cooperate to disturb the network and double-spend previously spent coins to their own account. The current trend of centralization of computing power in mining pools will increase this risk (Swan, 2015; Swanson, 2015).

Other problems surrounding Bitcoin and blockchain are not technical but social in nature. The public perception of Bitcoin as a technology used for illicit activities is a barrier to mainstream adoption of the technology (Swan, 2015). Many online marketplaces for illegal goods and services (such as Silk Road in the past) use bitcoins since it enables complete anonymity in transactions. Even though Bitcoin is a neutral technology, which means that it can be used for both good and bad, it enables illegal activities. However, the Bitcoin scandals of the recent past, related to theft and scams, seem to have become less frequent. The fact that Silk Road is now offline aids the reputation of Bitcoin as well (The Guardian, 2014). However, recently, critics have called the rapid increase in value of Bitcoin a bubble, thereby further affecting the public perception of bitcoin as a viable alternative to fiat currencies (The Economist, 2017).

Another current and future problem of Bitcoin and blockchain is the legal framework surrounding it (Swan, 2015). Cryptocurrencies do not quite fit in the existing legal frameworks of countries, with some countries awkwardly trying to fit it in. The Australian government cannot fit Bitcoin in the legal framework as a currency since their laws dictate that currency is nationally issued. In the US, the IRS treats Bitcoins as shares, while most other US government institutions treat it as currency. Taxation of Bitcoin is difficult since transactions are anonymous (Swan, 2015). If Bitcoin were adopted by the mainstream as a means of payment, this would therefore pose real problems in the field of taxation. Moreover, statistics such as GDP would be seriously affected as well (Tapscott and Tapscott, 2017). Due to these problems, some countries have responded by completely banning Bitcoin. China for example has banned the trading of bitcoins for all financial institutions. Moving past cryptocurrencies, the legal framework for other blockchain activities like smart contracts, asset management, and digital identity verification lags behind real-world developments (Katz, 2015). However, regulations regarding blockchain will be vital in the development of these technologies into mainstream use.

Lastly, another problem surrounding blockchain is the low level of investment it faces. Blockchain is in its nascent stage of development and needs significant investment to develop into a mature technology. The total investment in blockchain is about 5 times lower than in the internet when it was at a similar stage of development, as confirmed by a report by PwC (PwC, 2017).

To conclude, blockchain is a revolutionary technology because it enables the internet to transform from a medium of information exchange into a medium of value exchange without needing an intermediary. Blockchain technology is immutable, decentralized, public and encoded. Its main technological drawbacks are its scalability constraints, energy use, and security issues. Social drawbacks consist of the problems regarding Bitcoin's image, the legal framework surrounding the new technology and its low level of investment.

3. What research exists on the adoption of new technologies, applicable to blockchain?

Technology forecasting is an extremely challenging field of study, it is subject to fundamental uncertainty and is influenced by the developments of the technology itself and the socioeconomic system it is functioning in (Derbyshire and Giovannetti, 2017). The forecasting literature on blockchain is scarce, blockchain technology is still in its infancy and many of its uses are still to be discovered. Besides this, much of the literature on blockchain adoption is focussed on large companies operating in finance and insurance in the global north. The developing world is mostly excluded from the current research. The following section will provide a framework of existing research through which we can take on the challenge of forecasting the adoption of blockchain in Kenya by exploring the technology adoption of products, the theory of disruptive technologies, a framework by the Harvard Business Review on the timeline of blockchain development and lastly factors affecting leapfrogging.

In the widely cited book 'Diffusion of Innovations' by Everett M. Rogers from 1962 he provides a comprehensive framework for the diffusion of technologies. This framework is still very relevant today and the five distinct attributes Rogers describes are useful to analyse the adoption of blockchain. These five attributes of innovations are relative advantage, compatibility, complexity, trialability and observability (Rogers, 1995). Rogers emphasizes that the perception of these attributes by the receiver of the innovation is crucial in understanding its adoption. It is important to note that these five attributes interact with each other and can therefore possibly magnify or decrease each other's effects.

'Relative advantage is the degree to which an innovation is perceived as being better than the idea it supersedes'(Rogers, 1995, p. 213). The relative advantage can stem from economic profitability, ease of use of the innovation, increases in social status associated with the innovation and many other factors. Intuitively, economic profitability is an important factor and research shows that it is the most important determinant of relative advantage. However, this varies extremely, dependent on the receiver of the technology, small scale businesses are often less concerned with economic profitability than larger businesses. For individuals, status is often a more important consideration than for larger businesses. The timing of the economic benefits is also a crucial consideration, when the economic benefits lag behind the adoption of the new innovation, adoption rates will be lower because people tend to consider the short-term benefits. Incentives can increase the rate of adoption and can make people adopt the innovation that otherwise would not have. For a technology with network effects this can be a good strategy.

Compatibility is positively associated with the rate of adoption (Rogers, 1995). Compatibility is the degree to which an innovation is perceived to be consistent with existing elements in a social system. These elements are sociocultural values and beliefs, previously introduced ideas and the innovation needs of potential adopters. When an innovation clashes with cultural values and beliefs, adoption of the technology will be very limited because culture is relatively stagnant, and it will take a long time to change to allow for adoption. An innovation also needs to be consistent with old ideas. People assess innovation with their current worldviews, and when these clash, adoption is challenging. An innovation also needs to be compatible with current perceived needs and wants. Change agents need to assess the needs and wants of the adopters to ensure fulfilling these needs, which requires being close to the target group and understanding them. Some people might not be aware of their own needs until they get revealed to them, however this is very difficult. To increase compatibility, the new product needs to be positioned in the market congruent to the existing social system.

Perceived complexity of an innovation has a negative relation with its adoption. Complexity means how difficult an innovation is to understand and to use. When the potential of an innovation is unclear to possible adopters and they need to make an effort to find this out, they might be discouraged from adopting the innovation because of this barrier. When an innovation is simple to understand, its relative advantage will also become clearer.

Perceived trialability of an innovation is positively related to its rate of adoption. When an innovation can be tried out on a small scale the uncertainty of adoption will be reduced. When early adopters have tried out the product already and are positive about it, the majority does not have to try it themselves. Therefore trialability is more important for early adopters than for later adopters.

Observability of an innovation's results is positively related to its rate of adoption. When the results are easy to measure and communicate within a social system, this will increase the rate of adoption when the innovation has positive results. This means that the comparative advantage and the observability interact to increase adoption rates. Rogers notes that software is harder to observe than hardware and therefore states that when the software component is dominant, adoption rates will be lower (Rogers, 1995). Taken altogether, the framework by Rogers provides a clear and simplistic insight into the factors of a product which affect its adoption. Chapter 5 will delve into specific applications of blockchain and will use the five factors discussed above to determine the possibilities of blockchain adoption.

Another framework that is useful to assess future adoption of blockchain is the disruptive innovation theory by Christensen. In Christensen's 1995 article on disruptive technologies he introduces this concept (Bower and Christensen, 1995). He identifies two types of innovation, sustaining and disruptive. Established companies often fail when new technologies are introduced because they do not 'catch the wave' of the new technology. This happens when a new technology is not immediately useful in the current market they are serving. A small company will then often take the new technology that initially performs worse and improve it faster than the established technology is being improved. This causes the established technology to lose the market to the new disruptive technology, which in the end performs better. Established companies often do not pick up on this opportunity because they stay close to their market and because investments in disruptive technologies are often more risky. Their experience as a company is often more useful in the existing market which makes it harder for them to switch. Sustaining technologies on the other hand, are innovations that improve the performance of an established product slightly which stays close to the consumer's needs. Arguably, revolutionary innovation is a third kind of innovation. This is an innovation that is revolutionary in the way it functions technologically, but it does not have any widespread use so that it does not disrupt existing markets significantly. An example of this is the combustion engine car, being revolutionary compared to horses however before the mass-production of Ford it did not disrupt the market. These characterizations by Christensen are useful to assess how blockchain can sustain or disrupt existing markets.

Adoption does not occur consistently, there is temporal and spatial variation. One commonly accepted model of technology adoption is the technology adoption life cycle model (Rogers, 1995; Moore, 2001). Adoption occurs in five distinct consumer groups with clear characteristics for each group. The model is a generalization of reality, however it provides good insights in possible adoption paths for blockchain applications. The model is presented in figure 3.

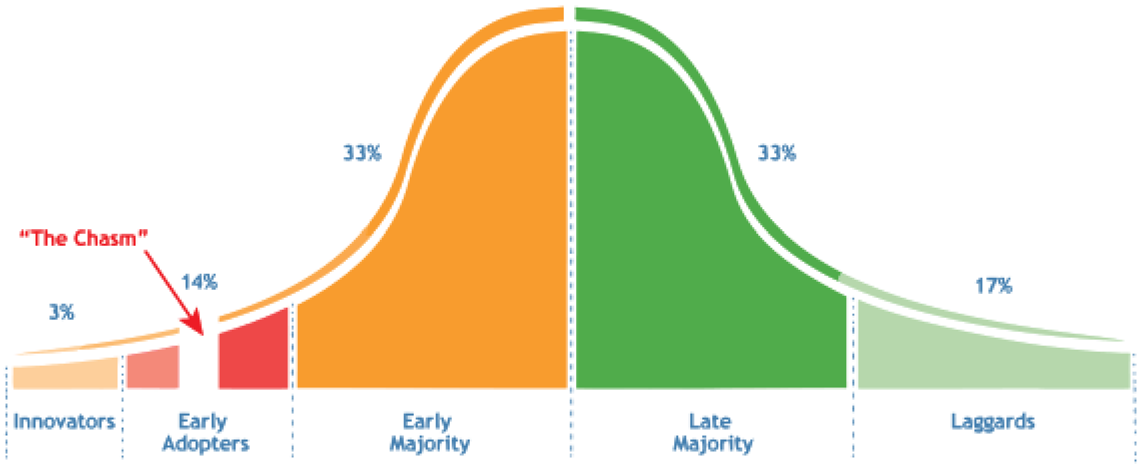

Figure 3 The Technology Adoption Life Cycle Model (Alexandrou, 2013)

The first adopters, the Innovators, are eager to try new ideas. Generally, Innovators are relatively rich, venturesome, cosmopolitan, well-connected to other Innovators, and knowledgeable about new technologies. They are intrigued by the newness of the technology and usefulness is secondary to them. The Innovator plays an important role in the adoption of a new technology by being the gateway of new ideas flowing into a social system. Early Adopters, like Innovators, are quick to adopt a new technology. However, they differ on various other factors. They are not cosmopolites, but localites. They are more connected to the local social system and have the greatest level of opinion leadership in a social system. Unlike Innovators, they are not tech-lovers. They are educated and find it easy to understand and appreciate the merit of new technologies for the function they have. They are very independent in their judgement of the new technology and do not require references to adopt a new technology, they are the opinion leaders.

The Early Majority adopts new technologies just before the average member of society. At this moment the new technology will be quite well-known in society and it has become clear that it is not just a fad, Early Adopters have established that the innovation has real benefits and the early majority wants to benefit from this practically. They deliberate longer because they are more conservative and are less rich than the Early Adopters. The Late Majority has a similar decision making process to the Early Majority. However, they are much more sceptical of new technologies. They are often older, less educated, less rich and are not confident in their own ability to handle new technologies. They are also often less socially connected. They wait until the new technology has become the standard in society. Through peer pressure from the Early Majority they are convinced to adopt the new technology. Laggards, the last group to adopt new technologies are traditional, old, least educated and possess small financial capabilities to adopt a new technology. They simply do not like new technologies since they mostly look to the past for guidance. They are the most socially isolated and very local. Making these people adopt a new technology is near impossible and will often only happen when it is inevitable for them.

Various other lessons can be learned from the technology adoption life cycle. Technology spreads from more connected areas to less connected areas, from urban to rural areas. Earlier adopters are often larger companies, more commercially oriented and are more specialized. Earlier adopters are often more educated/literate and have a higher social status. Earlier adopters are more favourable of change, view science and education in a more positive way and have higher aspirations (Rogers, 1995). These generalizations are useful in assessing how blockchain will spread.

