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Public implementation of Blockchain Technology

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Abstract: This paper discusses the avenues through which a public implementation of blockchain could deliver efficiency gains in the running of a government. We discuss some of the current inefficiencies in recordkeeping and the efficiency improvements that could come about if recordkeeping, including keeping track of tax liability, would be "put on the blockchain". We discuss some of the current issues with transaction costs and property rights that governments face and how these could be addressed with blockchain. We also discuss issues with asymmetric information in general and moral hazard in particular that are ripe in the delivery of public services and how blockchain could be used to reduce them to achieve efficiency gains and better outcomes for public policy.

Keywords: Blockchain, government, recordkeeping, transaction costs, asymmetric information, principle-agent problem, moral hazard.

JEL Classifications: D7, D8, H2, H5

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1. Introduction

Governments control a large share of modern economies. The share of government in GDP is over 30% for all but two OECD countries and over 50% for eight countries, including Finland, France and Denmark at the top end (OECD, 2017). Taxpayer money funds schools, public healthcare, emergency services, infrastructure, law and enforcement, national security, welfare system and many other services that are enjoyed by all citizens. By definition governments are huge bureaucracies, and the sheer size of governments is bound to create inefficiencies. How much tax payer money is spent on tracking tax liability and payments? How much of the tax owed is not paid when, due to incomplete information, the cost of determining everyone's tax liability may not be in the best interest of the government? Unemployment benefits protect workers from sudden loss of employment until they find a new job but at the same time diminish the incentive for the recipients to look for employment. How much more is paid in unemployment benefits than would be if we could somehow remove this moral-hazard issue? Similarly, the public health system is a key part of developed economies but the system, as any insurance provided, may give citizens less of an incentive to look after their own health. How much more do the taxpayers pay towards treatments because of this moral-hazard issue? These are but some of the examples of inefficiencies in governments that are created by issues with record-keeping, informational asymmetry and transaction costs. What if there was a mechanism that could reverse some of this waste and improve government efficiency? This paper discusses the role that blockchain technology could play in correcting for inefficiencies in government, focusing on possible solution to recordkeeping, informational asymmetry, moral hazard and transaction costs.

The majority of current literature on blockchains discusses the benefits blockchain technology can have to improve recordkeeping, which is the focus of section 2 of this paper. Improved recordkeeping has a wide range of economic implications - the reduced cost of intermediation in the economy has the possibility to increase GDP and reduce inefficiency. The areas where improvement in recordkeeping would be fruitful are endless and include the determination of tax liability, tracking of royalty payments for uses of intellectual property and auditing of company financials or health and safety practices.

Information symmetry is a critical component of the perfect market but very seldom realised. In section 3 we summarise some of the key issues that arise from asymmetric information. We argue that with an increase in transparency, public sector bodies may find a wider pool of viable bidders, lowering the expected cost of public procurement. We discuss how improvements in transparency around taxation may increase of tax revenue from both individuals and corporations due to diminished tax avoidance or evasion efforts.

One of the most promising areas for the use of blockchain is combatting issues with moral hazard that arise when parties in a transaction have incomplete information on each other. Moral hazard issues are apparent in health or unemployment insurance. Incomplete information allows the insured party to engage in actions or transactions, unobservable to the insurer, that are detrimental to the insurer as they pay costs that are not correctly incorporated in insurance premiums. Incomplete information also affects decision-making when the decisions are delegated, which is known as the principal-agent problem. The agent takes action on behalf of the principal, and when information is incomplete and the principal is not able to fully monitor the behaviour of the agent, the agent may not make decisions that best benefit the principal. The government acts as the agent when it makes decisions on behalf of the society. It also acts as the principal in government procurement. Furthermore, the government acts as an insurer to many areas of the economy, such as the central banks' role as lender of last resort, public healthcare insurance and unemployment or welfare benefits. Blockchain provides the ability to increase the availability of information and impose smart contracts that limit the negative costs inflicted on the government from these market inefficiencies.

In section 4 we investigate the assignment of property rights and the possible implications of using a government-backed cryptocurrency to define and to enforce property rights. We investigate intellectual property for new innovations, the collection, storage and ownership of personal information and the piracy of creative works. It is very important to have clearly-defined intellectual property rights for new innovations as they are key drivers of growth in an economy. It is also important to think about who has the right to information about an individual. Currently, a lot of personal information is being collected, stored and used for commercial purposes without the individual having access to it, which means that the individual cannot decide what happens with data about him or her and cannot transfer it to a party when it would be in his or her or even the society's best interest to do so. This creates issues that can have far-reaching consequences. Music and TV piracy are causing producers and artists not being compensated for their work thus dis-incentivising creative works. Each of these problems either stems from poorly defined property rights or property rights which are difficult to enforce, both of which may be able to be solved through the use of blockchain technology.

