Blockchain in agriculture

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Abstract

Agriculture is the production of food, fibre and data. The data attests to the qualities and properties of the food and fibre, and is therefore economically valuable. Yet while data is cheap to add, it is often costly to verify. In consequence, a significant percentage of the final cost of agricultural produce goes to costs of establishing provenance, proving compliance with standards and regulations, undergoing inspections, audits, and process monitoring, as well as costs of intermediation, quality assurance, and branding. Blockchain, a new technology that enables different parties along a supply chain to trust digital data (it is sometimes called a 'trustless' technology), has the potential to lower transaction costs and improve the efficiency of agricultural supply chains by reducing the need for monitoring and verification of data. Yet while hugely promising, the technology is still new and experimental, and faces a number of significant barriers to adoption.

1 Blockchain: The latest agricultural technology?

Agriculture is the original transformative human technology. The Neolithic agricultural revolution gave us towns and cities, and in the 1700s the British agricultural revolution ignited the industrial revolution (Russell 1966). Agriculture is itself an evolving technology through experimental discovery of what plants and animals thrive where and with what support. Australian commercial agriculture, for instance, is based on crop and livestock species introduced from elsewhere. But technology is also applied to agriculture. The invention of tools such as the seed-drill, steel plough, and mechanical harvesters, to improved practices such as rotational cropping and animal husbandry, to modern scientific breeding and engineering of plant and animal varietals conducted by specialized research institutes (Griliches 1957, Pardey *et al* 2010, Potts and Kastelle 2017) have all boosted agricultural productivity. The advance of agricultural technologies connects agricultural inputs – such as seeds, stock and capital – to agricultural outputs, such as wheat, cotton, and wool (themselves inputs to food and clothing). Technological change means new inputs, or new ways to transform these into outputs through better knowledge and protection technologies. The farm, and its productive capacity, is the focal point of this view of agricultural technological change.

But farms produce more than just crops and livestock. They also produce facts. These are the data that constitutes the information records (of what happened when to what by whom) that create value when attached to products leaving the farm. These data have value to those downstream of the farm, those who contract, transport, process, as the intermediate or final consumers of the farm's eventual products. Not only do these data need to be created and attached, it also needs to be trusted in order to have value. Blockchain is an innovation that better connects the farm to the world. It adds value by lowering the cost of moving data created on-farm for off-farm processing and consumption.

2 The blockchain agricultural revolution

Agriculture remains one of the least digitised industries in the world. Much of the information that is produced on-farm is difficult to transmit (i.e. export) off-farm because it is neither created nor processed in a way that facilitates trusted, low-cost transmission. The low levels of digitisation in much modern agriculture is a basic constraint on the productive ability and efficiency of farming to capture value from information.

As in all industries, information capture and use of information technologies can facilitate improved farm management practices, leading to productivity growth and improved on-farm yields. However, digitisation and information technology is also an input into the value equation of *provable quality* of farm produce.

Provable quality of farm produce refers to characteristics such as:

- Commodity type or grade
- Quantity measures (e.g. tonnage delivered, headcount, etc)
- Quality measures (e.g. milkfat content, protein yield, fibre diameter, etc)
- Specific batch conditions (e.g. harvest time and location)
- Consistency or purity or those measures (e.g. blended or not)
- Compliance with standards (e.g. organic, GMO, pest free area status, etc)
- Compliance with rules (e.g. workplace laws, environmental regulations, trade agreements, etc)
- Safety information (e.g. preparation, toxins, handling, etc)
- Provenance and authenticity (e.g. farmer identity, regional identity)
- Complementary information (e.g. tasting notes, nutritional qualities, stories)
- Organisational conditions (e.g. coop, small farmer, agribusiness, etc)
- Legal properties (e.g. ownership, contract conditions)

These information characteristics and attributes all impact on the price of the farm commodity. Missing information causes a product to trade at a discount to a full information price, as does uncertainty about the quality of the information.

Creating and appending data and information is costly. But it is economically worth doing to the extent that data have value to downstream users, and eventually to consumers, in order to discern qualities of the product. Creating trust (e.g. through branding or regulation) or proving truth of the data (e.g. through inspections, samples, or guarantees) is also costly. The amount of data provided, and the trustworthiness of those data will be supplied in proportion to the cost of producing that data on farm and the willingness to pay by downstream users.

Novak *et al* (2018) have estimated that the cost of trust is on the order of 35 percent of the total value of economic production. Blockchain is an *institutional technology* for industrialising the cost of trust (Davidson *et al* 2018, Berg *et al* 2019). The economic benefit of blockchain is that it lowers administrative and monitoring costs associated with transactional data. As Catalini and Gans (2017: 12) explain:

> "While blockchain technology is often compared to communication protocols such as TCP/IP – which focuses on how *information* is packetized and routed through the internet – it fundamentally differs from them because it allows for the secure transfer and enforcement of *property rights*."