One common adaption of the technology adoption life cycle is the addition of a chasm, proposed by Geoffrey Moore (Moore, 2001). He argues that between the Early Adopters and the Early Majority there exists a large gap that needs to be crossed by the technology in the adoption process. This is because the two groups have very different expectations from the technology. The first group is interested in technology and is willing to take a risk to be the first one to try out the technology. They are also willing to put in significant amounts of time to understand the new technology. The second group is mainly interested in practical benefits of the technology, they want clear benefits that are easy to attain. When the technology does not have clear benefits that can be easily conveyed the technology risks not being adopted by the Early Majority. The Early Adopters are the opinion leaders in adopting the new technology and they have a large influence on later adopters. For successful market-wide adoption the Early Adopters need to be very positive about the technology. The product also needs to change to a 'whole' product. That means that the new technology must have customer support, training and other aids to make it very easy for the Early Majority, who are not willing to experiment and do research on the product like the Early Adopters. Crossing this chasm is a challenge for all technologies, especially for blockchain applications, since blockchain is often conceived as complex.

The timespan of the technology adoption cycle varies per technology. It is hard to predict how blockchain will move through this, Iansiti and Lakhani (2017) provide a useful framework for this however. They compare the adoption of blockchain to the adoption of the internet almost 50 years ago. This is because just like the internet, blockchain is a foundational technology, not a disruptive technology like many name it (Pilkington, 2015; Iansiti and Lakhani, 2017). The internet has been the foundational technology for services like email, which disrupted the market for mail. Similarly blockchain is the foundational technology for Bitcoin, or cryptocurrencies in general, which have the potential to disrupt the conventional financial markets.

The analogy can be drawn further, the internet protocol enabled decentralized information sharing through an open, shared, public network, and similarly, blockchain enables decentralized value sharing through an open, shared, public network. The internet enabled significant reductions in the costs of information connections, the blockchain protocol enables significant reductions in the costs of transactions. The first uses of the internet and blockchain have been single-use: email among researchers in the US and Bitcoin for a small number of transactions for a small number of people. After these first uses, localized adoption of the internet and blockchain took place. Many companies have adopted the internet protocol to create localized networks to share information within their companies. Similarly, many financial institutions are currently exploring and adopting a localized, small-scale version of blockchain in their own infrastructure.

Iansiti and Lakhani (2017) use this analogy described above to argue that blockchain will follow the internet in the way it is adopted and present a framework for blockchain adoption, as presented in figure 4. The model explains the way in which a foundational technology evolves into applications through two dimensions: the degree of novelty and the amount of complexity and coordination. The first dimension, novelty, is the degree to which the application is new to the world. The more novel it is, the harder it is for adopters to understand what functions it serves. The second dimension, complexity, is represented by the level of coordination involved. The more parties involved, and the more diverse these parties are, the more coordination is required increasing complexity. The four quadrants follow each other from single use, to localization, to substitution, to lastly transformation.

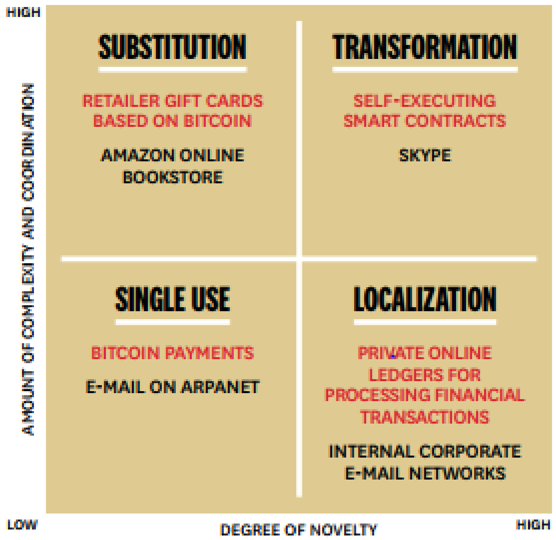

Figure 4 Framework for blockchain adoption (Iansiti and Lakhani, 2017)

In the single-use quadrant are low complexity and low novelty applications which are focussed on one service. They are comparatively better and lower in costs but only in a very specific situation. That is the category where Bitcoin exists in now, the application is disruptive but on a very small scale. Its effect on society is almost negligible but its real influence exists in the hype surrounding it. Therefore, in Christensen's framework this technology would be considered revolutionary, because of its small disruption (Bower and Christensen, 1995).

The second quadrant is the localization phase. The innovations taking place are high in novelty however they are undertaken by only one, or a few very similar parties. This is what many financial institutions are working on right now, incorporating blockchain in existing infrastructure and applications. This phase is similar to the adoption of intranet email in corporations in the 80s and 90s. These applications are sustaining innovations created by incumbents to gain a benefit in their efficiency. Their individual effects can be small but their overall economic effect can be considerate.

The third phase is the substitution quadrant. This applications in this phase are relatively low in novelty, since they are based on existing services, however now using the new foundational technology to provide these services, replacing existing infrastructure. They do require a large amount of coordination though, since they involve many diverse parties. In the case of the internet an example is ecommerce, and for blockchain the example used by Iansiti and Lakhani is using cryptocurrencies outside of the designated ecosystem in the broader economy. Another example would be a property registry based on blockchain, piloted in various countries already. The challenge this phase brings along is that individuals, businesses and institutions have norms, laws, traditions and practices that need to change to enable these new applications. In Christensen's framework, this quadrant is sustaining innovation since it allows incumbent firms to improve existing services (Golden, 2017).

Applications in the last quadrant could completely transform political, economic and social systems by being both novel and complex. It involves coordination between many diverse actors and requires social, legal and political change. Smart contracts are the prime application in this category. In this category fit the real 'disruptive' technologies in Christensen's framework (Golden, 2017). According to Iansiti and Lakhani reaching this full potential will take decades, similar to the full scale adoption of the most complex and novel applications of the internet. This timeframe is quite conservative for multiple reasons.

The main reason the timeframe might be too conservative is the fact that the world today is not the same as it was when the internet was developed. The world is more connected, educated, globalized, and is used to working with digital technology. Besides that, the necessary infrastructure, e.g. broadband cables, Wi-Fi, computers and data providers already exist. Blockchain is often named the internet 2.0. This perfectly captures how blockchain is very different and innovative compared to the internet as we know it, however it does not have to be built up from scratch, there is already a base to work on, which will shorten the timeline of technology adoption. Bernard Golden, a blockchain expert, is also of the opinion that it will be shorter than 30 years (Golden, 2017). The reasons he provides for this are twofold. Firstly, most of the infrastructure already exists as mentioned before, secondly, people are already used to working with digital technology. In terms of the adoption model by Rogers (1995), the compatibility of blockchain with current society is higher than the compatibility of the internet with society 30 years ago. People are used to banking through their phones, digital communication and typing on a keyboard. This will accelerate the adoption of blockchain.

The above framework provided by Iansiti and Lakhani (2017) is a useful base on which to build a conceivable timeframe of blockchain development and adoption. Even though their timeline might be too conservative, the order of innovations is likely to follow their predictions. However, this prognosis is based on the west, there is no timeline for developing countries yet. In order to answer the larger question regarding the ability of blockchain to leapfrog developing countries to higher levels of development the next section will be devoted to the existing literature on leapfrogging and how it can occur.

Leapfrogging is a concept in theories of development which can accelerate development drastically by skipping old, inferior, more expensive or less efficient technologies and immediately moving on to a more advanced technology. This means that developing countries do not need to go through the same trajectory as developed countries in order to reach higher levels of development but can adopt high technologies quicker through the shortcut of international diffusion of technology (Fong, 2009). ICT's are often mentioned as the prime technology that enables leapfrogging (Steinmueller, 2001). Historical evidence suggests that this has occurred multiple times in various places on earth and that it provides real opportunities for developing countries to even surpass developed countries when the conditions are favourable (Brezis, Krugman and Tsiddon, 1993) (Soete, 1985). These conditions are important in assessing the eventual impact of blockchain applications.

Firstly, the costs of the technology. When supply is limited to one or a few sellers, the new advanced technology might be prohibitively expensive (Brezis, Krugman and Tsiddon, 1993). The existence of patents might increase prices too or even completely prevent diffusion (The World Bank, 2008). The technology might also of itself be expensive to purchase. Secondly, the technology might not be appropriate for the local conditions to be adopted. Most high technologies are developed in western countries where western contexts determine the development of the technology (Weil, 2013). The technology might then not be suitable for conditions in developing countries. The technology might also be too complex to adopt easily. A technology is rarely just a blueprint that can be used by everyone. Tacit knowledge, knowledge that is difficult to transfer or explain, often plays a big role in utilizing technology effectively (Weil, 2013) . The technology might require trained staff or customer support. Lastly, complexity in terms of how a technology connects to the world, is an important factor. A stand-alone technology, a technology that does not need integration in an existing system of any kind, is the easiest to adopt (Islam, 2009). The more support in terms of both physical and human capital such a technology needs to integrate it in the existing system, the harder it is to adopt. On the other hand, the less integrated the technology is, the lower its impact will be in terms of positive externalities on the system (Fong, 2009). The local conditions are therefore crucial in the possibility of leapfrogging.

The capability of a country to adopt a new high technology and use it to leapfrog past older technologies is the absorptive capacity (Islam, 2009). The next chapter will delve into the specific absorptive capacity of Kenya as a case study for the adoption of blockchain.

4. How ready is Kenya for blockchain?

Country profile

Kenya is an equatorial East-African country covering an extensive and diverse terrain from the Indian Ocean to Lake Victoria to Lake Turkana, neighbouring Tanzania, Uganda, South Sudan, Ethiopia and Somalia. Kenya has a population of approximately 48 million people. Its population is ethnically diverse and is one of the youngest populations in the world due to Kenya's high birth-rate, averaging at 19 years (Central Intelligence Agency, 2017). However, Kenya's birth rate is steadily declining, from over 8 births per woman in 1970 to less than 4 births per woman in 2015. In the demographic transition model a declining birth rate is a consequence of modernity, which is associated with new technology adoption (Kirk, 1996). Only 27% of the population lives in urban areas, mainly in the capital Nairobi and the port city of Mombasa. Kenya has been a presidential representative republic in a multi-party system since 1992, however it is classified by The Economist Intelligence unit as a hybrid between a democracy and an authoritarian regime with low scores for all political indicators (Economist Intelligence Unit, 2016). Corruption is rife in Kenya, Kenya ranks 145^{th} of all countries with a score of 26 out of 100 according to the corruption perception index by Transparency International, only slowly improving over time (Transparency International, 2016).

Kenya is the economic, financial, and transport hub of East Africa (Central Intelligence Agency, 2017). Its $70 billion economy has averaged 5% growth for the past 8 years and is expected to keep growing in the future. Since 2014, Kenya ranks as a lower middle income country with a GDP per capita of $3,400 in Purchasing Power Parity terms. Although Kenya has seen large growth in the past years, around 40% of the population lives under the poverty line and a similar share of its workforce of 19 million people is unemployed. Agriculture encompasses 35% of the economy but 61% of the workforce because the majority of the sector is small-scale, low investment agriculture (Central Intelligence Agency, 2017). Agricultural products are a large share of exports, with tea, coffee and fresh flowers being its main export products. Droughts threaten the agricultural sector and make many Kenyans food insecure through high food price inflation (USAID, 2016). Despite being the regional industrial centre, industry comprises only 17% of the economy and many industrial products need to be imported from countries like China, creating a large current account deficit (Kenya National Bureau of Statistics, 2017). Tourism is the main service sector and is growing fast, with 37% in 2016 (Central Intelligence Agency, 2017). The Kenyan government aims to increase tourism even more as part of a plan to reach a middle income country status with a GDP per capita exceeding $10,000 by 2030 (Ministry of Information Communication and Technology, 2007). Reducing corruption will be a large challenge in achieving that goal.

Kenya's absorptive capacity

Assessing a country's potential to adopt blockchain is a great challenge. Various factors need to be taken into account. Governmental institutions, regulations, technological infrastructure, education level and business environments vary greatly among countries in the world. Blockchain adoption will not follow the same pattern across the world and a systematic way of measuring countries' capabilities regarding IT related adoption needs to be used in order to assess its diversity. Such measures exists, the Networked Readiness Index (NRI) produced by the World Economic Forum provides a score for almost all countries and is the most extensive index compared to other indexes such as the Digital Planet report and the report by the International Communications Union. The NRI is an international assessment of countries' capacity to exploit the opportunities provided by ICT's, and maps out factors that contribute to this capacity (WEF, 2016). The NRI is a composite indicator built up from 4 sub-indexes, 10 pillars and 53 individual indicators spanning from business and political environmental factors to infrastructural and educational factors. The individual indicators are sourced for 50% from reports of various international organizations including the World Bank, UNESCO and other UN affiliated organizations and the International Telecommunications Union. The other half of the indicators are derived from the World Economic Forum's annual Executive Opinion survey. The NRI scores every country on a scale of 1-7 and a score for every sub-index, pillar and indicator. This makes the NRI a useful and diverse basis to assess the capacity countries have to exploit the opportunities blockchain offers, even though it does not include all relevant factors. The following section will use the NRI as a basis for assessing Kenya's readiness for blockchain adoption but will incorporate other research to fill some gaps in the NRI and to make the NRI more relevant to blockchain. For more detail on the creation of the NRI see the World Economic Forum report (WEF, 2016).