We discuss the different blockchain types and their suitability for public bodies in Section 5. Some trade-offs exist between the ideal characteristics for recordkeeping - correctness, decentralization and cost efficiency – and there is no one blockchain type that dominates the others in all situations.

A new technology, such as blockchain, is likely to be very expensive to implement. Because of that, the decision makers need good estimates of the impact that blockchain can have for a firm, an industry or the economy as a whole to be able to decide if the technology makes cost-benefit sense. Section 6 discusses strategies for ex-post empirical investigations of the impact of blockchain technologies and covers both micro studies focusing on individual blockchains and macroeconomic studies focusing on a country as a whole.

Section 7 concludes and offers some ideas for future research.

2. Recordkeeping

Improved recordkeeping affects the economy through reduced intermediation costs, such as the costs of auditing, tracking down tax liability and ensuring that the owners of intellectual property rights receive compensation from the usage of their intellectual property. Essentially, recordkeeping provides the means to facilitate transactions and to enhance traceability. At each stage of a product's release to the market, information is created, and this information can be collected for the purpose of certification, traceability and marketing. A company may want to keep track of the quality of raw materials used in production, the techniques used to produce the good, how long a perishable item is in transit and the locations it has travelled. It may be crucial that this information is recorded in an irrefutable but accessible way to ensure to the final customer that the information is legitimate and has not been tampered with. A firm that collects and records this information prices the costs of these tasks into the product itself. As such, any new technology that has the ability to decrease the cost of information-attainment process, such as an irrefutable, accessible blockchain, not only reduces the cost of collecting and storing information but also the prices of final goods. As verification costs decrease, markets grow with an increase in the number of buyers and sellers that find it profitable to transact (Catalini & Gans, 2016). This means that blockchain has the ability to enhance labour productivity and thus GDP per capita through reducing inefficiencies in the collection of data.

An area of recordkeeping where blockchain technology would give obvious and immediate benefits to government is taxation. The costs of tax administration are driven by the difficulties in identifying taxpayers, assessing tax liability, collecting taxes and enforcing tax payments. In Indonesia, for instance, the average cost of local tax administration as a percentage of revenue generated is estimated to be over 50% - thus out of each rupiah collected, citizens get at best .5 rupiah worth of services (Lewis, 2006). In New Zealand, problems with the current system are high costs of compliance and administration (Inland Revenue, 2015). These two examples suggest that modern taxation systems could be greatly improved upon. A nationally-implemented blockchain with the purpose of recording all transactions could lead to an automatically-generated goods-and-services-taxation reports that bypass the need for individual reporting, eliminating human error. Traditional cryptocurrency blockchains contain irrefutable information about transaction costs, the buyer and seller and the time of transaction. A year-to-year ledger of an individual's or a business's inflows and outflows would provide a net position and thus the net tax payable of that year. This type of taxation system would be entirely transparent and involve minimal input from third parties, greatly reducing the compliance and administration costs involved in the taxation system.

Academic research on integration of blockchain technology into taxation systems has been limited, but such integration would likely be immensely beneficial for increasing the proportion of tax liability that is received by a nation's government. The most notable research into a possible blockchain taxation system was conducted by analysing VATCoin – a "cryptotaxcurrency" (Ainsworth et al., 2016; 2018). VATCoin works in tandem with Digital Invoice Customs Exchange (DICE) – a scheme created by the EU with the intent of increasing taxation compliance and reducing fraud through a technologically intensive system with real-time transaction documentation. The VATCoin/DICE system is proposed to heavily reduce the estimated annual 150 billion Euro fraud costs in VAT payments. The practical implementation of such a system is yet to be seriously pursued, however.

Transparency may also have more direct financial advantages for public sector bodies. Armstrong et al. (2011) show that information asymmetry can act as an independent risk factor when calculating a required rate of return. While focussing on private sector firms, the results can be extrapolated to the public sector and the credit rating of a sovereign state. This could be of significant interest to countries with less favourable credit ratings as a potential way to assure investors and to expand the country's financial system (Chinn & Ito, 2002).