To the extent that supply chains are made of transactional information (content labels, bills of lading, trade finance contracts, destination manifests, etc) and the need to audit and monitor those data, a technology that lowers the cost of trusting that information lowers the cost of trade. Furthermore, if that same technology facilitates adding further trusted information, then that information increases the value of that commodity. By both lowering cost and increasing value, blockchain technology potentially increases profitability of agricultural produce along the value chain, or can thereby facilitate more competitive pricing. The application of blockchain technology to supply chains is called 'tradetech' (Allen et al. 2018).

With a few exceptions such as local farmer's markets, agricultural supply chains are mostly long and complex. Agriculture is a competitive business, and most production occurs at industrial scale and due to regionality and seasonality is sold into global markets. Agricultural produce is often processed and mixed, and requires careful handling (e.g. treatments, refrigeration, or special transport). It is often sourced from multiple locations with distinct quality variation due to multiple small producers. Most agricultural produce is perishable, or variable in quality in ways that can be difficult to observe. For these reasons, information about, say, food provenance, traceability and transparency of all handling and processing, and compliance with rules and regulations at every point along the supply chain is crucial to ensure the quality, safety and value of agricultural products. To the extent that these value conditions ultimately reduce to problems of digital information creation and trust, then blockchain technology (a.k.a. distributed ledger technology) will be a key infrastructure component of future global agricultural supply chains (Papa 2017, Deloitte 2018, Bermeo-Almeida et al. 2018, Caro et al. 2018, Mire 2018, Tripoli and Schmidhuber 2018).

3 What is Distributed Ledger Technology?

Distributed ledger technology refers to a digital system (i.e. technology) for recording and updating a data structure (i.e. ledger) simultaneously in multiple places (i.e. distributed). Distributed ledger technology enables data to be shared, replicated and synchronised on multiple nodes over a peer-to-peer network that is governed by an open-source protocol. To update a ledger, all nodes construct transactions from the network and then a consensus algorithm uses a voting mechanism to establish the true state of the ledger and from which all nodes are then incentivised to update their own records. A blockchain is a type of digital ledger technology (directed acyclic graphs, or DAGs, are another type) with a cryptographically concatenated data structure and network architecture described by Nakamoto (2008). The bitcoin blockchain, for instance, entails a proof of work mechanism and a cryptocurrency (e.g. Bitcoin). A blockchain is a specific arrangement of technology components – including: public key cryptography, peer-to-peer networking, databases, game theory, consensus algorithms – that records and tracks information in a distributed and decentralized manner. This configuration provides participants of the network with secure access to information on the ledger at any point in time.

The practical significance of distributed ledger technology is that it achieves an ongoing updatable, synchronised, secure and trusted record-keeping system without centralised control. There is no 'trusted node' in the system that all other nodes refer back to when updating their copy of the records. There is no 'trusted intermediary' that brokers transactions in the network, or that needs to be trusted to keep track of who owns what, or who owes what. Blockchains thus facilitate peer-to-peer transactions and value transfer. Blockchains are sometimes described as a 'trustless' technology. This does not mean that trust is free: trust still needs to be produced, although now using an industrialised process of third-party mining (Berg *et al* 2019). Rather, blockchain is *a new architecture of trust* (Werbach 2018) in which consensus updates of records – i.e. the social facts upon which commerce and society are constructed – are achieved across a distributed system without anyone in the system needing to trust anyone else. Blockchain technology enables two unknown parties to transact without needing to mutually trust a third counterparty (e.g. a broker, a bank, an agent, a government office).

4 New economics of agriculture

The new economics of a blockchain-enabled economy – so called *Institutional Cryptoeconomics* – are outlined in Davidson *et al* (2018), and Berg *et al* (2019). The specific application to the new economics of agriculture is a special case following an analysis, as outlined above, of viewing agricultural production as the co-production of information that has transactional value.

Institutional cryptoeconomics predicts that blockchain technology adoption into modern agriculture will have the following effects:

(1) Increased return to on-farm digital investment, but requires coordination for payoff
(2) Price wedge between quality and commodity production, incentivising information provision where quality exists
(3) Redistribute value along supply chain (toward farm)
(4) Promote market disintermediation and structural dehierarchicalisation

One – Digital upload is a necessary condition for blockchain technology adoption, which is in effect an internet application. But the benefits to investment in blockchain technology adoption do not accrue to an individual farm (as with, say, mechanisation, or improved seeds), but only to a completed adoption sequence along the value chain. Economists call this a 'sequential production technology' (Kremer 1993). The full benefit requires all parts of the value chain adopt an interoperable version of the technology. This therefore requires coordination to incentive or require adoption along the supply chain. Berg *et al* (2019) argue this is the role of the *V-form organisation*, but such coordination can also be done by an industry association or by government (Berg et al. 2018).