Figure 5 depicts Kenya's NRI score compared to the lower-middle-income group average score and figure 6 depicts the USA's NRI score compared to the high-income group average. Kenya's Networked Readiness Index is 3.8 out of 7, ranked 86th out of 139 in 2016. The USA's NRI score is 5.8, ranked 5th worldwide. Comparing figure 5 with figure 6 it is clear why blockchain adoption in Kenya will not follow the same path as in the United States, the country where most forecasts regarding blockchain are based on. Kenya consistently scores lower on all factors that aid in the adoption of new ICT technologies as shown in the visual representation of the scores.

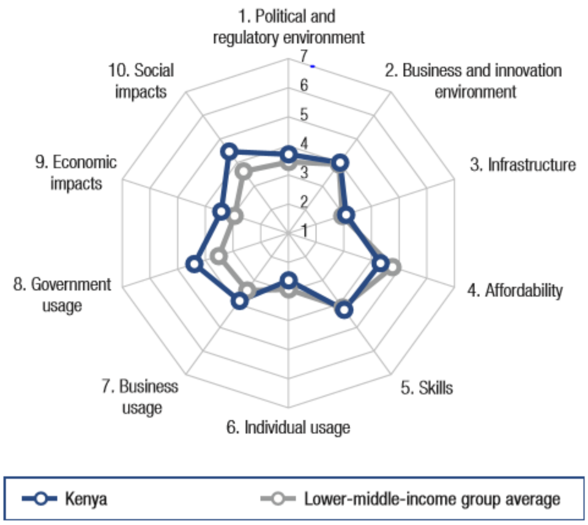

Figure 5 The NRI score for Kenya (WEF, 2016)

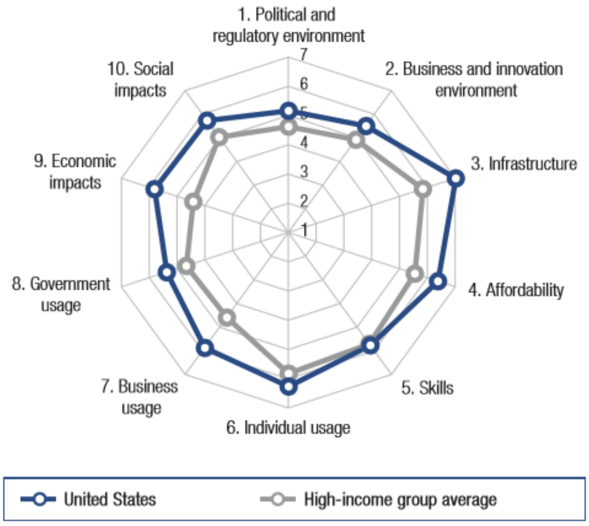

Figure 6: The NRI score for the United States (WEF, 2016)

Table 1 NRI scores (WEF, 2016)

Country	**NRI Score**	**Rank**
Singapore	6.0	1
United States	5.8	5
Netherlands	5.8	6
Mauritius	4.4	49
Rwanda	3.9	80
Kenya	*3.8*	*86*
India	3.8	91
Ghana	3.5	102
Ethiopia	3.1	120
Chad	2.2	139

Table 1 shows the NRI score for various countries which are a good benchmark to compare Kenya to. Firstly, rich countries such as Singapore, the United States and the Netherlands all have a high NRI score and rank. Figure 5 provides more insight in the individual indicators for the United States which are representative for most of the richer countries. Mauritius is the highest scoring African country. Rwanda's GDP per capita is lower than Kenya's, however its NRI score is higher. Ghana is similar to Kenya in terms of GDP per capita however its NRI score is lower, which shows that Kenya's readiness for ICT technologies is above average for its GDP level (WEF, 2016). Neighbouring Ethiopia is much poorer and similarly score lower on its NRI. Chad is the lowest scoring country in the world, which shows that blockchain adoption will not be consistent across developing nations.

Table 2 Detailed NRI Score for Kenya (WEF, 2016)

	INDICATOR	RANK/139	VALUE
	1st pillar: Political and regulatory environment		
1.01	Effectiveness of law-making bodies*	60	3.9
1.02	Laws relating to ICTs*	63	4.0
1.03	Judicial independence*	61	4.1
1.04	Efficiency of legal system in settling disputes*	52	4.0
1.05	Efficiency of legal system in challenging regs*	44	4.0
1.06	Intellectual property protection*	81	3.7
1.07	Software piracy rate, % software installed	80	78
1.08	No. procedures to enforce a contract	122	44
1.09	No. days to enforce a contract	47	465
	2nd pillar: Business and innovation environment		
2.01	Availability of latest technologies*	50	5.1
2.02	Venture capital availability*	54	2.9
2.03	Total tax rate, % profits	69	37.1
2.04	No. days to start a business	108	26
2.05	No. procedures to start a business	120	11
2.06	Intensity of local competition*	23	5.6
2.07	Tertiary education gross enrollment rate, %	133	4.0
2.08	Quality of management schools*	56	4.4
2.09	Gov't procurement of advanced tech*	37	3.8
	3rd pillar: Infrastructure		
3.01	Electricity production, kWh/capita	122	203.1
3.02	Mobile network coverage, % pop.	119	89.1
3.03	Int'l Internet bandwidth, kb/s per user	83	25.2
3.04	Secure Internet servers/million pop.	101	7.8
	4th pillar: Affordability		
4.01	Prepaid mobile cellular tariffs, PPP $/min.	21	0.10
4.02	Fixed broadband Internet tariffs, PPP $/month	116	74.19
4.03	Internet & telephony competition, 0–2 (best)	1	2.00
	5th pillar: Skills		
5.01	Quality of education system*	36	4.3
5.02	Quality of math & science education*	78	3.9
5.03	Secondary education gross enrollment rate, %	107	67.6
5.04	Adult literacy rate, %	88	78.0
	6th pillar: Individual usage		
6.01	Mobile phone subscriptions/100 pop.	121	73.8
6.02	Individuals using Internet, %	80	43.4
6.03	Households w/ personal computer, %	109	12.3
6.04	Households w/ Internet access, %	102	16.9
6.05	Fixed broadband Internet subs/100 pop.	121	0.2
6.06	Mobile broadband subs/100 pop.	116	9.1
6.07	Use of virtual social networks*	60	5.7
	7th pillar: Business usage		
7.01	Firm-level technology absorption*	54	4.8
7.02	Capacity for innovation*	42	4.3
7.03	PCT patents, applications/million pop.	90	0.2
7.04	ICT use for business-to-business transactions*	41	5.1
7.05	Business-to-consumer Internet use*	54	4.7
7.06	Extent of staff training*	46	4.2
	8th pillar: Government usage		
8.01	Importance of ICTs to gov't vision*	18	4.8
8.02	Government Online Service Index, 0–1 (best)	76	0.43
8.03	Gov't success in ICT promotion*	21	4.8
	9th pillar: Economic impacts		
9.01	Impact of ICTs on business models*	40	4.9
9.02	ICT PCT patents, applications/million pop.	82	0.1
9.03	Impact of ICTs on organizational models*	52	4.4
9.04	Knowledge-intensive jobs, % workforce	n/a	n/a
	10th pillar: Social impacts		
10.01	Impact of ICTs on access to basic services*	52	4.5
10.02	Internet access in schools*	91	3.9
10.03	ICT use & gov't efficiency*	39	4.6
10.04	E-Participation Index, 0–1 (best)	33	0.65

Table 2 shows the build-up of Kenya's NRI score with statistics on all indicators. Various important factors in blockchain adoption are missing from the NRI however, for example, the tertiary education enrolment rate indicator is in itself not enough to assess IT related knowledge, the amount of students studying computer science is much more important, data on this is unavailable however. The availability of venture capital for start-ups is quite high in Kenya, with a rank of 54. Though other elements that aid start-ups are not considered, for example the availability of so-called 'hubs' in Kenya. These hubs provide market infrastructure, facilitate network building, and develop skills and capabilities of entrepreneurs and firms, to bridge the institutional gaps in Kenya (Littlewood and

Kiyumbu, 2017). These hubs certainly have the potential to improve the business and innovation environment.

Regarding infrastructure, Kenya scores poorly. This is because parts of Kenya are not fully covered by a mobile network and because internet usage, electricity production and the amount of secure servers is low. These factors are key in being able to adopt IT based innovations. Other important factors are not included however. For example, only 36% of the Kenyan population had access to electricity in 2014 (Crandall *et al.*, 2012). Kenya has also built the National Optic Fibre Backbone, which connects all of Kenya's 47 counties with high-speed optic fibre cables, which improves Kenya's digital infrastructure significantly (Oteri, Kibet and Edward, 2015). Additionally Kenya has a strong linkage to other countries through various submarine cables which has significantly improved international bandwidth prices in Kenya, with more cables planned (International Telecommunication Union, 2014).

Kenya scores low on affordability, fixed internet broadband tariffs are, corrected for purchasing power, one of the highest in the world. Mobile cellular tariffs on the other hand are especially cheap, ranking as one of the best in the world. Internet and telephony competition in Kenya ranks as highest in the world, with a full score, which means that the market for 17 categories of IT services is fully liberalized and has full competition (WEF, 2016). The World Economic Forum argues that this positively benefits digital connectability. According to the International Telecommunication Union Kenya's mobile data is very affordable, being 4.4% of Gross National Income per capita for 1GB of mobile data, while the world average was 6.8% (International Telecommunication Union, 2014). However the NRI score weighs the fixed internet tariffs as heavy as the cellular tariffs, which is inaccurate since not even 1% of all internet subscriptions in Kenya comes from fixed lines (Communications Authority of Kenya, 2017). Digital communications in Kenya are thus more affordable than the NRI score suggests.

The digital skills in Kenya are average according to the NRI. Secondary education enrolment rate is low however, ranking 107th in the world. While the adult literacy rate is 78%, which ranks 88th. Data on other important factors in digital skills is scarce. Statistics on the amount of computer science graduates would be incredibly useful but unfortunately unavailable. Education is very important in creating digital skills by teaching maths, language and science. According to King et al. governments need to invest in knowledge deployment (education) in order to significantly produce and use IT innovation (King *et al.*, 1994). Kenya's education index, as part of the Human Development Index by the UN is 0.51/1, which ranks averagely for a developing African country (UNESCO, 2011). With 6.3 mean years of schooling this is quite low, however, the expected years of education is currently 11.1, which shows progress is being made. What is crucial however, is the fact that English is the lingua franca of computing (Herring, 2008). The fact that English is also an official language in Kenya is therefore a large advantage for Kenya, especially since it is the main language in its educational system (Bunyi, 1997). Lastly, knowledge can also be imported by employing well-educated foreigners. The main group of immigrants to Kenya is from other countries in the global south, only 16% of all immigration is not African, or around 50.000 people in 2009 (Ratha *et al.*, 2011; International Organization for Migration, 2015). On the other hand, large groups of skilled Kenyans are leaving the country to work elsewhere, which makes the effect of migration on the digital skills in Kenya hard to asses. However, generally speaking Kenya is experiencing a brain drain, which can be extremely prohibitive in adopting high technologies.

The individual usage of digital technologies is relatively low in Kenya. What the NRI does not take into account however, is the unevenness in usage of digital technologies. There is a general divide in developing countries, and especially in Africa based on gender, location and age (Aker and Mbiti, 2009). Internet use rates in Africa are estimated to be 25% higher for men than for women, with this divide increasing in the previous years. The internet use statistics for people aged 15-24 is almost double as high as the general population. Similarly, urban areas are generally completely covered by mobile networks, while some rural parts of Kenya still do not have mobile network coverage, which has created a spatial digital divide (Crandall *et al.*, 2012).

