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A new food chain: Adoption and policy implications to blockchain use in agri-food industries

Kathleen Krzyzanowski Guerra[1] | **Kathryn A. Boys**[2]

[1]John Glenn College of Public Affairs, The Ohio State University, Columbus, Ohio, USA

[2]Department of Agricultural & Resource Economics, North Carolina State University, Raleigh, North Carolina, USA

Correspondence
Kathryn A. Boys, Department of Agricultural & Resource Economics, North Carolina State University, Box 8109, Raleigh, NC 27695, USA.
Email: kaboys@ncsu.edu

Funding information
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Abstract

Legislation and regulation proposed to study, fund, and govern blockchain use is emerging among both US federal and state governments. These regulatory requirements, however, are not fully consistent across jurisdictions, which may add further challenge to the adoption of this technology by agri-food system firms. This study compiles and provides a descriptive overview of legislation and regulations related to blockchain technology. Implications of the current regulatory approach on the adoption of blockchain on the US agri-food system, and specifically of the wider adoption of distributed ledger technologies on food safety and market access of smaller scale farm operations, are considered.

KEYWORDS

agri-food, blockchain, cryptocurrency, legislation, regulation

JEL CLASSIFICATION

O33; O38; Q13

In an unprecedented age of connectivity, technological growth, information sharing, and innovation, blockchain is increasingly being viewed as a coordinating technology for agri-food sector businesses. Blockchain offers a system of storing data, sharing information, and allowing for increased transparency (Figure 1; reprinted from Schweizer et al., 2019). Unlike cloud services which are typically centralized with an organization or entity holding responsibility for

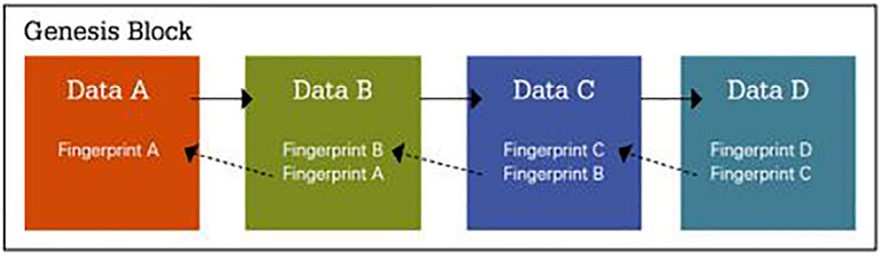

FIGURE 1 Illustration of data blocks forming a blockchain [Color figure can be viewed at wileyonlinelibrary.com]

providing services and computing power needed for service delivery, blockchain in its "original" form was intended to be a decentralized, peer-to-peer network (Liu et al., 2011; Nakamoto, 2008). Initiatives using blockchain "projects" seek to leverage this technology to more efficiently share information between supply chain partners.

While most well-known applications of blockchain are their use in the creation and trade of cryptocurrencies, such as bitcoin, Ether, and XRP,[1] blockchain technology has the potential to be applied in an extensive variety of other settings, including the agricultural and food system. The agricultural and food system depends upon a value chain that includes production and processing, transportation, retail, and other associated services. To efficiently produce and transform raw agricultural commodities to processed foods on consumer tables, domestic agri-food markets and supply chain linkages must also be linked with a global trading system. Currently, blockchains are not widely adopted by agri-food firms. A majority of companies that are using blockchain are still exploring approaches to use it internally for their own recordkeeping and information storage. Blockchain does, however, offer the potential for companies to integrate and share information with their supply chain partners, and to more efficiently administer their contracts.

These innovations have extensive implications for agri-food system food traceability, implementation and verification of product standards, governmental regulatory compliance, data management, and the adjudication of domestic and international business disputes. As reviewed by Zhao et al. (2019), current literature examining the use of blockchain in agri-food industry settings is largely focused on (1) general analysis of the current application of blockchain technology in supply chain management; (2) applications of blockchain technology integrated with the Internet of Things (IoT)[2]; (3) proposals for alternative blockchain-based traceability models that could be used in agri-food supply chain settings; (4) empirical studies where blockchain was incorporated into current traceability systems and agri-food manufacturing; and (5) how blockchain technology along with other technologies (e.g., AI, big data) can revolutionize the current agri-food industry.

In addition to these issues, the lack of regulatory harmony and regulatory uncertainty have also been identified by several cross-industry and academic studies. A recent multinational survey of blockchain-savvy executives, for example, found that the biggest barrier to blockchain adoption is regulatory uncertainty (PwC, 2018). Regulatory uncertainty has also been identified as a significant or perceived barrier to the adoption and implementation of blockchain by several studies (Biswas & Gupta, 2019; Kamble et al., 2020; Kouhizadeh et al., 2021; Pawczuk et al., 2018, 2019, 2020; Wang et al., 2019), including several that specifically examine the adoption of blockchain in agri-food sectors (Kamilaris et al., 2019; Yadav et al., 2020; Zhao et al., 2019). Additional concerns surrounding the regulation of blockchain include balancing pragmatic regulation with the potential growth of the technology (Kiviat, 2015; Yeoh, 2017), lack of international standards that offer protections and encourage compliance while also allowing technological innovation to flourish (Fyrigou-Koulouri, 2018), jurisdictional limitations to regulating blockchain (Kiviat, 2015), and the enactment of laws like the European Union's General Data Privacy Regulation (GDPR)[3] impeding the growth and implementation of blockchain in global supply chains (Peel, 2019).