3. Informational asymmetry

The idea of a 'perfect market' is economic utopia that is rarely actually experienced in the real world as it requires costless exchange which itself requires all individuals to be have full information on the preferences and transactions of others. However, if we were to get close to this, social welfare would be improved (Riley & Hirschleifer, 1979). Maximising possible transparency of information is necessary in the public sector to protect against corruption or misuse of public funds and should be at the height of public interest across the globe. Reducing information asymmetry lends economic advantages beyond a lack of corruption, spanning the complete reach of public services. Many of the benefits from reduced information asymmetry come about due to the mitigation of the principal-agent problem and moral hazard issues that improved information delivers.

The supply chain is an important part of government services. As governments are often unable to provide the expanse of public services completely on their own, public goods and services can involve a complex network of contracts, all with critical procurement processes with the public sector acting as a buying agent on behalf of the general public. In the interest of the best possible outcome for public funds, information asymmetry is highly undesirable between the public body and either contractors or the general public. Yang et al., (2009) discuss supplier reliability and its impact on designing contracts. Asymmetric information leads to sub-optimal contracts, high costs associated with reducing the asymmetry and unwillingness of managers to engage with riskier parties thus limiting the number of potential bidders. This means that improving transparency in contractual relationships has the potential to lower the cost of public procurement.

The ability for a government to collect tax enables it to undertake projects that enhance the welfare of its citizens. We discussed in Section 2 the potential for blockchain to reduce the cost of recordkeeping of transactions, which implies both that more of the tax liability is recovered and that the cost of the collection is reduced, allowing more of the collected tax to be used in social-welfare-enhancing projects. Another problem that governments face is intentional tax avoidance or evasion, both among individuals and companies, for which behavioural remedies could be used alongside better recordkeeping. While not directly related to tax collection, some valuable lessons can be learned from Van Dijk & Grodzka (1992), who detail the effect that information asymmetry can have on an endowed person's willingness to contribute to public step goods. A step good, similar to a 'kick-starter', is one that only goes ahead if a certain funding target is reached. The authors find that an increase in transparency regarding the endowments and contributions of others encourages those who are wealthy to contribute more. We believe that this finding would also apply to the decision of individuals and firms to pay taxes. Evidence in both Australia and the United Kingdom has already shown that these types of remedies can yield tangible results. Gillitzer and Sinning (2018) monitor the effect of sending reminder letters to small businesses about their upcoming tax payments and find that those receiving letters are 25% more likely to make a payment on time than a control group who do not receive a reminder letter. Similarly, a study by the UK Behavioural Insights Team (2012) study highlights the importance of transparency and reports that informing taxpayers that "9 out of 10 people in an area had already paid their tax" resulted in significantly higher tax payments. Allen et al. (2016) investigate tax avoidance incentives of companies and found that declining coverage from analysts and less monitoring from public authorities lead to a heightened aggressiveness towards tax evasion. Thus, reducing information asymmetry in the taxpaying environment could lead to positive outcomes for tax revenue for public bodies. These results demonstrate the potential for increased transparency through a blockchain solution to achieve improved outcomes at a potentially lower cost than other more traditional solutions.

Moral hazard issues arise due to asymmetric information. They arise when individuals engage in excessive risk sharing because of actions taken privately affecting the probability distribution of their decision (Hölmstrom, 1979). Consider two individuals operating in an uncertain environment where risk sharing is desirable. One individual, the agent, takes unobservable actions on behalf the other, the principal. The action taken by the agent depends on the extent of risk sharing between the principal and the agent. This action then affects the total amount of consumption or money that is available for the two parties. Governing officials elected to their roles act as agents on behalf of the public that voted them in. If the principal, or the public in this instance, does not have complete information on the actions of the agent, or the government, the government's behaviour may not match the platform that got it elected and thus welfare is reduced (Grossman & Hart, 1983). Regulation on the blockchain would increase public information of the behaviour of elected agents. This would limit the ability of governments to act in their own private interest because they are motivated to serve the principal, the public.

The principal-agent problem is also found along the public procurement supply chain. There is a double nature of principal-agent interactions in politics as the government not only acts as the agent but also the principal in procurement. Politicians do not have the expertise to implement policies that they advocate and therefore require a set of agents, the regulators, to deliver public services (Lane, 2013). The methods used by many governments to ensure that agents is acting in the best interest of the government incurs high transaction costs, but with increased transparency and reliability of information these costs would be reduced.