This property of being a sequential production technology is, arguably, the main barrier to innovation adoption of blockchain technology into agricultural supply chains. The benefits indicated above only accrue if all parties along the supply chain adopt the new technology. This creates incentive problems when different players along the supply chain have different capabilities and capacities to adopt the new technology. It also raises the prospect of hold-up problems resulting in innovation bottlenecks (Barrera and Hurder 2019). The extent to which this is a problem, or creates opportunities for bargaining, will depend upon the extent of competition (i.e. possibilities of substitution) at each phase of the supply chain.

Two – Adoption of blockchain technology will change the distribution of value allocated to information supply. In extant agricultural markets, bulk commodity prices accrue to low information outputs (i.e. products destined to be blended or sold by quantity measure). Premium prices accrue to provable quality, such as branded products. A key role of intermediaries (such as food manufacturers) is to attest quality, which earns a super-normal return. But downstream uncertainty means that many quality products will trade at a discount, which then creates a 'lemons problem' (Akerlof 1970), in which producer incentives to add quality are low, because they will be paid the median price of the product category. Blockchain adoption therefore predicts that by reducing information asymmetry there will be an increased return that is proportional to quality of product because the reduced cost of information attestation of that quality. This also predicts that low quality produce will be less able to mix with higher quality, driving a price wedge into many extant markets. Higher quality produce will be rewarded with higher prices, and agricultural markets will become more efficient.

Three – The effect of reduced information asymmetry and increased market efficiency is that value will be distributed along a production process where quality is added, not just where it can be efficiently proven or attested. In modern global agricultural markets, this usually happens close to the final consumer, with branding. However, blockchain technology is expected to push that further back down the value chain closer to the farm-gate. An obvious application of this is to improve the efficacy of fair trade (Rijmenam and Ryan 2019: 114-24).

Four – The automation of trust in information through blockchain technology facilitates *disintermediation*, where intermediaries were essentially playing the role of trusted third-party brokers between two trading parties (Casey and Wong 2017). Examples are not only in disintermediating agricultural trade, but also in agricultural services such as insurance or payments using smart contracts (Ge *et al* 2017, Lin *et al* 2017). This also causes *dehierarchicalisation* – where the reduced transaction costs of peer-to-peer trades unbundles the value of a large administrative hierarchy to allocate, monitor and manage resources across the span of the organisation.

The combination of the disintermediation effect and the dehierarchicalisation effect implies that the industrial structure of global agricultural production will evolve toward greater use of market coordination with less vertical integration and greater firm specialisation, and new business models. The resulting rise in peer-to-peer trade will potentially evolve into something akin to a global *'digital farmer's market'*, in which the information benefits of a local farmers market (i.e. a very short supply chain, which therefore carries not only fresh produce, but also high bandwidth easily-verifiable information) is replicated at a global scale.

The structural effect of new and better technology to connect farmers into a global value chain is to connect farmers and food consumers more directly by disintermediation of the value chain (with respect to information loss) into a blockchain-based industry utility for agriculture.

5 Industry utility

The main application for distributed ledger technology in agriculture is in relation to the provision and security of information along global supply chains. Because blockchain is an institutional and transactional technology, it can be understood as a new kind of *economic platform* to facilitate transactions (Mattila and Seppälä 2018) or, in the language suggested by CSIRO's Data61 (Turner 2018), as an *industry utility*.

The benefits of blockchain as a digital economic platform accrue to consumers, producers, governments, and complementary technologies. As an industry utility, blockchain enables low-cost high-trust information about provenance regarding proof of on-farm claims of quality with respect to, for instance, ingredients, growing conditions, location, purity, etc, to move between producers and consumers. This same technology also allows producers to prove to regulatory and standards bodies compliance with mandated production conditions and processes (e.g. use of pesticides, animal welfare conditions, proof of origin, etc). Proof of regulatory compliance, and evidence it has not been tampered with, is valuable economic information for downstream consumers in export markets. The benefits accrue to consumers in surety of information claims, and to producers in lowered costs through machine automation of inspections, auditing, and other costly administrative processes in supplying high-trust information. Access to such an industry utility will therefore be likely to improve the profitability and therefore sustainability of high-quality agricultural farming practices.

Blockchain-based industry utility for agriculture also facilitates integration with other Web3 or Industry 4.0 digital technologies of automation in agriculture. Automated sensing technologies, such as Internet of Things (IoT), can provide the hardware layers that upload information to blockchain-enabled supply chains. Artificial intelligence and machine learning technologies embedded into machinery can enable automated technologies such as irrigation systems, plant or harvesting equipment, or transport vehicles to engage in smart contracting and payments (e.g. automating payment upon delivery through tokenisation). These same sensing and contracting capabilities enable blockchain-enabled, contract management, trade finance and insurance markets to emerge in order to improve operational efficiencies and risk management in agricultural markets.