This study contributes to existing literature in two ways. First, it offers an explicit discussion of blockchain technology adoption and the implications of its use by firms in the agri-food sector. Included in this discussion is a consideration of the impact of wider adoption of blockchain on food safety as well as market access of small-scale farmers and those based in developing countries. Second, it offers a novel consideration of blockchain technology through a regulatory lens. In doing so, this study compiles and provides a descriptive overview of US federal and state regulations related to blockchain and cryptocurrencies. The implications of this regulatory approach on the adoption of blockchain by agri-food system firms are also considered.

This discussion proceeds as follows. Section 1 provides an introduction to blockchain technology and the implications of differing approaches to offering permission to control and participate in the blockchain's consensus process. Section 2 offers a discussion of how blockchain is applied in the agri-food sector and describes issues and impacts of blockchain technology in agri-food chains. Section 3 considers the US legislative environment surrounding blockchain. The process used to compile an inventory of US federal and state legislation, and a descriptive overview of these findings with particular consideration of the implications of this regulatory environment to blockchain adoption in the agri-food sector is provided in this section. Section 4 offers study conclusions and considers the potential future governance of blockchain.

BLOCKCHAIN AND DISTRIBUTED LEDGER TECHNOLOGY

Distributed ledger technologies, like blockchain,[4] allow two or more people, businesses, or computers to exchange information (or value) in a digital environment without needing a third-party intermediary or platform between them (Furlonger & Uzureau, 2019). Blockchains are commonly viewed as a decentralized (distributed), peer-to-peer database with built-in mechanisms that ensure trust, security, and transparency (Mougayar, 2016). At its core, however, blockchain is an open-source (publicly accessible) code that users may employ as a foundation from which to develop data storage and data sharing platforms. By way of example, an individual or organization can leverage blockchain's potential by building an application (which may include another blockchain) upon the open-source code of an existing blockchain to fit their specific needs.

In a simple blockchain, a single "block" is composed of timestamped pieces of information (data), a digital fingerprint, and the fingerprint of the previous block. It is the fingerprinting process that links the blocks together—hence the name "blockchain." The fingerprints must meet established cryptographic criteria. This forms a somewhat immutable record, where alterations may not be made but only updated to subsequent blocks (Ølnes et al., 2017; Tapscott & Tapscott, 2016). Public blockchains offer the advantage of having no single point of control and no single point of failure. Owing to this and the fingerprinting process, proponents argue that blockchain is robust, transparent, and virtually incorruptible.

Blockchains are characterized by several key features. The decentralized or distributed nature of blockchain is due to the lack of a centralized authority governing the transaction process and peer-to-peer collective control of the network (Buterin, 2014; Nakamoto, 2008). The ability of peers to share or trade data, or other assets, without a third-party intermediary to verify or validate the transaction offers peer-to-peer direct relationships (Tapscott & Tapscott, 2016). Trust, which is intrinsic to blockchain, stems from the complexity of authenticating the data stored on the blockchain, or verifying the transactions; doing so requires the entire network to be in consensus regarding the validity and legitimacy of a particular piece of data (Jaikaran, 2018; Mougayar, 2016; Tapscott & Tapscott, 2016).[5] Information transparency is enhanced through the ability of all blockchain participants to access the entire transaction history of the database.

It is worth noting, however, that while blockchain was initially conceived as a completely decentralized technology, different "forms" of blockchains have emerged. It is possible for a blockchain to be private rather than public,[6] and to contain permissions which prevent certain actors from performing specific functions. For example, because of privacy and other concerns, private blockchains (those that are permissioned) are far more attractive options than public blockchains in the financial services sector (ESMA, 2017; Hackett, 2017; Mougayar, 2016).[7] Consortium blockchains offer an additional form of blockchain; these blockchains are considered "partially decentralized" as they allow a number of organizations to form a network which, as a group, determine whether the right to read the blockchain is public or private (Buterin, 2015). Additional technological considerations of these alternative forms of blockchain are described in Appendix A.

ADOPTION OF BLOCKCHAIN TECHNOLOGY IN THE AGRI-FOOD SECTOR

Among its potential uses, the ability of blockchain to store, rapidly verify, and share information offers the most important benefits to agricultural and food system applications. In business-to-business transactions among suppliers, this technology can reduce redundancies and cost in paperwork processing, while also mitigating the burden and chance for error in information sharing and communications. In business-to-consumer relationships, information concerning the provenance of food and its ingredients can also be shared with end consumers to respond to consumers' desire to know where their food came from, who grew it, and what growing techniques were used (New, 2010). Additionally, product attributes such as its environmental impact, whether ethical labor practices were used, and information relevant to food safety assurance can be communicated to consumers. Consumers also benefit from having additional and more timely information which they value in their food purchase and/or consumption decisions.

In terms of benefits for producers, cattle farmers would be able to track what their cows ate, what and when medications were administered, individual animal health histories, and have the ability to record and share all of this information with consumers via a blockchain application (Tapscott & Tapscott, 2016). In addition, this information could enable farmers to identify opportunities to improve their production practices and tailor their outputs to better match their customer or end-consumer preferences (Future of Agriculture, 2018a). Further, blockchain could help improve the sustainability of production systems by helping to counter the loss of genetic diversity. Having a detailed history of an animal's lineage, along with the previously mentioned production and functional traits (e.g., fertility, health), could enable farmers to make more sustainable breeding decisions (E. Goddard as cited by Kim & Laskowski, 2017).