The Government provides many services to the general public that alter the tax-payers' incentives in a way that can be negative to the wealth of the nation. Moral hazard can arise in these scenarios, affecting government finances and thus public welfare. For example, governing bodies that provide unemployment benefits tend to have citizens who are less incentivised to be actively searching for viable employment opportunities (Johnson & Klepinger, 1994). The reduced effort to look for employment is likely to be unobservable to governments that fund the benefit. An individual that has health insurance but smokes has to personally pay only a fraction of the long-term healthcare costs if he or she is diagnosed with cancer as a result of smoking. The government bears the cost of this moral-hazard issue as the provider of the public health services. The natural remedy to the moral-hazard issue is investing resources into third-party monitoring of the actions. In simple scenarios this can be viable option, in which case the first-best solution can be obtained by forcing a contract that imposes penalties against dysfunctional behaviour (Brewer III et al., 1997). However, it is often impossible or uneconomical to obtain perfect information using traditional methods, in which case the blockchain could play a vital role.

Systemic banking crises place enormous pressure on national governments to financially intervene (Hryckiewicz, 2014). Many countries operate central banks that act as the 'lender of last resort' in the case of financial downturns. Alongside this, in order to maintain the stability and integrity of the financial sector, governments offer bailouts to banks that are 'too big to fail'. Complete deposit insurance, however, worsens the bank's incentives to behave prudently and limits the market incentives to monitor banks, again due to moral hazard (Mariathasan et al., 2014). Banks tend to be more leveraged, weakly capitalised and exposed to more severe liquidity mismatch when they are perceived as more likely to benefit from government support. Hryckiewicz (2014) found that government intervention, in general, results in a negative impact on banking stability due to increased risk. The systemic consequences of moral hazard were apparent in the 2008 collapse of Lehman Brothers (Mariathasan et al., 2014). Government support to banks can be detrimental and, hence, should be either limited or designed in a way that ensures the banks bear the costs of their risky behaviour (Allen et al., 2015). Limiting the support banks receive reduces the incentive of banks to take excessive risk, limiting the risk on taxpayers' money. Hellmann et al. (2000) look into capital requirements to offset the adverse moral hazard effects of guarantees. They conclude that while possible to combat moral hazard, this requires an inefficiently high amount of capital because of the relationship between deposit rates and capital requirements that only become effective when they raise banks' costs sufficiently to impact the banks' willingness to pay, and thus solutions need to be found elsewhere. Before the Global Financial Crisis in 2008, the Central Bank of America never disclosed information about its recipients of payments. The banks were able to operate with the knowledge that they use tax payers' money but tax payers did not know where their money was being spent. After the crisis, new regulation was brought in with the intention to improve transparency between the public and the Central Bank, with mandatory disclosure of recipients and payment sizes. This change informs the general public of bailout recipients and works as a deterrent for banks to take lender-of-last-resort loans because of the attached signal of vulnerability, potently threatening share price and the company value. Blockchain would further increase the transparency between tax payer and banks, which would further reduce banking risk.

Government guarantees are also prevalent in health and life insurance industries. Similar to banking bailouts, insurance companies have excessive risk-taking behaviour compared to insurance companies without deposit insurance. Brewer III et al. (1997) took advantage of the differences in the way guaranty funds are managed across the different US states to empirically test the effect of the financial structure of government guarantee on the behaviour of life insurance companies. They found that risk-taking by life insurance companies was higher in states with taxpayer-underwritten guaranty funds than in states without them or where guaranty funds are funded by the surviving industry. The states that do not provide tax advantages for the investments of life insurance companies provide more incentives for the insurance companies to control their risk levels without outside regulatory intervention.