Blockchain technology offers the prospect of a decentralised industry architecture to supply trade and administrative services across the agricultural sector's value chain (Allen et al. 2018). A decentralised supply architecture has a significant advantage over centralised platforms or service companies, in that it makes possible a kind of shared information infrastructure, or industry utility, that is less likely to concentrate market power in a particular organisation or intermediary that can exploit its position at bottlenecks in the value chain in order to extract rents. Instead, a shared, open, protocol-based transaction platform will likely reduce the costs of verification, auditing and monitoring (i.e. costs of trust) across the supply chain.

The basic infrastructure requirements to support development and adoption of distributed ledger technology are broadly those of digitisation and deep penetration of the internet into business and society. This same argument for digital industry utilities build on blockchain is also occurring in other sectors. In law, a consortium led by IBM, as technology provider, a large Australian Law firm (Herbert Smith Freehills), and in research partnership with Data61 has proposed the *Australian National Blockchain*,[1] as a new industry utility to digitise and automate smart contracts for commercial law.

Blockchain based platforms for agriculture have been already built and launched by private Australian organisations, and have early customers using these already. These include

[1] https://www.australiannationalblockchain.com/

Sydney-based digital infrastructure and exchange provider AgriDigital,[2] which has substantial experience in providing infrastructure and services for Australian grain markets, and new blockchain-start-ups such as AgriChain (formerly BlockGrain).[3] It is expected that the number of commercial service providers in this space, both from new start-ups and new service lines from traditional agricultural service companies, or even technology companies, will continue to grow.

6 Barriers to adoption

Technology maturity

DLT is still an early-stage experimental technology and currently has a number of significant limitations in relation to scaling, interoperability, user experience, and market development beyond proof-of-concept phase (Data61, 2017). The regulatory environment into which this new technology is emerging is also immature, both here in Australia and in overseas markets. Yet as a largely open-source technology, there is significant user-led research and development that is pushing back on these limitations (e.g. with respect to improved technical efficiency, higher transactions throughput, greater security, better user-experience) and there is growing business and regulatory familiarity, particularly in fin-tech and trade-tech space. However, blockchain is still in its infancy in *agtech*. Nevertheless, blockchain technologies are rapidly evolving and we can expect significant technological developments and infrastructural adoption over the next decade (Data61, 2019).

Energy cost

Energy use has often been noted as a potential barrier to large-scale adoption of blockchain technology. However, blockchain's administrative efficiencies are expected to translate into environmental benefits once substitution effects of blockchain use play out. It is well known that public blockchains using the proof-of-work mechanism for consensus (such as the Bitcoin blockchain, which uses the Nakamoto consensus protocol) consume large amounts of electricity in their mining operations. (Costly mining is necessary in a proof-of-work consensus mechanism to mitigate against Sybil-attacks.) However, a correct accounting of the economic cost of mining expenditure in manufacturing trust needs to be compared to what it substitutes for, which are operations to manufacture trust using often more expensive procedures. An example is when Australian fruit-growers need to fly-out inspectors from Japan to audit regulatory compliance in Tasmanian fruit harvests and processing. The relevant comparison is the cost of mining versus the full audit cost, including air travel and labour costs. Furthermore, new consensus protocols such as proof-of-stake are much lower cost to implement (relying instead on a punishment mechanism to 'slash' staked tokens if bad transactions are validated). Enterprise blockchains (i.e. private blockchains that use proof-of-authority consensus protocols) do not use mining and have considerably lower resource costs.

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[2] AgriDigital research reports can be found here: https://www.agridigital.io/resources/reports
[3] https://agrichain.com/about-the-platform/

Education

At this stage, a major barrier to blockchain development and adoption in Australian agriculture resides with education. Blockchain is a very new and somewhat esoteric technology. It is entirely unlike any earlier generations of agricultural technologies, and even smart, digital-savvy people can find this technology baffling. There are almost no native experts in the field, and the agtech companies who have sought to engage with this experimental technology have been on a very steep learning curve.

The role for government, public research and industry associations at this early stage is to promote education and awareness, which are best done through specific proof of concept experiments and pilot programs, along with ongoing research on blockchain platforms as industry utilities. This industry focused education is being undertaken in part by public research organisations such as CSIRO's Data61 and RMIT University's Blockchain Innovation Hub, among others, but there is a need for more targeted industry education.

Unfamiliarity with the technology is a risk factor because it leads to uncertainty in decision-making. Education is needed. This may need to involve travelling education provision, talks, demonstrators and suchlike in rural areas. Proof of concepts and early trials also need to be promoted and further advanced. Risk perceptions with the technology are largely derivative of its association with cryptocurrencies, and the volatility and scams and illegal activity therein. Many very early stage technologies go through this chaotic phase before maturing as regulated technology.