Several examples of blockchain platforms and companies that have adopted blockchain are presented in Table 1. Organizations developing blockchain platforms for use in the agri-food

TABLE 1 Examples of platform and company applications of blockchain in the agri-food sector

	Main purpose	Application	Physical technology	References
Platform				
Ripe.io	Track and trace food in real time; transparency from "seed to sale"	Blockchain and cloud hosting	Sensors, IoT, AI	Ripe.io, n.d.
Beefchain.io	Create "rancher-centric" supply chain; animal identification and origin assurance	Blockchain	RFID, other IoT devices	BeefChain, n.d.
Provenance UK	Transparency, authentication of claims, certification	Blockchain	QR codes, labeling, smart tags	Project Provenance, 2016
Wholechain	Traceability, authentication of claims, and sustainability	Blockchain (both open source and permissioned options)	QR codes	Wholechain, n.d.
Company				
Cargill	Track turkeys to origin farms	Food safety, farm-to-fork transparency		Painter, 2018
Coca Cola	Prevent labor abuses	Enforce employee labor agreements among sugar cane suppliers		Chavez-Dreyfuss, 2018
Louis Dreyfus, ING, Societe General	Minimize transaction costs	Track a cargo of US soybeans shipped to China		Terazono, 2018
Walmart	Food safety	Require leafy greens suppliers to use blockchain starting in 2019		Corkery & Popper, 2018

Note: Partially adopted from Schweizer et al., 2019.

sector differ in their scope and features. Many offer the ability for users to track and trace their food from its inputs (i.e., seed, animal genetics), along production and processing steps, through distribution networks, and into retail or foodservice settings. Platforms vary in the extent to which they are designed to enable data from physical technologies, such as radio frequency identification (RFID), quick response (QR) codes, or internet-enabled sensors and devices to be directly aggregated into product records.

IoT refers to the system of internet-connected objects that can collect and transfer data and/or receive instructions, process data, and analyze data without the need for human intervention. Thus, the IoT includes RFID devices and sensors, wireless sensors, and wearable devices among many other technologies that can gather significant amounts of data and communicate it via the Internet (Reyna et al., 2018). In addition, the IoT can leverage cloud sharing to provide users with the ability to collect and analyze both live and historical data from connected devices (e.g., IBM's Watson IoT Platform). Platforms aggregate this information and typically develop a dashboard through which users can access this information in real time.

While adoption of blockchain technology is increasing among agri-food supply chain participants, applications of IoT aside from internal purposes are rather limited in their scope and are largely in pilot testing stages. By way of example, a collaboration between Louis Dreyfus, ING, and Société Générale tracked a US shipment of soybeans to China. In addition, there are many examples of specific industries that have made use of blockchain. From providing authentication services for extra virgin olive oil (Arena et al., 2019) to providing traceability of Irish beef (Deloitte, 2018), wine (Biswas et al., 2017), and rice (Kumar & Iyengar, 2017), and collecting and making available quality measurements through grain supply chains (Lucena et al., 2018), industries in a variety of settings are exploring ways to adopt this technology.

Issues and impacts of blockchain technology adoption on agri-food supply chains

Through a systematic literature review, Zhao et al. (2019) identified five distinctive themes of applications of blockchain technology in agri-food sector value chain management: value-chain traceability (Boehm et al., 2018; Kumar & Mallick, 2018; Tian, 2017); applications in information security (Davcev et al., 2018; Leng et al., 2018; Neisse et al., 2017); applications in manufacturing settings such as through smart contracts (Li et al., 2018); manufacturing resource allocation (Zhao et al., 2018), and process, data, and quality management (Kumar & Mallick, 2018); and sustainable water management (Civic Ledger, 2017; Poberezhna, 2018). As these applications have already been at least somewhat addressed, they will not be explored further here. Instead, our discussion will focus on several less examined issues relevant to blockchain use by agri-food industry stakeholders: the risk and regulatory uncertainty of adopting blockchain, the use of blockchain to improve food safety, and the impacts of blockchain adoption on market access by developing country participants.

Risk and regulatory uncertainty in adopting blockchain

The perceived risks associated with blockchain and its wide variety of potential use-cases present challenges for regulators, policymakers, and consumers alike. There are also concerns around a lack of concrete universal standards, data portability, security, user collusion, and consumer safety (Jaikaran, 2018). These and other concerns are mirrored in the realm of agri-food sector blockchain applications. A lack of consistent and clear regulation, accessibility gaps, technological literacy, privacy issues, required IT infrastructure, scalability, internal governance mechanisms, and human error (or validation structures) are all potential challenges associated with the use of blockchain in agri-food (Addison et al., 2019; Kamilaris et al., 2019; McKenzie, 2018; Pearson et al., 2019; Zhao et al., 2019). There is also a need to address uncertainties of the benefits that are accrued through data sharing across stakeholders. More pointedly, agri-food companies that want to use blockchain and encourage various stakeholder support should undertake efforts to demonstrate benefits proportional to, if not outweighing, the risks of data sharing (Ramachandran, 2017).

Blockchain and food safety: Significant promise, limited current potential[8]

With its ability to seamlessly and fully transfer information across market participants, blockchain offers firms potentially enhanced methods to monitor food safety. When combined with RFID technology, for example, holding times and temperatures throughout a food's manufacturing, warehousing, and transportation steps would be quickly observable and verifiable. This would provide assurance that required handling conditions have been met, or, alternatively, would permit lots requiring additional quality testing/or disposal to be quickly identified.