Government guarantees are also found in the insurance policies that governments provide though public healthcare. The same moral hazard issue that applies to private healthcare also affects public healthcare because of government subsidies. There are two types of moral hazard that affect health insurance - ex-ante and ex-post moral hazard (Zweifel & Manning, 2000). Ex-ante moral hazard includes issues that arise prior to the incident and the insured party's actions, and subsequent incentive to prevent loss are influenced by the presence of insurance coverage. Ex-post moral hazard, however, occurs after the incident. For example, when health insurance provides income support, the incentives of patients to return to work are reduced. Blockchain creates benefits though the use of a decentralised database that provides access to many different parties and has trustworthy information. For example, Gem, a United States start-up, is involved in implementing Ethereum blockchain technology in healthcare sectors (Mettler, 2016). Storing data on the blockchain reduces operational problems so treatment is characterized in a transparent manner with new information available to all medical stakeholders. Improved information not only helps limit medical negligence but also informs the insurer, or the government, what treatments they are funding and the history of patients. Estonia collaborated with Guardtime to operate healthcare on a platform-based on blockchain technology (Mettler, 2016). This software allows insurance companies the ability to retrieve all information on medical treatments performed in Estonia to aid their insurance decisions. The transparency from the software reduces moral hazard for government-subsided public healthcare because it limits the general public's ability to hide health information.

Unemployment benefits are another form of insurance affected by moral hazard in many developed economies. Unemployment insurance provides consumption-smoothing benefits that a private economy cannot provide. Ultimately, too much consumption smoothing can be bad. If the government cannot observe job search effort by the unemployed, unemployment is likely to be higher and consumption smoothing will lessen the incentives of unemployed to seek employment (Wang & Williamson, 1996; Chetty, 2008). Intuitively, unemployment benefits distort the relative price of leisure and consumption, lowering the marginal incentive to be 'actively searching' for employment. Finally, the same moral hazard issue also affects other forms of welfare payments by government. Blockchain would increase the availability and distribution of information allowing payments to be verified more easily and thus mitigating this moral-hazard issue.

The summary of these conclusions is that an increasing exposure to information brings many advantages to the public, including in the form of reducing principal-agent problems in procurement and government decision-making and reducing moral hazard in policies that provide insurance.

4. Transaction costs and property rights

The term transaction cost has two distinct definitions associated with it. The first definition refers to the costs associated with making a transaction, including bank transfer fees, lawyer fees and any other third-party costs. It has long been noted that a cryptocurrency could reduce these costs as it can cut out a lot of the middlemen that are usually present in transactions, but only if a cryptocurrency is embraced by the government as official legal tender. The second definition of transaction costs refers to the cost associated with the defining and enforcing of property rights, a definition that arose from the seminal works of Coase (1937). The Coase theorem states that an efficient outcome can arise from any starting allocation of resources if property rights are well defined and costs of bargaining are low. This theorem gives direct guidance to a government for how to facilitate efficiency - define property rights and provide avenues for people to bargain (Allen, 1999).

A government-backed cryptocurrency has some desirable characteristics, such as speed, security and stability (Gupta et al., 2017). The speed relates to how quick and easy it is to do transactions. A government-backed cryptocurrency allows for transactions to take place without the need for intermediaries to authenticate them. This characteristic reduces the costs that intermediaries put on transactions, enabling transactions to be done faster and with a lower cost. Cryptocurrencies are also very secure, which means that individuals do not require a third party, such as a bank, to hold their money. This allows for individuals to have stewardship of their money and control where it is used. However, there are some unwanted consequences. The main negative effect of cryptocurrencies is that when individuals are not storing their money in banks, there is less deposit money available for banks to invest. This can be a big problem for the banking system as a whole but could be managed through careful implementation of government-backed cryptocurrency. A cryptocurrency is very stable, more so than traditional currency. Unlike for real money where negative interest rates would result in individuals withdrawing the money from banks and holding it as cash, setting the lower limit of zero to cash interest rates, cryptocurrencies can have negative interest rates as they are completely virtual and therefore cannot be withdrawn. It is this removal of the zero lower bound for interest rates that makes monetary policy more stable with cryptocurrency than with cash (Koning, 2016).

Property rights define who have the rights to do something and cover all aspects of society from the right to buy a good or service to the right to noise or quiet. Many property rights are already well-defined by law; for example consumers only have the right to buy alcohol if they are over 18 and no one has the right to steal property. However, when property rights are related to either new issues or new ideas, they can be harder to define (Investopedia, n.d.). When people are developing new ideas or new technologies, there is a lot of risk associated with the possible return on the R&D investment. Can the innovation can be monetized? Can the inventor prevent from using their idea thus diluting any commercial gains? This second issue is becoming increasingly important as disseminating information with the internet is becoming fast and cheap. Currently, governments use a variety of tools to define the rights of use of new innovations, such as copyrights and patents. These tools work well but can involve long court disputes to figure out who had the copyright/patent first and if people were in breach of the copyright/patent. The costs associated with going to court to enforce property rights could outweigh the possible benefits from innovating, which may lead to fewer people investing their time and money into it. This is a key reason why it is necessary for property right enforcement to be cheap, easy and quick to enforce as innovations are hugely important to economic growth (Foss & Foss, 2008).