Consortia

Beyond considerations that are to be expected with the adoption of any early stage radical technology – namely level of maturity of the technology, fixed costs of adoption, and familiarity and knowledge of the technology – all of which are expected to improve with further development and experience, the most significant barrier to adoption of blockchain technology into agriculture is the requirement that multiple components of a value chain adopt the technology simultaneously, which requires coordination. This can be facilitated by individual farms and other organisations that extends well beyond Australian farms joining into consortia. The problem is: who builds and leads these consortia to coordinate adoption across multiple stages of the agricultural value chain?

Such a consortia building mechanism will need to incorporate various organisations along the supply chain, such as suppliers, insurance and finance, processors, logistics providers and other services, along with regulatory agencies at State and Federal levels of Australian government. This will then need to be coordinated with counterpart organisations and agencies at the regional and international domain.

A key challenge in building such consortia is overcoming what economists call the 'hold-up problem' (Barrera and Hurder 2019). Joining a platform consortia requires all parties to make consortia-specific investments (such as adopting a specific protocol or installing specific hardware). Prior to joining a consortia each party has a range of competitive options, but after joining and making the specific investments their bargaining position vis-à-vis the consortia weakens, and particularly with respect to dominant or larger members. These hazards of opportunism need to be overcome in order to induce smaller more vulnerable members to join a consortia in which larger players need to be able to credibly commit not to exploit (or 'hold-up') smaller members in respect of reallocation of the gains from platform adoption across the supply-chain after each party has made relationship-specific investments.

Solutions to this consortia building and joining problem can involve seeking to exploit existing trust relationships, such as through trusted agricultural service providers seeking to broker these relationships. Or a solution could come through trusted industry associations or other forums for negotiating consortia and providing independent governance and assurance. There is a potential role for government in facilitating these arrangements. But a further option, as recognised by Barrera and Hurder (2019), is that blockchain technology itself may provide the mechanism to construct credible commitment of consortia parties not to exploit each other.

7 Financial, regulatory and legal considerations

Because the benefits of the adoption of blockchain technology accrue across a network or value chain, economic models of the value of blockchain adoption cannot meaningfully be estimated at the level of a single farm, or independent of the expectation of complementary adoption decisions along the value chain. This is the sense in which blockchain is an *institutional technology*, rather than a general-purpose technology (Davidson et al. 2018). Benefits accrue to a system of adoption, and therefore industry adoption requires coordination, guidance and incentives.

This is not the task of individual farm managers or agronomists, but will require group action by coalitions, consortiums, collectives or associations. These group-level benefits to DLT adoption enable lower transactions costs between operations, facilitating new business models that enable, for instance, data generated on farm to be pushed much further down the value chain and valued accordingly.

Financing the build for an agricultural DLT *industry utility* is a significant challenge, owing to its economic characteristics as a common pool resource or local public good. Free-rider problems constrain the private incentive to pool investment to develop and build an open-platform joint infrastructural resource. An enterprise blockchain solution – such as is being developed by IBM-Maersk consortium with the TradeLens platform, or with IBM-Walmart consortium with the FoodTrust platform – does not suffer these same investment incentive problems, but strong network effects mean that it does risk creating a monopoly platform (Mattila and Seppälä 2018). In this case, new regulatory models of platform competition will need to be developed to deal with the new challenges that blockchain industry utilities will present under different ownership models and access regimes.

Industry associations, private collectives (von Hippel and von Krogh 2003), or public provision will most likely be necessary to develop this infrastructural resource in order to overcome these collective investment problems, and also to ensure that control of standards is open rather than proprietary. An open platform will have greater innovation potential than a proprietary platform, even if the incentives to build an enterprise or proprietary platform are greater. However, blockchain technologies are at this early stage still largely built on open source software, with few intellectual property barriers. This means that private investment has less of a hurdle to clear, and furthermore may have 'contribution good' characteristics (Kealey and Ricketts 2014).

Distributed ledger technology is best understood as a transactional infrastructure (i.e. an industry utility) that needs to be adapted to the specific regional, technical and business model requirements of an industry production model, as well as to a specific regulatory and legal context. The costs of building such infrastructure will be ideally apportioned over the value chain in such a way as to align with the accrual of benefits. A producer levy or a consumer tax is likely the most efficient way to fund open access public infrastructure. A fee for service model on the other hand will be the most likely funding model for enterprise provided infrastructure.