In addition, blockchain has been touted as a tool to reduce waste and improve efficiency during food recalls. In instances where blockchain is used by multiple partners along a supply chain, blockchain can track information upstream and downstream from where a food-safety event is identified. Buyers of an affected lot could be precisely identified, and the product could be specifically removed from retailer inventories. Blockchain would also permit more precise trace-back to the origin of an outbreak. The use of blockchain thus also has obvious implications for assigning liability in cases of foodborne illness. Compare this to current recall practices that are often slow, or unable, to identify the source of a problem. During the time it takes to identify the cause of a foodborne illness outbreak and to determine which specific product lots may be contaminated, the affected products can continue to be consumed—thereby enlarging the reach and damages caused by the outbreak. During this period of uncertainty, agri-food firms are usually proactive and recall any potentially affected products, frequently leading to the destruction of larger quantities of food products than is necessary.

At present, however, the potential that blockchain offers to improve food safety is rather limited. Blockchain has not been widely adopted by firms, and companies that are using blockchain are still exploring approaches to access and make use of all the information which is (or could be) transferred via blockchain. For an agri-food firm to be able to reap the full potential food safety benefits, they would need to adjust not only their own internal recordkeeping and information storage practices but also *all other* businesses along their supply chain to participate in the blockchain network as well. Common rules and standards of data entry, reporting, and access would be required.

As blockchain applications continue to develop, it is likely firms will integrate more upstream and downstream supply chain partners. In this environment, firms also must determine whether it is to their advantage to make full use of blockchain by posting all information related to their food products. It has been proposed, for example, that results of product and facility testing be posted directly to the blockchain by third-party labs and auditors. While this certainly would offer benefits in terms of the efficiency of reporting and documenting test results, a firm could increase their exposure to liability or risk relationships with their buyers if it is documented that they are aware of a food safety problem but do not take what are deemed to be sufficient steps to address the issue. The alternative of allowing companies to choose—or not—to post test results may address some of this concern; however, it also opens the possibility of firms ordering duplicate tests and selectively putting good results onto the blockchain, thus reducing confidence in the system.

Small-scale farmers in low-income countries

The applications of blockchain described herein have largely highlighted the use of blockchain in developed country settings and for large-scale operations. Should blockchain become more widely adopted among buyers (including cooperatives), but adoption among producers is uneven, the required use of blockchain technology may inadvertently become another barrier to market entry and participation for smaller-scale farmers. This may be specifically problematic for smaller scale farmers in developing country settings.

To be sure, many of the inherent benefits of blockchain, such as recording transactions in real time, without need for an intermediary and with an immutable record of transactions, could offer important benefits to small-scale farmers. This is particularly the case in developing country settings where producers are often smallholders selling to buyers who have relatively more market information and negotiating power. Importantly, these inefficiencies can contribute to consumer food price volatility in local markets. In addition, transactions in these settings can involve a lot of paperwork. As this requires literacy, it creates an additional opportunity for corruption—with smallholder farmers likely to be particularly harmed. In using a blockchain application, "the transaction between a farmer and a cooperative or the farmer and the supplier, all these transactions get recorded immediately and, because they've both got a clean record, there's no possibility for there being any mistakes, any corruption" (Lea, 2016).[9] Blockchain technology has also been used as a means to provide farmers a digital identity and to offer income verification, thus helping them to gain access to financial services and credit (Agriledger, 2020). In addition, using blockchain has been proposed as a means to improve crop insurance uptake and reduce transaction and administration costs by providing insurers information on the history of the farming operation, which is important for determining the amount that should be insured and assessing risk (Bolt, 2019). For both insurers and the insured, transparency can be improved and administrative costs further decreased by using smart contracts in which payouts are automatically triggered when extreme weather events occur, which have a scientifically verified impact on crops (Bolt, 2019).

Importantly, several notable challenges exist in using blockchain in low-income country settings. First is access to smartphone devices and connectivity. Several blockchain applications that have been developed for use in these settings are designed to be accessed through mobile platforms. While smartphones have become ubiquitous in many developing countries, their adoption is more prevalent in urban areas. Owing primarily to its cost, it is recognized that enabling smallholder farmers to access to blockchains technology remains a considerable challenge. Some blockchain platforms are looking to partner with technology companies to provide phones to small-scale farmers. To date, however, where successful, these efforts have been short-term programs focused in relatively small geographic areas and have been supported through donations and grants. A sustainable model, or a variety of models, is needed to facilitate more widespread access to smartphones and thus to blockchains in these areas. Training and ongoing technical support will likely be needed as many of these users may be inexperienced with smartphones or mobile blockchain applications; this may present challenges as well.

A second major issue is the cost of developing and maintaining blockchains. In these small-scale production settings, supply chain stakeholders, even collectively, often do not have the financing available to build and maintain these blockchains. In some cases, donors have supported development and maintenance of these projects.[10] Once in place, transaction or maintenance fees, or some other method of payment such as tokens (e.g., FarmShare) could be used to finance these blockchains (Kim & Laskowski, 2017).