A blockchain has interesting applications to intellectual property. Putting intellectual property on a blockchain allows the tracking of who uses it and can then be combined with a smart contract to ensure that when someone does use it they also pay for it. A great example of this is work done by the World Economic Forum (WEF) in the Amazon Rainforest. The Forum is attempting to map the genome for each biological organism in the rainforest and then put this information onto a blockchain that has an in-built smart contract. This is being done so that anyone who uses this information will have to pay for it. The impacts of this blockchain are two-fold. Firstly, there will be money flows back to the countries where the information came from and, secondly, harmful uses of the rainforest will be cut down (the Economist, 2018).

Problems concerning information are not solely business problems, and a key problem facing today's society is who has the right to an individual's data. Currently a lot of information is stored in databases and registers, and personal information is often spread across many different databases relating to different things. This information covers a wide range of things from credit scores to the posts liked on Facebook. Having personal information spread across different sources creates inefficiencies. For people to be able to access information about themselves they must request it from whoever owns the database, rather than being able to access it freely at their leisure. However, data stored by a reputable third party has a legitimacy about it that is difficult to replicate by other methods. This is because the party that stores the data for people has the data of many people, and thus if the data was inaccurate people would stop trusting this data provider and use a different one instead. If the data comes from an individual, however, it is difficult to tell if the data is accurate – has the individual lied or not. The main problem here is the asymmetry of the information. Currently, the solution is to use reputable third parties, but it would be much more efficient if individuals had a way to demonstrate that their data is accurate and a way to store and keep track of the use of their own data (Zyskind & Nathan, 2015).

Rights to information is currently a big issue for medical data because as a person goes through life they use many different medical institutions, each of which stores data about the individual. This makes it difficult for a person to access their data when they need to go to a different medical institution (Azaria et al., 2016). The solution to this would be a digital wallet, created by using blockchain, which stores all the data pertaining to an individual. This would include the individual's medical history, credit history and all other relevant data. Having a digital wallet with this data on it gives individuals the ability to quickly provide their data when it is needed. This gives individuals back ownership of their data whilst also providing the validity that it needs. A digital wallet involves storing personal data on a blockchain overseen by the individual, so the individual can see who is accessing their data and give or take away permissions as they deem appropriate. This removes inefficiencies from the economy but also gives people power over their own data (Zyskind & Nathan, 2015).

There is also a huge problem facing TV networks and film and music companies where content is leaked online so people can stream it for free. This is a significant problem for the producers of this content as enormous numbers of people are getting to see the films or TV shows and hear music for free. It was estimated in 2006 that this costs the US economy $20.5

billion dollars annually. This predicament does not have any easy traditional solutions apart from shutting down the streaming sites or tracking illegal users and fining them. This highlights the problem that arises from not being able to enforce property rights effectively, and until a proper solution is found content will continued to be leaked and companies will continue to miss out on large amounts of revenue (Elder, 2016). Again, blockchain is a promising technology for keeping track the use of the copyrighted material and ensuring that the users of the material pay for the use with smart contracts.

5. Blockchain technology types

Blockchain is not just one technology but there are at least four types that differ in the way they are managed and thus have different outcomes. According to Abadi & Brunnermeier (2018), the ideal qualities for a recordkeeping system are correctness, decentralization and cost efficiency. However, one type of blockchain, with the possible exception of permissioned blockchains, can usually attain just two of the three qualities. True decentralized blockchains, such as Bitcoin, exhibit correctness and decentralization but require costly computational algorithms to be performed across a network of public miners. Centralized blockchains attain correctness and cost efficiency at the cost of decentralization as one sole entity has the ability to override, edit or delete entries previously entered on the blockchain (Seth, 2018). Centralized blockchains have the possibility of becoming compromised, however. Permissioned blockchains, such as used in Ripple, are the most likely solution to the trilemma of recordkeeping. Trusted nodes on a permissioned blockchain network can instantly, correctly and cost effectively verify transactions entered onto the blockchain through consensus measures (Cachin, 2016). It could be argued that permissioned blockchains fail the decentralization criteria as they are underpinned by a consortium of entities that grant permissions, but nevertheless permissioned blockchains are the closest to attain all three aspects of ideal recordkeeping. In our opinion, a decentralised blockchain that is run within the organisation is the most appropriate form of blockchain for use in small business and local government endeavours. For larger organisations or central government applications, permissioned blockchains appear to provide the best outcomes.