The business usage pillar is ranked quite highly at 50. It is important to note however that 5 out of these 6 indicators are taken from the Executive Opinion Survey, meaning that these are perceived values, not actual. Patent Corporation Treaty patents per capita is ranked quite low. However, this arguably not very relevant for blockchain because for many blockchain uses the software is open-source (Pilkington, 2015). The government usage pillar is ranked even higher at 45, especially the perceptions of Kenyans on the government's vision and successes regarding ICT are high. This is because the Kenyan government plans to make the country a regional ICT hub and transition the country into a knowledge economy (International Telecommunication Union, 2014). The Ministry of Information, Communications and Technology has written the Kenya National ICT Masterplan which outlines its goals and strategies to achieve this. One of the defined goals is to move up 15 places in the NRI ranking by 2017 since they implemented it in 2014 (Ministry of Information Communication and Technology, 2014). Kenya's online government service index is currently ranked at 76, with a score of 0.43, which they are also actively trying to improve. With the ICT Masterplan Kenya has devoted itself to innovate in terms of ICT technologies, however interestingly enough blockchain is not mentioned once in the 124-page masterplan. The Kenyan government takes up an active role in ICT, stimulating certain technologies and industries. This can have a positive impact on IT innovation, especially combined with the liberalized broadband and mobile internet market that Kenya has (King *et al.*, 1994).

The economic impact of ICT is high according to the NRI: people perceive ICT's to have a large impact on business and on organizational models of businesses. Data on the arguably most important part of the 9th pillar, the percentage of the workforce in knowledge-intensive jobs, is not available however. The real impact of ICT on the economy is therefore still hard to quantify. This pillar can be important in assessing the potential impact blockchain can have on the Kenyan economy since if many people have knowledge intensive jobs, blockchain can have more impact on these jobs. However the fact that this statistic is missing shows how underdeveloped this sector is. However the Kenyan government is trying to change that by making ICT a formal economic sector in order to better assess its size and impact (Ministry of Information Communication and Technology, 2014).

The social impacts pillar ranks highly at 52, the perceptions of ICT on provision of basic & government services is positive. The perceived internet use in schools is relatively low however, which is arguably very important in ensuring the continuous ICT development. The E-participation index, which assesses ''the quality, relevance, and usefulness of government websites in providing online information and participatory tools and services to their citizens'' ranks at 33 with a score of 0.65/1, which is very high. The social impacts pillar is not immediately useful in assessing the ability of Kenya to adopt blockchain applications. However it is useful in seeing how Kenyan society has been exposed to ICT already, since if their experience with digital technology has been positive, the more positive they will perceive future technologies (Rogers, 1995). In other words, higher social impact of ICT's improves the compatibility with blockchain.

As Kenya's NRI of 3.8 suggests, Kenya is not really ready for blockchain. Overall, the country's education system, infrastructure and levels of economic development partially inhibit it from fully exploiting new IT technologies like blockchain. There exists a large divide however, between the well-educated, English-speaking, rich people in urban areas with internet connection and the illiterate, poor, rural people without access to mobile services. The fact that the Kenyan government is actively trying to change this can have a very positive effect however. In 2013 its NRI score was only 3.5, ranked at 92. This shows Kenya's current progress in terms of IT related development. The Digital Planet report characterizes Kenya as one of the main ''Break Out'' countries. This group of countries currently scores low on digitization rates but are evolving rapidly. Kenya is ranked 4^{th} in terms of current momentum in improving the digitization of the country, which shows that even though its current digitization is low, this is changing very rapidly, which offers many possibilities for blockchain (Chakravorti and Chaturvedi, 2017).

Mobile phones in Kenya

An example of how a new technology can transform a society is the case of smartphones in Kenya. From 1999 to 2017 mobile phone penetration rate moved from 0.05% to approximately 88% (Oteri, Kibet and Edward, 2015) (Communications Authority of Kenya, 2017). This statistic is based on the amount of mobile phone subscriptions over the population of Kenya, the amount of active subscriptions is 40.2 million (Communications Authority of Kenya, 2017). A similar number of Kenyans also uses mobile money through their provider. Since people can own multiple active simcards the number of usable phone owners is likely to be lower (Oteri, Kibet and Edward, 2015). On the other hand, since 35% of Kenyans surveyed indicate to share devices, the household penetration rate for mobile phones is likely to be higher (Crandall *et al.*, 2012). The estimated number of data/internet users is 45 million individuals (Communications Authority of Kenya, 2017). This would amount to practically everyone in Kenya. Even though this is an estimate and the actual numbers are likely to be lower, it is clear that mobile phones and internet have become widespread since the beginning of the millennium which is extremely fast in the technology life cycle model. The impact of mobile phones on Kenyan society has been transformative.

The main benefit of mobile phones over traditional forms of communication is that it is cheaper, mobile and more flexible (Aker and Mbiti, 2009). Mobile phones particularly do not require extensive infrastructure such as electricity and fixed landlines that used to be necessary for telephony. Mobile phones improve people's access to market information, banking, health services and improve social relations (Aker and Mbiti, 2009). This makes the mobile phone essential to daily life in Kenya.

However, the introduction of mobile telephony has created a digital divide in Kenya. Mobile phone usage is higher with urban, young, rich and educated people (Poushter, 2015). The divide between 'normal' phone users and smartphone users is present along similar lines. According to a study by Jumia, over 60% of the population now owns a smartphone, allowing them to access the internet (Wachira, 2017). This statistic matches with data from the Communications Authority of Kenya (2017), which states that there are 29 million mobile data subscriptions in Kenya. This is a rapid increase since the introduction of smartphones only 10 years ago.

The presence of mobile phones and smartphones also has implications for blockchain adoption in Kenya. Firstly the rapid adoption of mobile phones in Kenya shows how a new technology with significant comparative advantages which suits the local conditions can transform a society and aid its economic development. On the other hand, it also demonstrates how effects can be different over space and time, with primarily the rural areas of Kenya still being excluded from this mobile revolution. Additionally, the fact that Kenyans are used to technology such as mobile banking might speed up blockchain adoption because blockchain technology is more compatible with Kenya's experience with technology (Rogers, 1995).Lastly, mobile phones in Kenya have paved a way for blockchain adoption because internet access is a crucial element of blockchain networks (Rafiee, 2018). The next chapter will delve into specific, relevant uses of blockchain to understand its potential for adoption in Kenya.

5. What are the possibilities for blockchain adoption in Kenya?

Recall that blockchain is a foundational technology, similar to the internet (Iansiti and Lakhani, 2017). Assessing blockchain adoption as a whole is not the best way to gain insight into the future of blockchain. Adoption will only occur when the blockchain concept can be put to practical use in a value adding way (Golden, 2017). Each use-case of blockchain is different and blockchain will have a varying impact in different sectors. Additionally, since blockchain is still in its infancy, workable blockchain applications are scarce, existing value adding applications are even scarcer. This makes blockchain adoption difficult to assess. The following section will explore the various sectors of society where blockchain can have a large impact. These sectors are financial services, trade and aid, property titles, democracy, identity management and smart contracts in chronological order of when blockchain is expected to be adopted.

5.1 Financial services

Financial services are the obvious first place blockchain will have an impact. Blockchain was invented with Bitcoin, which is a cryptocurrency. Blockchain is a technology that incorporates value transfers in ledgers, which is similar to the work of banks. Most academic research on blockchain most commonly mentions the banking sector as the place where blockchain will make an impact. However most research does not go into detail of specific applications in banks. As Peters and Panayi (2016) state: '' We are however unaware of any papers that go beyond this high level discussion and detail exactly how and what form blockchain technology may provide benefit in these aspects in banking settings.'' This is logical since many described blockchain innovations will function in the backend of banking systems and banks have no incentive to share their cutting-edge innovations in this field. Since in this area mainly permissioned private blockchains will function, patents are used by banks to secure their innovations (Zhao, 2017). Typically, international transfers are the place where blockchain is said to have the most impact, which will be explored first (Peters and Panayi, 2016). Subsequently, the potential of blockchain in conventional banking and lastly the possibilities of cryptocurrencies replacing current payment methods in Kenya will be explored.

Blockchain & international transfers

International remittances are one of the main sources of foreign income in Kenya. Valued at 476 million US dollars in the second quarter of 2017, equal to one third of Kenya's export value in products (Kenya National Bureau of Statistics, 2017). Remittances fill the current account deficit of Kenya by 40% which is very important for Kenya's trade position. Compared to the Official Development Assistence (ODA), remittances are currently almost of equal magnitude in Kenya (World Bank, 2017). Additionally, remittances provide additional income to poor communities, alleviating poverty and providing a steady income for many recipient households. Remittances also positively affect economic growth by providing an alternative source of finance and help to overcome liquidity constraints (Gupta, Pattillo and Wagh, 2009) (Fayissa and Nsiah, 2010). For developing countries in general, remittances play a large role in the economy. Sending remittances can be quite expensive however, for example, Western Union, a main provider of international money transfers, charges fees between 4-15% (Gupta, Pattillo and Wagh, 2009). Though traditional banks fees can be even higher (Gupta, Pattillo and Wagh, 2009). These high fees hinder the sending of remittances. Less money will be available to send and people will send money less often because this is relatively cheaper. Therefore it is part of the Sustainable Development Goals to reduce remittance fees to less than 3% (United Nations General Assembly, 2015). Additionally, international transfers can require significant amounts of time, international inter-bank transfers can take up to three days in Kenya (Equity Bank, no date). Some people therefore even resort to friends bringing the physical cash to its destination (Gupta, Pattillo and Wagh, 2009).

Blockchain based systems will enable transaction fees and transfer time on international transactions to significantly reduce (Swan, 2015). This is mainly because the technology used in international transactions is outdated and uncoordinated (PwC, 2017). Cryptocurrencies can be used to send money internationally from one bank to another or banks can share their ledgers through a blockchain application. To avoid mere speculation on the potential of blockchain applications in financial services, the case of Ripple, one of the few successful companies that currently use blockchain effectively in a product, will be more closely examined. The fact that Ripple is open about its functioning will provide a more concrete insight in the benefit of blockchain technology in banking.

Ripple

Ripple is a company which created the cryptocurrency called XRP on which it has built a real-time gross settlement system (Bank for International Settlements, 1997; Ripple, 2017b). This global cryptocurrency network functions with a distributed ledger with consensus based transaction confirmation. These transactions are then stored on the shared ledger built up by blocks. This is similar to the Bitcoin system. In various other ways, Ripple is very different from Bitcoin, this is because Ripple is a permissioned private blockchain, while Bitcoin is a permissionless public blockchain (see chapter 2). This implies various practical differences. Firstly, it is managed by a company, namely Ripple, which owns most of the currency. Secondly, it is much faster, a new block is produced every 4 seconds. Thirdly, it is much more scalable, allowing up to 1500 transactions per second (Ripple, 2017d). Fourthly, its verification-mechanism is not based on proof-of-work like Bitcoin, but on consensus of various nodes, only 55 in total, which are chosen by Ripple themselves (Schwartz, Youngs and Britto, 2014; Marquer, 2017). These nodes need to create consensus by an 80% majority. This consensus mechanism is much more efficient than the bitcoin proof-of-work mechanism, which requires large amounts of energy. The main difference between XRP and Bitcoin however, is the fact that with XRP various applications are built onto the network by the developer of the blockchain.

The main application built on XRP is xCurrent, which is an application designed for banks. Currently international inter-bank transfers take a long time, sometimes even up to 5 days (Peters and Panayi, 2016). Costs for international transfers are often also very high. xCurrent is a platform banks can connect to which facilitates cross-border transactions. It functions by sharing the bank's ledgers in a blockchain environment and using XRP to transfer value between the banks. This allows the banks to transfer internationally without using an intermediary bank (Ripple, 2017b). Over 100 banks have already connected to the system, enabling these banks' to communicate directly through Ripple (Ripple, 2017c). The bank's customers can send money abroad in a way that is almost instant, traceable, cheap and secure. However, this can only be done to banks that are connected to the Ripple platform. Ripple functions as a real-time gross settlement system, similar to that of a central bank in one specific country (Bank for International Settlements, 1997). Ripple in a way fulfils this service on a world-level. This service can help many people send remittances to developing countries like Kenya in a cheaper, faster way which will help both the sender and the receiver greatly. So far Ripple almost exclusively operates in developed countries, but they do have collaborations with banks in Mexico, Thailand and India. According to Ripple, they see no reason why their solution could not be implemented in a country like Kenya since its comparative advantage is so large. As Dr. Sutivong of the Siam Commercial Bank, user of the Ripple system states: ''We are proud to be the first bank in Asia to use Ripple's leading blockchain network solution to power real-time payments for our customers, whose families oftentimes depend on the availability of these funds for basic needs - time is of the essence to them'' (Ripple, 2017a).