OVERVIEW OF THE US LEGISLATIVE AND REGULATORY LANDSCAPE

In general, the United States has adopted a stance that, to the extent possible, blockchain technology should be allowed to evolve without encumbrance. This position is perhaps best represented by the Congressional Blockchain Caucus. This bipartisan group views blockchain as a transformative technology and promotes a "hands-off" regulatory approach, comparing the evolution of blockchain to that of the Internet. They maintain that in order for blockchain to reach its full potential, regulation cannot be too stringent (Congressional Blockchain Caucus, n.d.). A letter from members of this group sent to the National Economic Council in 2019 (Kim, n.d.) indicated their strong support for the proliferation and advancement of blockchain through collaborative public–private efforts that may diminish regulatory uncertainty (Hollingsworth et al., 2019). In their view, such collaboration would allow blockchain technology to facilitate economic growth and bolster efficiency in a variety of industries, as well as governmental processes (Hollingsworth et al., 2019; U.S. House of Representatives Committee on Science, Space, and Technology, 2018).

In a similar spirit, leaders of the US Securities and Exchange Commission (SEC) and Commodity Futures Trading Commission (CFTC) have argued for the importance of innovation alongside regulatory efforts (Clayton & Giancarlo, 2018). The former CFTC Chairman pushed for a "do no harm" approach through strongly coordinated, clear, and flexible regulatory efforts that will allow the technology to flourish (Giancarlo, 2016). Consistent with this position, the House Committee on Science, Space, and Technology has discussed the need for the United States to remain competitive in the global adoption and use of blockchain technology while also seeking reasonable regulation that will not stifle blockchain innovation (U.S. House of Representatives Committee on Science, Space, and Technology, 2018).

To provide a holistic overview of the political macroenvironment surrounding blockchain, it is useful to first examine proposed and enacted legislation relevant to this technology. The following discussion introduces the approach used to identify and compile legislation and regulations relevant to the use and development of blockchain. An overview of these regulations at the federal and state level, as well as those that are most relevant to agri-food sectors, is then presented.

Identifying relevant legislation and regulation

Federal legislation was initially identified using LegiScan.[11] A secondary search on Congress.gov was conducted to cross-reference all bills and resolutions and to identify any other pertinent legislation. Keywords of "blockchain," "distributed ledger technology," "digital ledger technology," and "cryptocurrency" were used find relevant legislation. Press releases, statements, guidance documents, and primers issued by federal regulatory agencies were also collected to better contextualize the federal regulatory approach to blockchain. Relevant federal legislation spans from the 113th Congress (met starting in January 2013) to the 116th Congress (concludes January 2021). Through this process, 51 pieces of federal legislation germane to blockchain and cryptocurrency were identified. Among these, 39 bills and resolutions are considered to be distinct.[12,13]

State-level legislation was collected using LegiScan and was cross-referenced with individual state legislature websites to ensure accurate representation of the current and emerging regulatory landscape. Through this process, 249 pieces of legislation (inclusive of bills and resolutions) from 43 states were collected. Upon careful review, 182 distinct bills were identified. Among these, 104 bills have been engrossed, enrolled, or passed.

US federal regulation and legislation

As a starting point to introducing legislation and regulation specific to blockchain, it is useful to first review the general areas of authority of the federal and state government. While virtual currencies (used interchangeably with 'cryptocurrencies' in regulatory documents) are largely beyond the scope of this paper, it is in this application of blockchain that federal jurisdiction and oversight of blockchain is most evident. US law does not currently offer strong, comprehensive federal oversight of cryptocurrency markets. In lieu of this, federal agencies are employing a largely collaborative oversight approach. As summarized in Appendix B, owing to its use in cryptocurrencies, most federal blockchain oversight is provided by the CFTC, Financial Crimes Enforcement Network (FinCEN), International Revenue Service (IRS), and the SEC. These agencies are predominantly concerned with the use of cryptocurrencies for illicit activities, and the circumvention of, or noncompliance with, federal regulations such as those related to anti-money laundering and countering the financing of terrorism under the Bank Secrecy Act (SEC, 2019). Other applications of blockchain that may fall under federal purview include smart contracts[14] which may be subject to various federal, state, and local laws (LabCFTC, 2018), and the management of federal records (Yaga et al., 2018).

As previously noted, federal congressional legislation and regulation directed at blockchain has overwhelmingly adopted a "do no harm" approach to regulating emergent technologies. With the exception of drawing a hard line on the illicit or malicious use of cryptocurrencies, Congress has generally demonstrated the desire to facilitate a legislative environment that will not hamper the potential growth and applications of blockchain. Indeed, three House Resolutions (H.Res. 835, H.Res. 1102, and H.Res. 1108) express strong support for blockchain technology and its potential while acknowledging that an innovation-friendly approach will facilitate technological growth.

Federal legislation

Of the 51 federal bills identified, 10 relate to combatting the financing of terrorism and similar forms of illicit finance; assessing the possible circumvention of US sanctions through use of cryptocurrencies; conducting trend analyses to better understand how cryptocurrencies may facilitate illicit activity; and/or the prohibition of issuing cryptocurrency for adversarial regimes.[15] Four bills explicitly require briefings, analyses, or reports detailing the potential threats of blockchain technology to national security and illicit financing activities.[16] Twelve bills urge or require in-depth studies and subsequent reports on the potential benefits of blockchain technology in a variety of settings, including healthcare and governmental operations.[17] An additional four bills relate to the creation of working groups or pilot programs to develop recommendations related to further research on, or use of, blockchain within the federal government.[18]