6. Measuring the impact of blockchain technology

Before concluding, we want to touch briefly on how governments can measure the success of blockchain technologies in mitigating the issues that we have covered in the paper so far. As discussed earlier, blockchain technology has the potential to improve market efficiency by improving record keeping, reducing informational uncertainty including moral hazard and reducing transaction costs. However, the benefits can be hard to quantify, especially ex ante when the technology is new, but a decision maker who chooses whether or not to invest in blockchain needs accurate estimates of the benefits. There are a number of blockchains already in use and these can be used to get some idea of the magnitude of the potential gains.

Empirical analysis of the effects of the blockchain technology can be broken down into two components – valuing change at the level of an individual blockchain that has been implemented for a specific purpose, which we call the microeconomic level, and valuing the aggregate impact for the economy of all blockchain technologies used, which we call the macroeconomic level. These two levels require differing level of sophistication of econometric analysis to identify the impact.

Finding the effect of an individual blockchain involves first identifying a statistic that best captures the benefit of the blockchain and then either comparing that statistic before and after or using regression or other statistical analysis. We discussed in Section 3 the moral hazard associated with unemployment insurance as the very presence of it reduces the incentive to find a job, which is exactly why many governments require those who are unemployed to be actively looking for employment. If a blockchain technology was implemented here its goal would be to make it easier to see how many jobs beneficiaries have applied for. The blockchain could confirm that people have applied for jobs, which would then be used in conjunction with a smart contract to validate their benefit. If this works effectively then there should be less time spent monitoring beneficiaries, enabling more time to be spent helping them get jobs. The overall effect of the blockchain technology can be seen by comparing the average time beneficiaries spend unemployed with and without the blockchain technology. A more sophisticated method would be to run a simple regression analysis using time series information on time spent unemployed, other variables that likely affect the days spent unemployed, such as the average wages in the industry, and a dummy variable measuring one after the blockchain implementation and zero otherwise. The size and significance of the coefficient for the blockchain dummy reveals if the blockchain has been impactful at reducing the number of days spent unemployed.

From a property-rights perspective, blockchain technology tries to reduce the cost and time associated with accessing information. The medical information example in Section 4 can be used as an example here. Currently, medical data is stored by medical institutions, which causes problems when an individual goes to a different medical institution from where their data is stored. The main issues are the lack of accuracy introduced by the transfer of data and the time it takes to transfer the data - in the U.S.A it can take as long as 60 days to transfer medical information (Azaria et al., 2016). The lack of accuracy and wait for information to be transferred have been proven to have significant undesirable effects especially in areas concerning patient safety and continuity of care (Kripalani et al., 2007). If a digital wallet is implemented, then the accuracy should increase and the time delays should decrease significantly. The best way to measure the effect of this blockchain technology is to measure the time to transfer medical information and the amount of errors present in the data. One could simply compare the before and after values or run a similar regression as described above on time series data where a dummy for the blockchain is included. A value-of-life calculation could also be made by comparing the impact of the problems caused by delayed information or errors on an individual's quality of life. Again, to see the impact of the blockchain, a simple before and after comparison could be made or one could use regression analysis.

The macroeconomic level accounts for the impact of the many different types of blockchains – one perhaps targeting the healthcare industry and another attempting to increase transaction speed – and attempts to measure the net macroeconomic benefit of these blockchains. Expected macroeconomic benefits include increased GDP and labour productivity as the blockchain works to reduce the inefficiencies highlighted in this paper. The general difficulty in estimating the benefits of blockchain technologies ex-post, especially at the macroeconomic level, is in isolating the effects of the blockchain-related infrastructure/legislation. At the macroeconomic level, modelling blockchain adoption with a simple dummy variable fails to capture the intensity of blockchain adoption across sectors and across time. Thus, a simple regression analysis that we suggested above for the microeconomic analysis, using a dummy variable for blockchain, is likely to give biased estimates. Furthermore, even if the dummy variable approach was acceptable, it is difficult to have confidence that the coefficient for the blockchain dummy is capturing the effect of the blockchain instead of some other variable outside of the model that moved at the same time. To counteract these issues, we suggest using a synthetic control country to carry out regression analysis (Abadie et al., 2015), discussed below.