Even though Ripple is one of the most successful blockchain companies and XRP the second largest cryptocurrency in terms of market capitalisation there is much criticism on its business model (Rafiee, 2018). This is primarily because XRP is a pre-mined cryptocurrency and created by Ripple themselves, who then sells the coins. This means that Ripple still owns much of the XRP in circulation and is being criticized for this practice, since many people in the cryptocommunity think this is a sign of corporate greed (Rafiee, 2018). This is especially striking since Bitcoin was invented as an alternative to the traditional banking system and its associated greed (Bustillos, 2013).

Blockchain & local banking in Kenya

Kenya has a comparatively large 'banked'[1] population, namely 75%, which is much higher than its neighbouring countries and even higher than South Africa (Demirgüç-Kunt *et al.*, 2015). As a comparison, in the US, 94% of the people over 15 have a bank account. However only 54% of the Kenyan population has an account at a financial institution, the rest has a mobile money account (Demirgüç-Kunt *et al.*, 2015). Mobile money services like M-Pesa are very popular in Kenya, with over 60% of the population having an account conducting over 120 million transfers in September 2017 (Kalliola, 2005). As a comparison, in the same period only 18 million transactions were recorded by debit and credit card while interbank transactions only accounted for 300,000 transactions (Central Bank of Kenya, 2017). However the value of the interbank transactions was still 8 times higher than the total value of the mobile payments, showing how important conventional banking still is in Kenya, especially for large transactions.

Even though blockchain's largest comparative advantage lies in international transfers, many experts believe that blockchain also provides opportunities in conventional local banking. Integrating distributed ledgers in the bank's infrastructure will enable faster inter-bank settling of transactions (Peters and Panayi, 2016). Blockchain's immutability will prevent fraud and corruption in banking, which is still an issue in many developing countries, including Kenya (Brownbridge, 1998; Auka, Bosire and Matern, 2013). Besides its immutability, blockchain could offer real-time sharing of ledgers with the supervising authority (the Kenyan Central Bank) which could improve rule adherence. In general, blockchain will enable banks to improve in terms of efficiency, service and security. Various banks and payment providers in the developed world are already researching and developing blockchain in their infrastructure. A report by Accenture in collaboration with various banking actors estimates that blockchain technology could save $15-20 billion per year by 2022 in bank's infrastructure costs worldwide (Accenture, 2015). Even though adoption in Kenya will be more challenging because Kenya's banking market is small and Kenya's capacity to exploit new ICT's is lower, blockchain will likely have a large impact on the conventional banking sector in Kenya. Additionally, research has shown that the Kenyan banking sector is relatively inefficient and could greatly benefit from using new technologies (Fuchs, 2010; Kamau, 2011; Miencha *et al.*, 2015). Hence the comparative advantage of blockchain is even bigger if the Kenyan banks leapfrog from their current systems to a system based on blockchain. In the framework by Andersen (1995) this will be in a sustaining way, existing companies improve their performance through a new technology. The next section will explore the ways blockchain can disrupt the banking sector through applying cryptocurrencies.

Cryptocurrencies as an alternative for M-Pesa and conventional banking

Besides the impact on the conventional banking sector, blockchain additionally has the capacity to surpass the middleman and function without banks. Cryptocurrencies provide an alternative to fiat currencies for every-day use. Kenyan start-up Bitpesa[2] aims to provide international transfers through the Bitcoin network (Jackson, 2015). Another Kenyan start-up, Bitsoko, offers a more holistic solution integrating a mobile wallet with a point of sales service running on the Ethereum network. With transactions fees as low as 0.5% Bitsoko is much cheaper than other mobile money services like M-Pesa (Bitsoko, no date; Safaricom, no date). However, there are reasons that suggest why adoption of cryptocurrencies as a means of storing value and payment will not go mainstream in Kenya.

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[1] Individuals over 15 years old with a personal account, at a financial institution or through a mobile money provider.

[2] I contacted both Bitpesa and Bitsoko for more information however they unfortunately did not respond, this means all information is from their respective websites.

Firstly, currencies exhibit severe network effects, switching currencies is difficult because it is only beneficial when a large user group exists (Luther, 2016). This means that an incumbent means of payment will continue to exist even though superior alternatives are available. Switching will only occur when existing currencies lack trust and are unstable or with government support. Since Kenya's shilling is a stable currency according to Moody's and since M-Pesa is already very well established as a mobile money provider the comparative advantage of cryptocurrencies is quite low (Moody's, 2016; Communications Authority of Kenya, 2017). The network effects erase the comparative advantage of cryptocurrencies and make them incompatible with the current methods of payment. Additionally Kenya's central bank has positioned itself against the adoption of Bitcoin and advises not to use it (Kenyan Central Bank, 2015). However, in developing countries with an unstable national currency or countries where mobile money has not established itself yet, cryptocurrencies might provide a good alternative, especially with authorities in favour (Bustillos, 2013).

In terms of the diffusion of technology framework by Rogers (1995), Ripple and other blockchain applications in the banking sector fulfil most important criteria that help adoption. The relative advantage of Ripple xCurrent is great, being cheaper, faster and more secure. Similar advantages exist in the form of blockchain in local banking. The system is also very compatible with customers of banks. They will not notice any of the changes in the system behind the money transfer, but will only notice the lower prices and faster transfer times. Compatibility in terms of the users of xCurrent and other blockchain technologies, the banks, this is very hard to assess. Many banks have adopted xCurrent already, mostly in developed countries, but Ripple stated that they see no reason why Kenyan banks could not adopt Ripple applications. Perceived complexity is likely to be high, since blockchain is commonly perceived as a hard to grasp concept. However Ripple offers installation services and as a seller of the product xCurrent will guide the customer in adopting its products. Trialability is very low however with xCurrent, because it is a product with network effects, meaning that the strength of the product depends on how many banks have adopted the product. This means that the application cannot be tried on a small scale, it only functions when many banks adopt it. Observability is another factor that aids adoption, in the case of Ripple, its benefits are not very clearly visible in a social system. Rogers (1995) states that software is hard to observe which makes adoption rate lower. However, observing its great relative advantage over alternative systems, it is likely that Ripple will see adoption in Kenya and other developing countries. As stated before, the adoption of cryptocurrencies as a replacement for banks and M-Pesa in Kenya is unlikely, since cryptocurrencies exhibit severe network effects.

In the framework by Iansiti and Lakhani (2017), these applications fit in the bottom-left quadrant, because of its low complexity and novelty. It only involves a few actors and provides a service that already exists. Because of this, Iansiti and Lakhani predict that these applications will be developed in a short timeframe as described in chapter 3. This is an accurate prediction, besides Bitcoin being a suitable alternative for conventional international transfers, various other applications like Ripple already exist or are in development. In Kenya, start-ups like Bitsoko and BitPesa are currently in development and starting to be adopted.

In short, blockchain offers many possibilities for financial services in Kenya and in other developing countries. The benefits blockchain has in conventional banking are likely to be even larger in developing countries since remittances are very important to developing countries' economies and because fraud and corruption are more prevalent in developing countries, blockchain's comparative advantage is thus larger.

5.2 Trade & Aid

Trust is essential in economic transactions and for economic growth (Humphrey and Schmitz, 1998). Trust is often seen as an explaining factor as to why some countries or regions develop rapidly and why others fall behind (Humphrey and Schmitz, 1998). Facilitating trust is an extremely challenging endeavour with institutions, social capital and enforcement of contracts playing critical roles. As a developing country, trust in Kenya is likely to be lower. Unfortunately the World Values Survey has not surveyed Kenyan citizens as of yet, however it does show that other, similar, East-African countries have lower levels of trust than more developed countries (Ortiz-Ospina and Roser, 2017).

Blockchain is often seen as a technology that can facilitate trust, The Economist (2015) has named blockchain the ''Trust Machine''. Blockchain can facilitate this trust by providing a tamper-proof network which is transparent, secure and trustworthy (Mattila, 2016). Besides providing trust, blockchain is also able to overcome various other challenges like efficiency in communications between various involved parties and high transaction costs. Various authors have therefore named supply chains as a place where blockchain applications will be put to use (Swan, 2015; Mattila, 2016). In a similar vein, blockchain can create transparency and trust in aid networks (Biswas, Muthukkumarasamy and Tan, 2017). This section will explore the various ways blockchain can be adopted in trade & aid networks in Kenya.

Blockchain in global value chains

Current value chains are complex, commodities change hands various times before they reach the final consumer. Moving through the value chain, various parties alter and check up on the product before it reaches the consumer, who in turn wants to know more and more what has happened to the product before it reaches the place they buy it from (Al-Khatib, Vitell and Rawwas, 1997). Because value chains are so complex, it has become increasingly hard to ascertain what has happened to the product, specifically, whether the production process has been slave-free, child-labour-free and whether the product is authentic, safe and as organic as it says on the label (Sparke, 2013). Currently various standards and certifications by various organizations exist, labelling goods to enable consumers to choose responsibly. However its meaning and credibility is hard to verify by consumers (Castaldo *et al.*, 2016). Additionally, guaranteeing the integrity of the certificates is costly, even though they include extensive audits, issuing organizations are still not able to ensure the validity of the certificates (Elliott, 2012). The entities commissioned with the task of tracking measures of quality and sustainability function with centralized databases, the only form of credible data storage before blockchain, which are vulnerable to fraud, bribery and hacking, making the certification less trustworthy. Data on this form of fraud in Kenya is lacking, however observing the prevalence of corruption and bribery in Kenya in general and evidence from newspaper reports it is most likely to pose a problem in Kenya as well (Transparency International, 2016; Steiner, 2017; Transparency International and Kenya, 2017).

Blockchain provides a solution to these problems of trust. Blockchain's capacity to provide a distributed, tamper-proof ledger with access for all involved parties where blocks of information can be amended is very suitable for this issue (Pilkington, 2015; Swan, 2015; Kim and Laskowski, 2016). Goods can be traced back to their provenance and their journey can be followed, improving transparency (Dudder and Ross, 2017). Even though this was already possible through other technologies, the fact that blockchain is tamper-free and distributed makes blockchain comparatively more secure and less prone to fraud, something that is likely to be more prevalent in developing countries than in developed countries. Blockchain also enables more transparency for the actors in the supply chain, possibly improving the position of original producers, e.g. farmers, while decreasing the power of actors that do not add any value to the product, e.g. traders (Kim and Laskowski, 2017).

A theoretical example of adoption of blockchain in a supply chain is in the paper by Biswas et Al. (2017) describing a blockchain solution for reducing counterfeit and adulterated wine. Another example is the solution by Dudder and Ross (2017) showing the use of blockchain in the global value chain of timber, increasing security and transparency. A practical example of a supply chain that has adopted blockchain is the global supply chain of diamonds. Diamonds are an example of a product whose image is hampered by questions about its origin, brought to popular attention by the movie 'blood diamond'. The company Everledger has created a blockchain ledger which includes over 1.6 million diamonds which are traced through the global supply chain (Roberts, 2017). This allows for truly certifying the origin by inscribing a miniscule code in the diamond when it is produced. Another example is the start-up Provenance, providing blockchain applications for various supply chains. Their trial in the coconut supply chain in collaboration with Fairfood provides security in the farmer's fair wage and allows consumers to be certain about the coconut being Fairtrade. It does so by creating a digital copy of the product on the blockchain, which can be traced through the supply chain. All relevant information, including the farmer's pay is included in the blockchain, certifying that the farmers received a living wage (Provenance, 2017).