The remaining pieces of proposed federal legislation relate to the governance of blockchain. They include provisions prohibiting the use of blockchain and/or cryptocurrencies; the clarification of federal agency roles in regulation; the development of national standards regarding the legality of electronic records, electronic signatures, and smart contract stored or secured on blockchain; the appropriations of funds to help the Federal Trade Commission (FTC) to prevent unfair or manipulative acts or practices in cryptocurrency transactions; exemptions from existing laws and regulations for blockchain developers that do not have control over digital currencies; moratoriums dictating federal, state, and local governments are not to impose regulations or restrictions, such that the production or use of cryptocurrencies is disincentivized; and proposed amendments to the Securities Act of 1933 and Securities Exchange Act of 1934 to exclude digital tokens from the definition of a security.[19]

State-level legislation and regulation

As states wield sovereignty to enact state-level laws governing their respective populations, it is critical to also consider efforts of states to govern blockchain technology and its applications. Figure 2 provides a map summarizing which states have introduced legislation or regulation regarding blockchain and/or cryptocurrency. Additional details about the types of legislation that have been passed in each state are reported in Table 2, and a detailed inventory of this legislation is provided in Appendix C. Given the scope of this paper, states' legislative approach to blockchain technology is the focus here.[20]

The largest number of proposed or enacted bills are amendments to existing laws to include provisions related to blockchain, and research and development (R&D) in the form of studies, task forces, regulatory sandboxes, commissions, working groups, and pilot programs. Nineteen states have enrolled, engrossed, or passed legislation focused on R&D.[21] While their aims vary, they include efforts to examine how blockchain technology can improve state recordkeeping, information storage, and service delivery; the potential for economic growth through the use of blockchain; blockchain's applicability in various sectors; and state capabilities to leverage the

FIGURE 2 US state legislation or regulation regarding blockchain or Cryptocurrency, 2020

TABLE 2 State legislation related to blockchain and cryptocurrency

State	Amendments to existing legislation to include provisions related to...		R&D studies, task forces, regulatory sandboxes, commissions, working groups and/or pilot programs.[a]		Permits use of smart contracts in commerce	Ownership rights of information secured by blockchain	Use of blockchain for record keeping	Prohibits certain applications or use of blockchain	Resolutions recognizing potential of blockchain for economic growth and efficiency
	Blockchain	Cryptocurrency	Requirements to conduct	Appropriations to support					
Alabama			✓						✓
Arizona	✓	✓	×	✓	✓			✓	
Arkansas	✓				✓				
California	✓	✓			✓	✓	!	✓	
Colorado	✓	✓	✓	✓					
Connecticut	✓	✓	✓		†				
Delaware	✓					✓	✓		
Florida			✓		†				
Georgia		†	✓						
Hawaii	†	+	!	!					
Illinois	✓	+	✓		✓			✓	✓
Iowa	+				+				
Kentucky	✓		✓						✓
Maine			×						
Maryland	✓	✓	✓						
Massachusetts	+		+	+					
Michigan	✓	✓						✓	
Minnesota		+							
Missouri	†	+			†				

(Continues)

TABLE 2 (Continued)

State	Amendments to existing legislation to include provisions related to...		R&D studies, task forces, regulatory sandboxes, commissions, working groups and/or pilot programs.[a]		Permits use of smart contracts in commerce	Ownership rights of information secured by blockchain	Use of blockchain for record keeping	Prohibits certain applications or use of blockchain	Resolutions recognizing potential of blockchain for economic growth and efficiency
	Blockchain	Cryptocurrency	Requirements to conduct	Appropriations to support					
Montana	✓	✓							
Nebraska	†		+						
Nevada	✓	✓	✓			✓	✓		
New Hampshire			+						
New Jersey	+	+	✓				!		
New Mexico			†	†				†	
New York	!	+	✓		!		+		
North Dakota	✓	×			✓				✓
Ohio	✓		+		✓				
Oklahoma	✓	†	†		✓		†		
Oregon		✓	×					✓	
Pennsylvania									✓
Rhode Island	+	✓	+						
South Carolina	+	†	✓						✓
South Dakota	✓	✓							
Tennessee	✓	✓	†		✓	✓		✓	
Texas	✓	✓	†						
Utah	✓	†	✓	†					†
Vermont	✓	✓	✓						

TABLE 2 (Continued)

State	Amendments to existing legislation to include provisions related to…		R&D studies, task forces, regulatory sandboxes, commissions, working groups and/or pilot programs.[a]		Permits use of smart contracts in commerce	Ownership rights of information secured by blockchain	Use of blockchain for record keeping	Prohibits certain applications or use of blockchain	Resolutions recognizing potential of blockchain for economic growth and efficiency
	Blockchain	Cryptocurrency	Requirements to conduct	Appropriations to support					
Virginia	†		†	†					†
Washington	✓		†		✓				
West Virginia	✓		✓						
Wisconsin		×							
Wyoming	✓	✓	✓	✓					

Note: Legislation has been introduced (+), engrossed or enrolled (!), passed (✓), failed or been withdrawn (×), or died (†).
[a]R&D encompasses studies, task forces, regulatory sandboxes, commissions, working groups, and/or pilot programs.

technology in a responsible, well-informed manner. Though not necessarily prohibitive, R&D studies as required by legislation are prescriptive in that they specify sectors for which to study potential applications for blockchain technology.

In addition, 26 states have passed amendments to various state laws and statutes regarding issues such as the use of smart contracts in commerce, information storage via blockchain, the exemption of certain cryptocurrency transactions from state securities laws, and adding blockchain-related language or definitions to state banking laws and penal codes.