Take a model the goal of which is to find out the proportion of GDP that is attributed to the use of blockchain technologies. Our theory is that blockchain use increases the productivity of labour within a country, leading to a growth in real GDP, and therefore we would expect the study country to have a jump in GDP after the implementation of blockchain. As discussed above, because there are too many variables that contribute to the GDP and because not all can be measured in the model, it is questionable whether a significant coefficient for the blockchain dummy can be interpreted as the effect of the blockchain technologies. What we really would like is a country that is otherwise the same as our study country but that has not adopted blockchain technologies, in which case we could see if their growth paths diverge after the implementation of the blockchain technologies in our study country. Given the low likelihood of finding this identical twin, a synthetic control country can be created by a statistical program that finds countries and weights so that the weighted average of the countries together mimics the economy of our study country. Comparing the GDP growth paths of our study country and the synthetic twin gives us our best shot of finding the real effects of widespread blockchain use.

There are many difficulties in creating an accurate synthetic control country, however. What variables should we control for? Do these countries have differing levels of blockchain use themselves that would affect GDP? Having said that, studies estimating impacts of different shocks have found success using the synthetic control method, and we could look to these for guidance. For example, a study of the impact of increased terrorism in Basque on the region's real per capita GDP found a 10% drop post terrorism using a synthetic control of other Spanish counties (Abadie & Gardeazabal, 2003). An example of an early adopter is Estonia that in 2012 revealed itself as the most blockchain-friendly country in the world, using the technology in several sectors. Estonia could therefore prove to be a suitable testing ground to estimate macroeconomic effects of widespread blockchain use. However, we may need to wait a while before the impact of blockchain can be seen in GDP, even for an early adopter like Estonia.

6. Conclusion

In conclusion, literature has shown that information asymmetry, transaction costs and moral hazard create market inefficiencies in core governmental services. Reducing some of the market frictions created by unreliable or incomplete information is a huge issue that plagues many governments across the globe. Blockchain provides recordkeeping services that would solve many of these issues outlined in this paper. We believe that the advantages from blockchain arise from increased reliability and access to information for the government. Blockchain technologies have a huge potential to reduce inefficiencies in government and, due to the sheer size of governments, make a large difference in a country's economic wellbeing.

There is future potential for empirical studies examining the differences in quantitative benefits between traditional data keeping methods and storing information on the blockchain. Some strategies for ex-post analysis were discussed in Section 6. Another possibly fruitful approach, especially in countries that are yet to implement blockchain technologies, is to start by measuring the current inefficiencies public services, which would help rank order the areas where blockchain could make the biggest impact and incentivise the implementation of blockchain technology, yielding ultimately positive outcomes for tax payers. One key area we suggest looking into is the cost of obtaining and securing property rights, administrative costs in supply chain contracts and costs of administering a tax system.

Economic gains of blockchain occur through aggregate data collection in one place, which is why we do not recommend partial national implementation on a trial basis but instead suggest full trials to be implemented in smaller towns or cities by local city council. If implemented nationwide, looking at specific self-contained issues would be recommended. If installing a new blockchain system is undesirable on a trial basis we recommend using Estonia as a treatment county. One of Estonia's key implementation areas is healthcare which we recommend looking into as it provides some evidence of how these policies have helped Estonia so far. Comparing Estonia to other similar countries would provide an indication on the benefits blockchain provides towards a countries' economic wellbeing.

There are numerous examples of governments around the world pouring money into blockchain research funds in an attempt to better understand roles for the technology. For example, the UK Food Standards Authority recently trialled the use of blockchain technology in a cattle slaughterhouse, a place where inspection and collation of data is a top priority (Food Standards Agency, 2018). It seems that the question is not "if" anymore but "when". As governments gain a better understanding of the possible roles for blockchain they will be better able to write effective regulations that encourage blockchain integration.

Issues with the accuracy of blockchain data still exist as human error of inputting data could still detract from the quality of information submitted to the blockchain. Efforts must be made to make any data input process automated or extremely straightforward. Innovations, such as product tags that are attached to objects at the beginning of the production process and are sensed at each location the product is transported to, could provide a ledger of exact locations, dates, and times of when and where that object has been, all without the requirement of a third party or the risk of human error from recordkeeping. Furthermore, while human error cannot be completely ruled out, once any inaccuracies are identified, the blockchain allows the new accurate info to be overwritten at a very low cost.

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