Like many developing countries, Kenya's exports are mainly agricultural products: coffee, tea and flowers being the most important commodities (Kenya National Bureau of Statistics, 2017). Coffee and tea are primarily produced by over 1 million small-scale farmers who rely on the export of these commodities for their livelihoods (Condliffe, Love and Porter, 2008; CPDA, 2008). However, it is unclear how much of the retail value of coffee and tea reaches the small-scale Kenyan farmers due to the complex value chains (Condliffe, Love and Porter, 2008; CPDA, 2008). What is clear is that it is a very small part of the retail value and that many small-scale Kenyan tea and coffee farmers are impoverished. One estimate of the coffee sector is that small-scale farmers receive less than 10% of the retail value (Condliffe, Love and Porter, 2008). This situation is caused by various factors, however their poor leverage position and corruption are main reasons (Condliffe, Love and Porter, 2008; CPDA, 2008). Additionally the need for a quality tracing system in the coffee supply chain has been identified (Condliffe, Love and Porter, 2008). Similarly, the Kenyan potato sector has various problems surrounding a lack of trust between farmers and processors (Hoeffler, 2006). Farmers feel exploited by the processors and traders while they in turn see Kenyan potato farmers as unreliable in terms of quality and breaching of contract. A blockchain based value chain technology as discussed above can have serious positive effects on the lives of these farmers, improving transparency and increasing the leverage positions of small-scale farmers (Swormink, 2017).

Much research is currently done on implementing blockchain in supply chains in various places. IBM is currently cooperating with big players including Walmart and Maersk, small scale trials by NGO's like Provenance are examples of this. According to the framework by Iansiti and Lakhani (2017), these developments will take more time than the previously discussed financial applications. This is due to the fact that a supply chain is more complex and has various heterogeneous actors. Additionally these applications are relatively novel. Full scale adoption will therefore take a long time, even though individual small-scale cases similar to the Everledger solution can be expected in the coming years.

In developing countries, adoption will likely be even slower, however since many of these production networks are global, adoption can be eased by technology transfer from places with more investment in R&D. An example of this is the blockchain application by Maersk in collaboration with IBM, which has been trialled in the Kenyan port of Mombasa (Financial Times, 2017). This solution will track containers during their journey giving the suppliers, customs authorities, ports and customers insight in the process, digitizing the document flow which improves security and speed. This exemplifies how a global corporation like Maersk can introduce blockchain technology in a developing country, stimulating trade. However for small coffee and tea farmers, adoption will be more challenging. Firstly because they do not have enough leverage over the value chain to push for this technology that might improve their positions, these decisions need to come from the coffee corporations or from the consumers. Secondly, such applications require infrastructure that are likely to be missing in rural areas where the coffee producers live (Oteri, Kibet and Edward, 2015). Internet is necessary for adding information to the blockchain which is problematic since the area might not be covered by 3G network and because smartphones are prohibitively expensive.

In terms of the Rogerian (1995) criteria of technology diffusion, blockchain applications in the value chain fulfil most criteria. Firstly, its comparative advantage is great compared to other applications. Tracking with blockchain is more secure and tamper-proof. For consumers of for example coffee in western countries, a Fairtrade mark with blockchain traceability is better than current Fairtrade marks because it is more trustworthy. Compatibility is hard to assess in this case, on the one hand methods of tracing products through a value chain already exist, and on the other hand blockchain applications might be seen as too complex. Trialability is positively related to adoption, in this case one production chain is able to try out the technology to see its effects, however since it is a software innovation, its benefits might be hard to observe by other actors.

Blockchain in aid networks

In 2015 Kenya received $2.5 billion in aid (OECD, 2015). Which is almost exclusively Official Development Assistence (ODA) and less than 10% is private aid. Similar to global production networks, global aid is a complex network of various actors from different countries and different organizations. Blockchain has the capability to provide transparency and security and possibly take out the middleman.

Research has shown how people currently have low levels of trust in charities (Gaskin, 1999). There is a demand for more transparency and accountability. Blockchain allows for the secure sharing of charity's finances and real time tracking of funds. Additionally audits can be performed and written into the blockchain, securing that bad audit reports will not be hidden (Swanson, 2015; Peters and Panayi, 2016). This will reduce fraud and corruption, and increase trust in charities which could eventually increase donations since people are certain about what happens to their donations.

The majority of aid in Kenya is ODA and blockchain could make an impact here too. There is evidence that ODA increases corruption through its large influx of public money (Asongu, 2012). It is unclear how much of ODA is used for corrupt purposes, however it is clearly a problem (Kenny, 2017). Blockchain could be used to track the money to ascertain that the aid is arriving in the right place. Blockchain's feature of making tampering almost impossible is a large comparative advantage in the realm of ODA.

An example of how blockchain can dramatically change the flows of aid is the case of Usizo. In South Africa it is normal to have a prepaid electricity meter, which only functions when you have credits. A smart-meter which accepts Bitcoin has been introduced by start-up Bankymoon, making the purchase of electricity much easier (Higgins, 2016). At a public school in Johannesburg this concept was used to facilitate Bitcoin donations directly to the smart-meter. This allows the under-funded public school to use electricity and the donors to track this directly. This replaces the need for a large charity with additional costs and allows the full amount of the donation to reach its destination, something that does not occur in current charitable organizations. Researched U.S. charities allocated 87% of their spending to their programs, the balance was used for to cover overhead costs (Bowman, 2006). Even though the effect of overhead costs on the efficiency of charities is debated, blockchain could offer the demanded transparency in charities' finances (Gaskin, 1999).

5.3 Property titles

For any kind of high value property, it is crucial to have trustworthy ledgers to identify the current owner and to certify that the ownership is rightful. This ledger is usually centralized with a third-party managing the ledger, however the ledger could also be distributed, if there is a consensus on current ownership with a means to identify the owner (Mizrahi, 2015). This is exactly what Nakamoto (2008) designed in their proposal for Bitcoin: a consensus-based distributed ledger with historic records, with owners of Bitcoin using their public cryptographical key to identify themselves. Therefore, the blockchain can be used to keep track of property records, possibly even using the Bitcoin blockchain.

This blockchain system can be used for various kinds of high-value property, however arguably the best use-case is land. Registered property needs to be identifiable and land is by nature immovable and through developments in the availability of GPS services easily identifiable. Additionally, another reason why land is a good use-case is the fact that current land registry systems in many developing countries, including Kenya, have various problems.

In Kenya, the land registry system is facing many challenges (Mwagore, 2003; Makutsa, 2010; Kairu and Maneno, 2015; FAO, 2017). First of all, there is a large under capacity in terms of professionals. Kenya has fewer than 10 professional land surveyors per 1 million population, which is extremely low even for a developing country (Byamugisha, 2013). Additionally, these land surveyors are mostly unemployed due to low funding. Secondly, corruption is high in Kenya, especially in land services. According to the East-African Bribery Index 2017, the majority of the respondents (55%) was either implicitly or explicitly asked or offered to pay a bribe when interacting with the land services (Transparency International and Kenya, 2017). However, the overall indicator for bribery in land services shows bribery is becoming less common and having less impact than in 2014. The reason why people pay briberies vary, however the most common reason is that otherwise they could not access the service or to hasten the service. The process of registering property in Kenya is particularly bad, ranking 125th out of 189 countries assessed by the World Bank. It takes on average 9 procedures, 61 days and costs 6% of the property value (World Bank, 2017a). This is twice as long and expensive as the average OECD country. These factors make the Kenyan land registry quite ineffective and this has various negative consequences.

In general, land tenure is extremely complex in Kenya, with various actors laying claim to the same areas of land (FAO, 2017). Users are often not the formal owners and this often results in conflicts. Unclear tenure can also result in land grabbing by foreign companies and governments, buying land that is used by a community (Makutsa, 2010). Scholars have been critical of this land grabbing and have called for more transparency and community participation in the process (Zoomers, 2010). For the whole of Africa, it is estimated that only 10% of the rural land is formally owned (Byamugisha, 2013). Partly due to Kenya's poor land registry, only 6% of the land is privately owned, while 64% of the land is so called Trust Land, formerly native areas, waiting to be registered privately or by a community (FAO, 2017). The rest of the land is owned by the government designated for national parks, public works etc. The negative of effects uncertainty in ownership are low investment, land degradation, low credit collateral for rural farmers and large inequalities in ownership. Peruvian economist Hernando De Soto argues in his book *The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else* that the undocumented worldwide stock of capital of the poor is worth over $10 trillion, primarily in the form of land, he now puts this figure at $20 trillion (Casey, 2016). De Soto argues that securing this so-called 'dead capital' is a primary way of lifting people out of poverty (De Soto, 2001). Documenting the capital of the poor will enable them to use this capital as collateral on an investment and give more certainty so that people will invest into their capital instead of degrade it. Hernando De Soto has recently become a proponent of a blockchain based land registry to solve these problems because he thinks blockchain is the way to create trust in land rights and empower poor people (Casey, 2016). Additionally he thinks that because blockchain is tamper-free, people are more likely to share information about themselves: ''if you can get the right message about it out there, people will see that it's worthwhile recording yourself'' (Casey, 2016).

Blockchain's qualities of being immutable, secure, distributed and possibly transparent make it ideal for use as a ledger of land records. Additionally, it could function much cheaper and faster. Corruption will become much harder, people will be less apprehensive to share their data when they retain ownership over it and certainty in the system is created. Kenya's current land registry system could be drastically improved by moving to a blockchain based system, which has been tested in various places already.

Dubai's Land Department has already created a system of property registration on the blockchain, enabling a digital transfer process which can be completed in a few minutes from anywhere in the world, without the need to visit a government office (Dubai News Office, 2017). Other entities including the governments of Honduras, Georgia and Andhra Pradesh in India are piloting similar blockchain land registries, primarily to counter corruption (Underwood, 2016; Browne, 2017). Various kinds of blockchains are used in these projects, the Bitfury pilot in Georgia and the Chromaway pilot in Andhra Pradesh being the most interesting. Bitfury and Chromaway use the Bitcoin blockchain to 'colour' certain coins to signify a real-world asset (Mizrahi, 2015; Bitfury Group, 2016). In other words, certain bitcoin addresses will be associated with certain physical properties, allowing the trade of these physical properties to be recorded on the Bitcoin blockchain. Bitfury chose the Bitcoin blockchain since it is the most widely-used, public and is the most difficult to tamper with.

In Ghana, the state of land registration is similar to Kenya, with various disputes and low formal land registration. The start-up Bitland is aiming to register this land on a blockchain ledger to secure the capital so it can be used in the economy, without the corruption and abuses of power that occurred in the past (Bates, 2016). Bitland operates in a holistic way, besides working on the registration, they also focus on conflict resolution, education on the importance of property rights and building trust in communities. Additionally they work together with the Ghanaian land commission. Their collaboration with the authority on land means that once the land is recorded it will be admissible in court (Bates, 2016). The Bitland ledger will operate next to the land commission's records, so that it will act as a benchmark to prevent corruption. Since these problems regarding land do not only exist in Ghana but in various African nations Bitland has the intention to expand into other nations, possibly including Kenya[3] (Bates, 2016).

Blockchain is not a silver bullet that will solve all problems however. Recall that land is a contentious issue in Kenya with various actors laying claims to the same piece of land. A blockchain based land registry can create a database that cannot be tampered with by corrupt officials without noticing. However it cannot guarantee reliability of the information in the first place (Lemieux, 2016). When the ownership of land is unjustly accredited to a party to begin with, blockchain cannot solve this problem, in the worst case it will strengthen the unjust claim to the land. Similarly, blockchain cannot enforce the property rights it records. Blockchain can only provide integrity in the data that has been recorded in the system.

[3] Despite lengthy email contact and multiple promises of an interview I did not have the opportunity to interview someone from the Bitland team. Therefore all information on Bitland is from their website and whitepaper.

In terms of adoption, land registries are more difficult to assess than the previous applications since the adoption needs to be government-led, since the government is the authority on land ownership in Kenya. The Kenyan government does not mention blockchain once in their most recent ICT Masterplan, however, they do indicate the will to digitize government services and increase their security, transparency and accountability (Ministry of Information Communication and Technology, 2014). Blockchain would be ideal in this sense. On the other hand, the Central Bank of Kenya discourages the use of cryptocurrencies as mentioned before (Kenyan Central Bank, 2015). Even though blockchains do not need a cryptocurrency to function per se, the current pilots for land registries described above do. Lastly, the fact that blockchain prevents corruption might discourage some public officials in the Ministry of Land to adopt blockchain, since bribery and corruption are beneficial for them.