A new class of opportunity that blockchain platforms can furnish as trade infrastructure is that they can hard-code regulatory and legal framework rules into the platform, such that a contract or transaction is only valid if it is compliant with the platform rules (De Filippi and Wright 2018). The implication is that such a platform with hard-coded Australian regulation and law can then serve as a platform for the *export of Australian institutions* (e.g. to jurisdictions with weaker, missing, or even corrupted institutions). A further implication is that part of the institutional hard-coding could also include taxation, thus suggesting a viable public financing model of industry utility that bundles high quality Australian agricultural exports with high-quality Australian regulatory and institutional infrastructure. This institutional trade platform export model could plausibly extend through existing regional trade zones to align with extant trade treaties.

Successful coordinated blockchain adoption will change the economics of entire agricultural value chains.

First, the 'cost of trust' savings from DLT accrue to the entire value chain. This is because the substitution effect is away from individual business units requiring costly and often duplicative resources to audit, verify, monitor, and other activities necessary to trust data. The whole value chain becomes more globally competitive in consequence of the improved transactional technology. This cost saving (producer benefit) is also a consumer benefit, which at lower market price may induce increased demand.

Second, creative destruction consequences of blockchain industry utilities will fall on alternative technologies of trust. These are approximately: brands; regulations; and proximity. Consumer brands are an efficient model to manufacture trust to overcome information asymmetries through the creation of a costly hostage. In essence, a company stakes its expensively made brand reputation against a vouchsafe of quality. Knowing that a company has much to lose if it fails to deliver quality, consumers rationally trust a brand (Grossman 1981, Erdem and Swait 1998). But brands are costly assets to create, and to the extent that DLT technology can provide the same consumer service of quality reassurance, extant brands may be devalued. Regulations supplied by government are also a costly way to assure quality, and therefore to supply trust. Much of the cost falls on producer compliance, requiring specialised resources. This cost tends to favour larger organisations, who can better meet these specialised needs and fixed costs, and to disfavour smaller operations. Regulatory costs also inhibit innovation, tending to lock in existing business models. A third way to manufacture trust is simply to stay close to events: a farmer's market is not just a freshness technology but also a trust technology, enabling consumers to interact with producers. But the cost of this technology is that it inhibits scale and distance, and therefore discovery of new markets. For these three reasons, blockchain adoption will tend to induce structural changes in agricultural value chains.

Third, the adoption calculation for an individual farm is perhaps less on the benefit side (which accrues to being part of a DLT-enabled supply chain), but rather the hazard risk of being shut out. The implication of not being part of a DLT supply chain is a downstream suspicion that the absence of proof of quality is evidence of low quality, which will then be priced accordingly. The risk is that not being able to connect to a DLT-supply chain will constrain produce to a low-information commodity track, paid default low quality commodity prices. That sets up incentives to only produce low quality (i.e. unbranded, un-regulated, shipped) outputs. This may still be a profitable business model for industrialised suppliers.

Australia is currently in a strong regulatory position for the development and industry-wide adoption of DLT-enabled agricultural supply chains. This is in significant part due to Australia's high-quality cryptoasset regulatory landscape (Blandin et al. 2019), and due to well-informed government agencies and regulators (Novak and Poschesneva 2019).
The main regulatory work to be done to achieve this is to coordinate and integrate regulation and standards across the value chain, seeking to hard-code rules across multiple jurisdictions into a common digital standard trade infrastructure protocol.

8 Broader Issues for Australian Society and Rural Communities

Distributed ledger technology applied to agriculture is a species of automation and industrialisation. But it is an unusual one, whose effects will be *prima facie* difficult to see, because what is being automated and industrialised is human trust in social facts. What is being built is a new architecture of trust, a new way to manufacture trust in order to authenticate data, manage its analysis and automate its use (Werbuch 2018, Rijmenam and Ryan 2019).

Blockchain technology in transactional effect (if not in law) creates property rights for data. There will be important ethical considerations that need to be addressed around data privacy, data ethics, and access equality associated with the new affordances this technology brings. However, many of these issues already exist in current and extant ways of solving provenance problems and addressing compliance and auditing functions in agricultural supply chains. An expected benefit is to reduce the level of fraud in food products, whether counterfeit labelling or the incidence of false quality claims with respect to provenance or qualities such as sustainable harvest,[4] single-origin, fair trade, etc.

Blockchain has significant potential to reduce food safety breaches and improve public health.[5] Indeed, this is the major value proposition being advanced by technology companies such as IBM with their FoodTrust platform, or by AgriFood giants such as US-based Cargill with their blockchain turkey program. Blockchain integration into supply chains enables targeted rapid recall of batches of product found to be contaminated, without having to seek blanket recalls that can take weeks to implement.

Regarding the implications of blockchain and DLT adoption on rural communities, landscape sustainability and workplace health and safety, there is unlikely to be significant physical or environmental risk or disruption. However, there will likely be structural disruption to business models and industrial architecture due to disintermediation effects. There will likely be many tasks, operations and jobs that will be automated. These are net benefits, as they reduce the cost of trust and improve the overall economic viability of production, but economic disruption will occur. It would be useful seek to economically model these industrial dynamics in order to estimate the scale and distribution of their effect.