Similar to many regulatory voices at the federal level, some state lawmakers are advocating for a more friendly approach to blockchain technology, arguing that its proliferation requires governmental support. Resolutions recognizing the potential of blockchain or encouraging the study of the technology and how it may be adopted in state activities have been passed in a number of states including Alabama, Georgia, Illinois, Kentucky, North Dakota, Pennsylvania, and South Carolina.[22] Further, state representatives in Arizona, Colorado, and Wyoming have supported legislation to strengthen the growth of blockchain in their states (Desouza et al., 2018; Khawaja, 2019). It is also worth noting that similar to federal preemption laws, which stipulate that federal regulation supersedes state regulation, preemption is also evident in state-level governance of blockchain. Three states—Arizona, Illinois, and Nevada—have passed bills dictating that cities or towns may not impose additional restrictions on the use of blockchain.[23] State preemption may also reflect lawmakers' general preference to allow blockchain technology to evolve without requiring blockchain users to navigate overly restrictive or confusing regulatory structures.

Wyoming is often highlighted as one of the most welcoming states in terms of its regulatory approach to blockchain technology (Barber, 2019; Beck, 2019; Desouza et al., 2018; Khawaja, 2019; Long, 2019). Notably, this state's legislature has convened a Select Committee on Blockchain, Financial Technology, and Digital Innovation Technology, and its legislators have passed several bills to attract blockchain businesses to the state (Barber, 2019; Khawaja, 2019).[24] Among these are bills that create and appropriate funds to a blockchain task force, offer regulatory sandboxes for financial technology innovators to develop products and services, and exempt certain digital tokens from state securities laws, instead recognizing them as a distinct asset class. This latter legislation was the first of its kind anywhere in the United States and is being considered by several other states (Tinianow, 2019). In addition, Wyoming's legislation regarding Special Purpose Depository Institutions has been amended to allow these institutions to provide necessary services to blockchain innovators who frequently have difficulty in securing banking services. Owing to these efforts, Wyoming has been considered a leader by other states as they seek to develop legislation and regulations of their own (Chuang, 2019).

Regulation challenges and implications

Lawmakers and regulators demonstrate support for blockchain as a foundational technology when grappling with how its potential applications can offer innovative solutions while also stimulating economic growth (Desouza et al., 2018). At present, beyond its use in virtual currencies, there are no significant regulatory barriers to creating blockchain applications in other sectors. Perhaps of greater concern are uncertainties or outdated regulatory frameworks that may dissuade the use of blockchain (Chamber of Digital Commerce, 2019).[25] In particular, blockchain start-ups are encountering significant barriers of entry owing to uncertainty regarding state requirements. This lack of clarity is particularly problematic for companies using blockchain in interstate commerce, as entities must comply with both federal and various state requirements (Boring, 2016). The Chamber of Digital Commerce's "National Action Plan for Blockchain" argues that policy and regulatory clarity should be developed through a cross-agency cooperative approach between the public and private sector (2019). Two recent Congressional House bills, H.R. 8128 and H.R. 8153, also illustrate an interest in pursuing this type of collaboration, with the required study and report to outline best practices for public–private partnerships in blockchain (see Appendix Table B1).

While it is reasonable to imagine uncertainty about applicable laws hampering blockchain adoption, it has also been argued that varied state legislation offers a means to construct reasonable policy (Khawaja, 2019). Congressman Darren Soto (FL-09), for example, compares blockchain to the rapid growth of the Internet and dealing with interstate commerce, arguing that states can act as laboratories for legislation that may eventually be adopted at the federal level (Khawaja, 2019). Furthermore, in an effort to reduce barriers to blockchain use, six states have either engrossed or passed legislation exempting blockchain and digital currencies from state securities laws.[26]

Regulation challenges and implications for the agri-food sector

As previously described, blockchain is being used within the agri-food sector for purposes related to traceability, provenance, data sharing, and verification of claims. In order to create solutions and more efficient processes, these platforms largely rely on IoT devices to collect large amounts of data. RFID, sensors, and near-field communications (NFC)-enabled smart stickers or tags are often used to capture relevant data points (Project Provenance, 2016). RFID regulations fall under federal jurisdiction, as RF devices are regulated by the Federal Communications Commission (FCC) in accordance with 47 CFR 15 (FCC, n.d.). NFC is a subset of RFID with shorter communication ranges (NFC.org, n.d.).[27] Any RFID or NFC device, then, must comply with federal regulations. Devices equipped with cellular transmitters that use electromagnetic radiation, like smart meters, are regulated by the FCC as well (FCC, 2019; U.S. Environmental Protections Agency, n.d.).

Several potential applications of blockchain in the agri-food sector are subject to commercial law, which typically governs business, commerce, and consumer transactions (Legal Information Institute, 2019), and which fall under state jurisdiction. Contracts fall under commercial law and are typically enforced by state statutory law, common law, and private law (Legal Information Institute, 2019.). Nine states—Arizona, Arkansas, California, Illinois, North Dakota, Ohio, Oklahoma, Tennessee, and Washington—have passed legislation allowing the use of smart contracts by amending existing commercial laws (Table 2). Iowa, New Jersey, and Virginia have also introduced bills for this purpose.