The comparative advantage of using blockchain for land registries in Kenya is high, the current land registry system faces many problems as described above and moving to blockchain would solve many of them. Comparing Kenya to Dubai, where a blockchain system has been adopted, the comparative advantage of switching to blockchain is larger for Kenya than for Dubai. On the other hand, compatibility is likely to be lower, registries do not yet exist, adopting a new system might leapfrog Kenya to a better land registry system, however the step might be too large too. The perceived complexity of blockchain might also prove to be a challenge, all the countries where blockchain based land registries are being piloted cooperate with private experts in adoption. Trialability for governments is high, more advanced countries can try out the concept and, when it has proven to work, cooperate with developing countries to implement it there.

The timeframe of adoption depends on the exact details of the blockchain based land registry. As Iansiti and Lakhani (2017) state, adoption is negatively affected by novelty and complexity. In the case of Dubai, the system is low in complexity, since the Dubai Land Department controls the system and moves the data from their database to the blockchain. If the information provision is to be distributed, the adoption will take longer because of its increased complexity since more actors will be able to participate. Similarly, the novelty of the system will negatively affect adoption. If the registry will fulfil similar tasks to current land registries adoption can be more rapid than if the system will provide new functions.

In conclusion, a blockchain based land registry will greatly improve the current land registry system in Kenya. It can reduce corruption, improve transparency in land grabs, speed up and reduce costs in registering and transfer of property. Registering previously undocumented land of the rural poor will improve their business opportunities by providing a secure system for collateral property when applying for credit and allowing for certainty about land ownership, increasing the investment in land, preventing environmental degradation.

5.4 Democracy

The benefits of democracy are hard to overstate and one of the most important processes of a democracy is arguably elections. As a young democracy Kenya has had 7 general elections for the national government since Kenya's first multiparty elections in 1992. These elections have faced many problems, most tragically being the post-election outbreak of violence in 2007 throughout which over a thousand people lost their lives (The Commission of Inquiry into Post-Election Violence (CIPEV), 2008). This section will explore the potential of blockchain as a potential solution to various problems associated with voting in Kenya.

Kenya's national elections in August 2017 cost the Kenyan government over $500 million, which is $25.4 per voter (The National Treasury, 2017). This makes the Kenyan elections of 2017 one of the most expensive elections in the world, which is surprising since elections generally become cheaper when a country has more experience in having elections (The Electoral Knowledge Network, 2017). Worldwide, only elections part of peace-keeping operations are reported to be this expensive. In the 2017 elections, 90% of the expenses were directly related to the election process, only the remaining 10% was designated for security operations during the elections (The National Treasury, 2017). The fact that it took 3 days to determine the winner in the August elections make the high costs even more surprising.

The Kenyan elections of August 2017 had an eligible voter turnout of 77%, which is relatively high compared to other developing countries and compared to western countries (Doyle, 2000; Solijonov, 2016). The exact reasons Kenyans do not vote are not documented, however violence at poll stations and a lack of trust in the electoral system are cited as reasons (Cropley and Obulutsa, 2017). During the re-elections in October, the elections were boycotted by the opposition because they did not have trust in the system (Keane, 2017). Research shows that only 26% of Kenyans have confidence in the vote count, a number that has declined in recent years (Penar *et al.*, 2016). Kenyans have good reasons for this, the August election results were nullified on procedural grounds by the high court and during the October re-elections last year the head of the election commission stated he could not guarantee 'free, fair and credible elections' (Wafula Chebukati, 2017). He cited interference from politicians and threats of violence against his colleagues as reasons for this. The 2007 national elections are well-researched and a report by the EU electoral observers states 'Kenyan elections have fallen short of key international and regional standards for democratic elections' and that 'they were marred by a lack of transparency in the processing and tallying of presidential results, which raises concerns about the accuracy of the final result' (Collier and Vicente, 2012 p. 142). The report by the Kenyan election review commission states: 'the integrity of the process and the credibility of the results were so gravely impaired by manifold irregularities and defects that it is irrelevant whether or not there was actual rigging at the national tally centre' (Kriegler *et al.*, 2008 p. X). This vote rigging is mostly by the incumbent party affiliates, asserting much power over the election system.

Violence has played a major role in recent Kenyan elections. In August a senior election official was tortured and murdered before the elections (Al Jazeera, 2017). During the elections voting had to be suspended in some areas because security threats made it too dangerous for the elections staff (Hamza, 2017). As stated before, violence reached a climax after the 2007 elections, resulting in over 1.000 deaths and the displacement of over 600.000 people (The Commission of Inquiry into Post-Election Violence (CIPEV), 2008). Additionally, sexual violence was widespread and severe detrimental economic effects were reported (Dupas and Robinson, 2012). 42% of people surveyed believed that the trigger for the election violence were the election irregularities and the weak electoral commission (Dercon and Gutiérrez-Romero, 2012). A report by the Kenyan Commission of Inquiry into Post-Election Violence states that the violence was partially triggered by the perceived rigging of the elections. This shows that creating a trustworthy election system could even reduce violence in Kenya. A blockchain election system could facilitate this lacking trust in the Kenyan electoral system and do much more.

Blockchain records immutable transactions between actors. These transaction can be conceived of as votes as well. These votes can be transacted between the individual to the pool of votes of an election candidate. Votes would be distributed to all eligible voters who need proof of identification to obtain this ballot (Kartik, 2017). This system could be run on a public blockchain, not owned by a government entity. The system could function as a permissionless system, with the security being provided through incentive mechanisms, or by a permissioned system with possibly the validators being other nations' government institutions, democracy watchdogs or citizens[4]. Voters can vote through an app or website through their own device or at a polling station (Barnes, Brake and Perry, 2016). This would have multiple advantages over the current Kenyan voting system and other digital alternatives.

Firstly, blockchain voting could be much cheaper, even though cost estimates for current blockchain national voting systems are unavailable, the current $25 per voter would most likely not be reached since personnel, policing and infrastructure costs would be significantly less since the system would be digital. Secondly, the system would be transparent. In the system proposed by Kartik, voters would be able to trace and count the votes once cast (Kartik, 2017). However, people would not be able to trace back who voted what, ensuring privacy and prevent coercion or repercussions for voting. Thirdly, the system would not be tamperable, the cast votes are recorded in a block, the hash prevents any subsequent tampering (Poblet, 2017). This would prevent vote rigging and post-ballot fraud. Fourthly, the system could function much faster, possibly even real-time, preventing a period of uncertainty in which violence in Kenya has historically been high (Dupas and Robinson, 2012). Fifthly, the system would be distributed, thus harder to hack than a single central point (Kumar, 2017). A real benefit since there have been attempts to hack Kenya's election system. Lastly, since voting could be done through personal devices, people's opportunity costs of going to the polling station is not a barrier anymore, additionally voters cannot be obstructed to vote by violence, which occurred during the 2007 elections (Kriegler *et al.*, 2008).

Additionally, this system would provide ways to move past the current democratic systems. Once instituted, voting would become much cheaper both in costs of the system and in opportunity costs. This would allow for more frequent voting including referenda (Poblet, 2017). Besides this, this infrastructure would allow for alternative ways of organizing democracy, such as liquid democracy and quadratic voting (Democracy Earth, 2017; Poblet, 2017). Possibly even smart contracts could be instituted in government decisions (more about this in section 5.6). For more detailed descriptions and examples of voting systems running on blockchain see: Barnes, Brake and Perry (2016); Democracy Earth (2017); Kartik (2017).

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[4] A consensus mechanism I conceived of is a blockchain voting system, whereby half of the validators are international stakeholders such as the African Union, neighbouring countries and democracy watchdogs and the other half are citizens of the country. This hybrid system would need an overall consensus of more than 50%, e.g. 80% and a consensus rate of 50% per group. This would mean that similarly to the system of Ripple, consensus would be created by permissioned, known validators, picked by an authority, e.g. the electoral commission. The other half of the consensus would come from citizens, who are non-anonymous, allowing for repercussions in case of a network attack. This system would prevent attacks and prevent a majority of citizens to hijack the elections if the network needed only 50% majority for consensus. This system would thus be better than a form of consensus solely based on citizens while keeping the power to the people of the country, preventing the international stakeholders to use the consensus mechanism to influence the elections according to their agenda.

Adoption of blockchain voting in Kenya faces many obstacles however. Firstly and possibly most importantly, the fact that the incumbent party is not able to influence the votes in any way with a blockchain system might be a disadvantage in their eyes. Additionally, the blockchain can be seen as too complex. The comparative advantage of blockchain voting might be high, this is hard to observe since research into the validity of elections is challenging. Blockchain voting is triable, certain regions might adopt it during a trial phase, however, it is much cheaper per vote to create a nation-wide system because of economies of scale. A blockchain voting system is significantly different from the current Kenyan voting system, making it incompatible with the current system. However culturally the system might be compatible, since almost all Kenyans use mobile phones for various other purposes. However the people that do not own a smartphone or other device to access the internet might be excluded from an easy way of access to voting. Since these people are likely to be poorer and might therefore have different voting behaviour this inequality might be detrimental for the democratic validity of the voting.

Another challenge associated with adopting a blockchain is the question regarding identification. The systems discussed by Democracy Earth, 2017; Kartik, 2017; Allen *et al.*, 2017 the identification of the voters receives much attention. Barnes, Brake and Perry (2016) propose a separate blockchain for identification next to the blokchain of voting. The quality of blockchain to share between various ledgers in order to create a complex system of connected blockchains could aid the adoption of the next application, namely blockchain based identity management systems.

5.5 Identity Management

Approximately 1.5 billion people in developing countries lack legal identification (World Bank, 2017b). In Kenya, the legal identification system is relatively advanced for a developing country and has a registration rate of 84% (Wold Bank Group, 2008). However only half of the population has a national identity card. Despite's Kenya's above average registration rate, the system still faces many problems. There is only 1 registration centre per 50.000 people, which is relatively low (Wold Bank Group, 2008). Not even 30% of these centres have internet connection (Worldbank, 2017). Employees at these registration centres are reported to ask for fees when they are not applicable and ask for bribes to speed up the process (Transparency International and Kenya, 2017). The registration process is extremely complex and since it is centralized in Nairobi all documents are physically transferred to one centralized database. This supposedly requires one month, however residents report waiting for over 2 years (International Telecommunication Union, 2016). This centralization is according to the World Bank vulnerable to security breaches and misuse (World Bank, 2016). Minorities are often subject to stricter requirements and face discrimination. Women and poor people are also less likely to obtain an identity card (International Telecommunication Union, 2016). Additionally, there exists a black market for identity cards and since the cards do not have an expiry date many deceased people's cards are being used (Worldbank, 2017). Birth and death records are stored in one central location without a disaster recovery facility and the database with digital copies of all fingerprints is not encrypted. Lastly, most Kenyan services regarding identity and registration are not integrated between the different institutions.

The 'identification gap' of the poor is associated with various problems because the ability to identify yourself is useful in various instances. In Kenya, national ID cards are tied together with financial inclusion (International Telecommunication Union, 2016). Buying a SIM card, setting up a mobile money account, setting up a conventional bank account and registering property all require an ID card. Additionally, the Kenyan ID card functions as a passport to other East African countries, the ID is required in the voting process and is necessary to access various government services like hospitals. In light of the previous section on the benefits of property titles, Hernando De Soto argues that an identification system is crucial in giving people secure rights to property (De Soto, 2001). This is also why it is target 16.9 of the Sustainable Development Goals to achieve "legal identity for all, including birth registration" by 2030 (United Nations General Assembly, 2015).

The Global Center for Development and the World Bank have various recommendations in achieving this goal. They recommend low barriers for remote rural communities through mobile services (Gelb and Diofasi, 2016). Creating a digital database of identities, not only issuing cards: the core of the system needs to be the database, which needs to be secure and valid. Improving the interoperability of the records databases by increasing access by various government institutions but also private actors like banks and NGO's (World Bank, 2017b). Creating reliable points of service with fast access to the database by using biometrics and applying performance standards. Creating a system with low running costs but high security. Allowing people to access and control their own data, with ways to see which institutions have access to their data. Lastly, the risk of identity theft and database hacks need to be mitigated. A blockchain based identity management system arguably fits most of these requirements.

A blockchain based system would be decentralized and encrypted, making the system resilient against cyberattacks and physical dangers like natural disasters. The immutability of the blockchain would secure the data against hackers and tampering. The identity database would be interoperable, allowing various actors to access the data if they have clearance, with access restricted to only the necessary data, depending on which actor is demanding it (Shrier, Wu and Pentland, 2016). Currently many systems share too much data, for example how people need to share their ID card with all information when only the date of birth is requested. A blockchain based system would allow the individual to control who has access to their personal details, making people less apprehensive to share all their personal details with the government (Baars, 2016). When personal identities are recorded on the blockchain, it could be connected to other government services also running on blockchain, such as a property registry or a voting system (Augot *et al.*, 2017). This would allow smoother functioning of these government services with more security.