It is entirely expected that consumers will benefit from the eventual adoption of blockchain technology, both through lower prices (and therefore greater access to quality produce) in consequence of the reduced cost of trust, but also through increased information provision. Consumers value detailed information about agricultural products, and blockchain and DLT increases the quality and trust in this information. It also facilitates the automation of processing of this information, using shopping-bots or apps to audit the blockchain trail of information. This empowers consumers to make their own decisions, without being swayed by corporate or government power by way of advertising or industry capture.

9 Conclusion

[4] WWF-Australia has developed and world leading pilot in sustainable and ethical food provenance tracking (first trialled for sustainable harvest tuna caught in the South Pacific) called OpenSC. https://www.wwf.org.au/get-involved/panda-labs/opensc/opensc#gs.6tpw0i

[5] http://theconversation.com/blockchain-systems-are-tracking-food-safety-and-origins-106491

Blockchain technology, originally developed as a way to create an internet-native money (as the technology behind cryptocurrencies), has far broader application to provide next generation digital infrastructure to for global supply chains and agricultural trade. Blockchain technology will disrupt every industry that involves digital data, and agriculture is no exception. We can reasonably expect that the Australian agricultural sector will benefit from blockchain technology adoption to the extent that its underlying administrative and trading components can be digitised and then moved to blockchain technology as digital infrastructure. However, this benefit accrues across the value chain, and in order for individual Australian farms to specifically benefit will depend on coordinated adoption of the new technology across the sector. This is a significant challenge for several reasons, including: the early stage development of the technology, the relative unfamiliarity of the technology among parties, and the need to coordinate adoption. The technology is new, difficult, and disruptive. Nevertheless, the potential problems that it solves are significant, and if solved could bring substantial financial returns through higher prices and greater margins to Australian agricultural producers. These are good reasons for the Australian agricultural sector to continue to invest in blockchain technology.

References

Allen, D., Berg, C., Davidson, S., Novak, M., Potts, J. (2018) 'Blockchain Tradetech' SSRN https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3171988

Akerlof, G. (1970) 'The market for lemons: Quality uncertainty and the market mechanism' *Quarterly Journal of* Economics. 84(3): 488-500.

Berg, C., Novak, M., Potts, J., Thomas, S. (2018) 'From Industry Associations to Ecosystem Associations: Blockchain, Interest Groups and Public Choice' SSRN https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3285647

Berg C, Davidson S, Potts J (2018) 'Blockchain is a three-sided market' SSRN

Berg C, Davidson S, Potts J (2019) *Understanding the Blockchain Economy: An Introduction to Institutional Cryptoeconomics*. (Edward Elgar) (forthcoming)

Bermeo-Almeida, O., Cardenas-Rodriguez, M., Samaniego-Cobo, T., Ferruzola-Gómez, E., Cabezas-Cabezas, R. and Bazán-Vera, W. (2018) 'Blockchain in Agriculture: A Systematic Literature Review' In *International Conference on Technologies and Innovation* (pp. 44-56). Springer, Cham.

Blandin, A., Cloots, S., Hussain, H., Rauchs, M., Saleuddin, R., Allen, J., Zhang, B., Cloud, K. (2019) *Global cryptoasset regulatory landscape study*. Cambridge Centre for Alternative Finance. Judge Business School, University of Cambridge.

Bohme, R., Edelman, C., Moore, T. (2015) "Bitcoin: Economics, technology, and governance," *Journal of Economic Perspectives*, 29(2), 213–238.

Barrera, C., Hurder, S. (2019) 'Can blockchain solve the hold-up problem for shared data-bases?' Prysm Report.

Caro, M., Ali, M., Vecchio, M., Giaffreda, R. (2018) 'Blockchain-based traceability in Agri-Food supply chain management: A practical implementation' In IEEE IoT Vertical and Topical Summit on Agriculture -Tuscany, pp. 1-4.

Casey, M., Wong, P. (2017) "Global supply Chains are About to Get Better, Thanks to Blockchain." Harvard Business Review, 13 March. https://hbr.org/2017/03/global-supply-chains-areabout-to-get-better-thanks-to-blockchain.

Catalini, C., Gans, J. (2017) 'Some Simple Economics of the Blockchain'. MIT Sloan Research Paper No. 5191-16. SSRN: https://ssrn.com/abstract=2874598

Data61 (2017) *Risks and opportunities for systems using blockchain and smart contracts. CSIRO, Sydney.* https://publications.csiro.au/rpr/pub?pid=csiro:EP175103

Data61 (2019) 'Blockchain 2030: A look at the future of blockchain in Australia' Australian Computer Society and Data61 Report https://www.acs.org.au/insightsandpublications/reports-publications/blockchain-2030.html

Davidson, S., de Filippi, P., Potts, J. (2018) 'Blockchains and the economics institutions of capitalism' *Journal of Institutional Economics*, 14(4): 639-658.

De Filippi, P., Wright, A. (2018) *Blockchain and the Law: The rule of code*. Harvard University Pres: Cambridge, MA.

Erdem, T., Swait, J. (1998) 'Brand Equity as a Signaling Phenomenon' Journal of Consumer Psychology, 7 (2), 131

Ge, L., Brewster, C., Spek, J., Smeenk, A., Top, J. (2017) 'Blockchain for Agriculture and Food; Findings from the pilot study.' Wageningen, Wageningen Economic Research, Report 2017-112.

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technical change, *Econometrica* 25(4), 501–22.

Grossman, S. (1981) 'The Informational Role of Warranties and Private Disclosure About Product Quality," Journal of Law and Economics, 24(12), 461.

Kealey, T., Ricketts, M. (2014). "Modelling science as a contribution good." *Research Policy*, 43(6), 1014–1024.

Kramer, M. (1993) 'The O-Ring theory of economic development' *Quarterly Journal of Economics*, 108(3), pp. 551-575.

Lin, Y.P., Petway, J., Anthony, J., Mukhtar, H., Liao, SW., Chou, CH., and Ho, YF. (2017) 'Blockchain: The Evolutionary Next Step for ICT E-Agriculture' *Environments*, 4(3): 50.

Lucena, P., Binotto, A.P., Momo, F.D.S. and Kim, H., (2018) 'A case study for grain quality assurance tracking based on a Blockchain business network' arXiv:1803.07877.

Mattila, J., Seppälä, T. (2018) 'Distributed governance in multisided platforms: A conceptual framework from Case: Bitcoin' in A. Smedlund et al. (eds) *Collaborative Value Co-creation in the Platform Economy*. Translational Systems Sciences, 11.

Nakamoto, S. (2008): "Bitcoin: A peer-to-peer electronic cash system," White Paper.

Novak, M. Poschesneva, A. (2019) 'Toward a crypto-friendly index for the APAC region' SSRN https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3277266

Novak, M., Davidson, S., Potts, J. (2018) 'The cost of trust: a pilot study' *Journal of British Blockchain Association*, 10.31585/jbba-1-2-(5)2018

Papa, S.F. (2017) Use of Blockchain technology in agribusiness: transparency and monitoring in agricultural trade. In: Proceedings of the 2017 International Conference on Management Science and Management Innovation. Atlantis Press, Paris.

Pardey, P., Alston, J., Ruttan, V. (2010). The economics of innovation and technical change in agriculture, *Handbooks in Economics*, Vol. 2, Ch. 22. Elsevier: Amsterdam.

Potts, J. Kastelle, T. (2017) 'Economics of innovation in Australian agricultural economics and policy' *Economic Analysis and Policy* 54(1): 96-104.

Potts, J. Rennie, E. (2019) 'Web3 and the creative industries: How blockchain is reshaping business models' S Cunningham, Flew T (eds) *A Research Agenda for the Creative Industries* Edward Elgar.

Rijmenam, M., Ryan, P. (2019) *Blockchain: Transforming your business and our world*. Routledge: London.

Russell, E. (1966) *A History of Agricultural Science in Great Britain 1620-1954*. George Allen & Unwin: London.

Tripoli, M., Schmidhuber, J. (2018) 'Emerging Opportunities for the Application of Blockchain in the Agri-food Industry' *Food and Agriculture Organization of the United Nations*, Issues Paper, http://www.fao.org/3/ca1335en/CA1335EN.pdf

Turner, A. (2018) Speech given at D61. https://algorithm.data61.csiro.au/adrians-talk-at-d61-live/

von Hippel, E., von Krogh, G. (2003). "Open source software development and the private-collective innovation model: Issues for organization science." *Organization Science*, 14(2), 208–223.

Werbach, K. (2018) *The Blockchain and the New Architecture of Trust*. MIT Press: Cambridge, MA.

Further Resources

Deloitte (2018) Blockchain: Revolutionising the Agriculture Industry. https://www2.deloitte.com/au/en/pages/consumer-business/articles/blockchain-revolutionising-agriculture-industry.html

Mire, S. (2018) 'Blockchain In Agriculture: 10 Possible Use Cases' https://www.disruptordaily.com/blockchain-use-cases-agriculture/

AgriDigital. https://www.agridigital.io/

AgriChain: https://agrichain.com/

TradeLens. https://www.tradelens.com/

FoodTrust. https://www.ibm.com/au-en/blockchain/solutions/food-trust