However, the comparative advantage of blockchain based identity systems is debatable (Cooper, 2016). Since changes in identity are not usual, as with a property system, where changes need to be recorded in an immutable way, this does not add much. Because national identities are issued by a national government, the government will want to control the system. A conventional system with elements of blockchain such as decentralization, interoperability and encryption would have the advantages as mentioned above, but would prevent the system from becoming unnecessarily complex. However, the added benefit of blockchain technology being interoperable between ledgers can create an extra comparative advantage when the blockchain land registry and voting systems are connected to a blockchain identity management system. Cooper argues that a blockchain based identity system would only be beneficial when the current system is broken (Cooper, 2016). Since this is definitely the case in Kenya, a blockchain-like identity system could be a solution, however the exact needs of the system need to be further researched.

5.6 Smart contracts

The most advanced application of blockchain technology is arguably smart contracts (Chen et al., 2017). An analysis of blockchain's impact on Kenya would be incomplete if they are unmentioned. However, an important caveat is in order. Smart contracts' adoption in large parts of society is a long process which can last up to thirty years according to the framework by Iansiti and Lakhani (2017). This is because smart contracts are the most novel and organizationally complex application of blockchain technology that currently exists: smart contracts are often dubbed blockchain 2.0. It also does not fit in a specific economic or societal realm as the previously discussed applications but can only function when blockchain based applications have been adopted in these areas: its adoption presupposes the adoption of blockchain technologies in other areas of society. Hence there are large uncertainties in its functioning and adoption, however the potential impact is too large to leave unmentioned.

Smart contracts are in essence self-executing contracts (Swan, 2015). A commonly used explanation is the comparison with a vending machine. A vending machine is similar to a smart contract in the sense that it behaves algorithmically, it functions on an If-Then premise. If the right amount of money is inserted in the machine and a number is dialled properly, then the machine will dispense the product. The selling of the product occurs according to the code written in the vending machine, and when the machine is not broken there is no uncertainty in the outcome. Similarly, a smart contract is written in code, which automatically executes the contract. There is no possibility of contract breach since the contract is enforced automatically and autonomously by the code (Zhang et al., 2016).

Even though smart contracts were first described in 1996 by Nick Szabo, who coined the term, the invention of blockchain has enabled their adoption (Szabo, 1996; Cant *et al.*, 2016). Because blockchain is decentralized, there is no single point of authority or control. This enables a smart contract to function without the risk of the network being shut down. Since blockchain is tamper-proof and the code running on it unstoppable by a single entity it enables smart contracts to be trusted to execute (Sleiman, Lauf and Yampolskiy, 2016).

An example of how smart contracts can function in the future is the case of inheritance. A testimony can be written into a smart contract, outlining the division of the person's financial assets when the person passes away. When this happens, the assets of the deceased will be divided according to what is written in the contract. This presupposes that the concerned assets are recorded on the blockchain and accessible to the smart contract. It also presupposes a reliable source of information regarding the deceased (Zhang et al., 2016). When all these assumptions are fulfilled however, a smart contract would be more efficient, more reliable and will not require third-parties like notaries and lawyers (Frantz and Nowostawski, 2016; Juels, Kosba and Shi, 2016). The application of smart contracts is imaginable in all areas of the society which currently deals with traditional contracts and where parameters of the agreement are in some way measurable and quantifiable by the self-executing contract (Luu et al., 2016; Brock, 2017).

The benefit of smart contracts in Kenya could be even larger than in western countries. As stated before, in many developing countries trust levels are lower than in western countries (Ortiz-Ospina and Roser, 2017). Trust is essential to economic transactions (Humphrey and Schmitz, 1998). For example, when a firm delivers a product, it needs to trust that payment will occur. A comparative survey in Kenya and Ghana shows that 100% of the companies surveyed in Kenya report payment problems, the comparative figure for Ghana is 76% (Fafchamps, 2016). A smart contract could theoretically make payment automatic upon delivery of the good, when the goods are tracked by a system accessible to the contract (Sleiman, Lauf and Yampolskiy, 2016). Kenyan businesses also have a more challenging environment than in western countries when it comes to enforcing contracts. Kenya ranks 90th worldwide in the Enforcing Contracts Index of the World Bank (Bosio and Vilquin, 2013). It takes an average of 465 days and costs 42% of the claim value to enforce a contract through a court. A self-enforcing contract would prevent these delays and claim costs by autonomously enforcing the contract (Koulu, 2016). However adoption is challenging.

Even though the comparative advantage of smart contracts is great, allowing for more efficiency, less risk and more reliability, it is incompatible with current society. Firstly, assets involved in smart contracts need to be recorded digitally in a way that can be accessed and controlled by the smart contract. In the case of digital assets like cryptocurrencies, this is already occurring, however physical goods present additional challenges, since they are unlikely to be controlled by the blockchain network (Sleiman, Lauf and Yampolskiy, 2016). Secondly, smart contracts are incompatible with our current society because smart contracts challenge our current legal system and even our understanding of law (Koulu, 2016). Breach of contract would be a concept of the past, 'code is law' would be the guiding principle. However the use of smart contracts for criminal acts then becomes a crucial challenge: a criminal act could be written into a smart contract and the judicial system would not have to the power to stop the contract from executing (Juels, Kosba and Shi, 2016). Trialability of smart contracts is low, since smart contracts are subject to network effects, similarly to digital currencies, because if more assets are recorded on the blockchain, more options for smart contract adoption are available. Therefore smart contracts cannot be used to their full advantage on a small scale. Because smart contracts will operate in the background of economic transactions, observability is low as well, as software is hard to observe (Rogers, 1995). Lastly, complexity, both in terms of reading and understanding the code in the contract and the governance of such contracts is believed to be a major hindrance to mainstream adoption of smart contracts (Frantz and Nowostawski, 2016). This argument can be extended to all blockchain applications and is a major obstacle to adoption, the following section will discuss general obstacles and considerations in blockchain adoption.

6. General obstacles & considerations

The previous chapter has explored the various blockchain applications could be adopted in Kenya, including their individual obstacles. Before concluding this thesis, some general obstacles and considerations regarding blockchain adoption in Kenya will be discussed.

One of the main benefits of blockchain is the possibility of cutting out the middleman, there is no need for a third party like a bank to ensure the data is correct, the blockchain provides that trust. However, there is a large likelihood that true disintermediation will not occur, other intermediaries will take over, namely blockchain experts and developers. ‘’Looking at email, people could set up their own email server… however the majority of the people use Gmail… that is just human nature, most people cannot be bothered to do these things.’’ (Rafiee, 2018). In the case of cryptocurrencies this is already common, many people do not buy bitcoin through the Bitcoin network directly, but use a third party wallet operator. Similarly, smart contracts need to be written in code, which is often not understandable for the people using them, which requires them to trust a third party to write the code. The complexity of blockchain combined with the lack of user-friendly interfaces in blockchain applications provide a real challenge to understanding and eventual adoption by the average person (Frantz and Nowostawski, 2016; Tapscott and Tapscott, 2017). The potential of blockchain to empower people only applies to those that know how to use it (Seulliet, 2017). A new digital divide could arise, between the people that know how to use the blockchain for their advantage and those who do not (Swan, 2015). The fact that education in developing countries like Kenya is rated poorly will provide additional challenges in using blockchain for inclusive development, the digital divide can grow in a new way, based on digital skills.

The digital divide in the conventional sense, the divide in access to digital technology, can be a large obstacle in blockchain adoption, especially for government applications. In the discussed applications of blockchain in elections, property titling and identity management, the Kenyan government is likely to want these services to be universally accessible, which is challenging since not all people and localities in Kenya have internet access. If a blockchain based voting system is adopted, voting can be made possible through mobile phones, computers or at polling stations (Barnes, Brake and Perry, 2016). However, the people without internet access will only have the opportunity to vote at a polling station, creating inequalities in the ease of voting for people, especially when richer people have access to easier voter methods. This inequality can be a major objection to blockchain based voting and other blockchain government services in Kenya.

The electricity use of blockchain networks is an important obstacle in blockchain adoption. Recall that blockchain as a technology is in its nascent stage. The most proven and well-established way of reaching consensus is the proof-of-work mechanism, used in the most researched blockchain networks: Bitcoin and Ethereum, which uses large amounts of power (Swanson, 2015). Ethereum is moving to a proof-of-stake consensus mechanism (see chapter 2) to avoid wasting large amounts of energy, however this is proving much harder than initially foreseen (Tapscott and Tapscott, 2017). Bitcoin’s hefty energy usage is a large obstacle in blockchain adoption, both on itself and relating to the international power dynamics involved in them. Most of the mining power in the Bitcoin network is located in China because of the low electricity prices there (Yang, 2018). The fact that the majority of the votes is located in just one country can have consequences for blockchain governance. Electricity production worldwide is distributed unevenly and this can create an unequal balance of power when the consensus of the blockchain is based on processing power using large amounts of energy. Since poorer countries generally have lower electricity production capacity, this can great international imbalances in the consensus power of a worldwide network.

7. Conclusion

Blockchain is a revolutionary technology capable of transforming economies and societies. Through blockchain it is possible to create a trustworthy record of valuable transactions without needing a third party validator or authority. Blockchain’s qualities of data immutability, transparency and decentralization make fraudulent activities on a blockchain ledger practically impossible. Therefore blockchain’s benefits are larger in developing countries where fraud and corruption are more common. However, the scarce blockchain literature mainly focusses on blockchain in a western context. This thesis aimed to explore the possible blockchain based applications in Kenya to create an initial insight into where this immature technology is capable of making an impact.

The financial service sector is the first area where blockchain is likely to create a change. International remittances are important for Kenya, however conventional transfers are sometimes prohibitively expensive because the technology used in international banking today is outdated. A blockchain application like Ripple could greatly improve the speed and security of international transactions. Similarly, blockchain can be used in conventional banking for more efficiency, security and transparency. Additionally, cryptocurrencies have the ability to surpass the intermediaries and be used instead of fiat currencies, however the popularity of M-Pesa, the stability of the Shilling and the negative view of the Kenyan Central bank on cryptocurrencies are likely to prevent this, since money, and thus cryptocurrency, exhibits strong network effects and needs a large comparative advantage to overcome this.

Blockchain’s capacity to provide transparent reliable data could be used in complex value chains where transparency and integrity is needed. It could greatly increase the trust between various actors in a value chain, especially in developing countries, where trust is particularly low. Similarly, blockchain could provide trust and transparency in aid networks, where there is a lack of trust and a call for more transparency. Blockchain even could surpass the charities and enable direct international donations.

In various government services where fraud is likely to occur blockchain can provide a basis for an integer data system. In Kenya, elections, land registries and to a lesser extent identity management systems could benefit from using blockchain to provide a tamper-proof mechanism that can ensure no fraud has occurred in the data, something that could even prevent conflict in the case of elections. The fact that the Kenyan governments has devoted itself to improving government e-services and reducing corruption shows that adoption of blockchain can occur in this area.

The most advanced application of blockchain is smart contracts, which are self-executing contracts enabling automatic and autonomous transactions, reducing the risk and therefore need for trust in an economic system. Adoption is however contingent on blockchain adoption in connected realms such as banks and property titling and is likely to take decades.

Kenya’s capacity to exploit the benefits of blockchain is relatively low. Its education system, digital infrastructure and levels of economic development partially inhibit it from fully exploiting new IT technologies like blockchain. Additionally a large divide exists between the rich, urban and well-educated, who have benefitted most from previous new technologies like the mobile phone and the smartphone, and those that could not due to a lack of financial means, physical access or education. This divide can harm blockchain adoption in areas where universal access is preferred, for example elections. Additionally the relatively low quality of education in Kenya is more likely to prevent disintermediation in various sectors since blockchain experts and developers are necessary to build and understand blockchain applications.

Overall, blockchain is a revolutionary technology with a large potential of changing various elements of Kenyan society. The exact trajectory and forecast of this change will require much more academic research into this topic, especially with regards to using blockchain as a tool for inclusive development. However the envisioned possibilities discussed in this thesis have the potential to be transformative.

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