States also have jurisdiction over how public records—including property records—are to be recorded at the county level. This is particularly relevant for those that see blockchain as a way to store and share land records (Addison et al., 2019; Tripoli & Schmidhuber, 2020). While public records, including deeds, must be recorded by the county based on state guidelines, the regulation of use of land records is less clear. If anything, the challenges for agri-food companies seeking to use blockchain platforms for this purpose are time and resources to digitize records that are available only at county courthouses (Solove, 2002). Several other states have passed legislation that explicitly addresses ownership rights of information secured by blockchain (California, Delaware, Nevada, and Tennessee). With awareness and concerns regarding privacy and data ownership increasing, it is likely that more states may opt to enact similar legislation to respond to fears that reliance on blockchain for storing and sharing records may jeopardize private data ownership (Bloomberg, 2018; Frenkel & Roose, 2018; Hill, 2020; Tasca, 2018).

In addition, though limited, there is state-level legislation directly related to the use of blockchain in the agri-food sector. More specifically, Colorado has passed a bill extending responsibility to the state Commissioner of Agriculture to appoint and convene a group to study potential applications for blockchain in agricultural operations. Included in the scope of this study is the intent to develop insight into how blockchain may facilitate traceability, inventory control, monitoring of weather conditions, verification, management of records, tracking of resources, and asset exchange (Colorado House Bill 19–1247).

CONCLUSIONS

Blockchain technology offers various possible applications that may impact the way that individuals, firms, and governments interact with one another. When intertwined with food systems, blockchain can offer increased transparency across supply chains, accountability, heighted verification of certifications, comprehensive data storage, and more efficient information sharing practices (Addison et al., 2019; Kamilaris et al., 2019; Tripoli & Schmidhuber, 2020). Aptly noted by Yaga et al. (2018), blockchain is not a “magic” technology but, rather, should be regarded as a tool that may be useful in certain circumstances.

To date, the literature examining the use of blockchain in agri-food industries has identified several main challenges of adopting blockchain technology in this sector. These include blockchain storage capacity and scalability issues, privacy leakage, high cost, throughput and latency issues, lack of skills, and regulation (Zhao et al., 2019). While none of these challenges is unique to this sector, the geographically disbursed and complex nature of the agri-food sector's supply chain linkages makes differences in blockchain regulation across jurisdictions a potential challenge to the uptake and scalability of this technology by industry stakeholders.

The success of blockchain to be used effectively as a tool will in some ways be reliant on the larger regulatory context that they are operating within. Yet, until regulators and policy makers more fully understand the true impact of blockchain, regulating in an efficient manner will be a difficult task. To date, US legislation related to blockchain has largely adopted an approach of amending existing legislation to include provisions related to the technology. Federal agency regulation and Congressional legislation are primarily concerned with the risks associated with one functionality of blockchain—cryptocurrency—as the elements of cryptocurrencies linked with public blockchains can allow pernicious financial activity that ultimately may present risks to national security. Owing to concern of cryptocurrency use for illicit activities, the related regulatory environment is accordingly strict. In terms of other applications of blockchain, however, legislators continue to leverage flexible regulatory approaches so as to not hamper innovation (Dewey, 2020). In addition, through legislative mandates and appropriations, several studies, task forces, and regulatory sandboxes have been convened, demonstrating a need and desire for more information about blockchain technology, its potential uses, and the implications of its adoption.

Potential future governance of blockchain

Optimism for the potential of blockchain is grounded by the realities of the current regulatory environment governing the use of this technology. Currently there are no significant regulatory barriers to creating blockchain applications. Despite this, there are concerns that outdated regulatory frameworks and variances between state and federal regulations governing blockchain may dissuade the use of this technology and pose challenges to firms seeking to maintain their compliance to regulatory requirements. Though uncertainty or confusion about applicable laws may present challenges to compliance, varied emerging state-level legislation may offer a means to develop a reasonable, balanced policy that can eventually be more widely implemented (Khawaja, 2019).

Important as well are the implications of the globalized nature of agri-food sector supply chain linkages to the potential uses of blockchain technology. While this study is focused on the US regulatory environment, there are many unanswered and evolving questions regarding the relative roles of national government and multinational institutions in coordinating, enforcing, and providing oversight of regulations concerning this technology. The International Monetary Fund, for example, has proposed greater international cooperation and coordination concerning cryptocurrency regulation (Hagan & Mayeda, 2018), and the World Bank has been active in coordinating efforts of some national governments, central banks, and standard-setting entities to research blockchain pilot applications (World Bank, 2018). As many national governments have yet to introduce any regulatory or legal governance of blockchain within their borders, the role of multinational institutions and collaborations will be important in informing, if not also shaping, both national and cross-border governance of this technology. From a US perspective, the potential challenge of regulations (or lack thereof) in other market areas is likely to become increasingly important with time. Already there is a perception that, by 2023, China's relative global standing in developing advanced blockchain projects will eclipse that of the United States (PwC, 2018).

These regulatory considerations are important to the uptake of blockchain in the agri-food and other sectors. Studies have demonstrated that blockchain can reduce transaction costs times, reduce risk for stakeholders, offer more efficient transaction processes, and share real-time data (Bumblauskas et al., 2020; Kamath, 2018; Kamble et al., 2020). As it is a relatively new technology, policymakers should heavily weigh the potential benefits that blockchain has for agricultural supply chains, as well as various other sectors, when devising regulatory approaches (Kamble et al., 2020; Yeoh, 2017). Furthermore, the lack of established international coordination and collaboration presents an ongoing challenge for optimal blockchain adoption, as global supply chains operate in a complex regulatory and legal space (Fyrigou-Koulouri, 2018; Kshetri, 2018). As such, policymakers may want to increase focus on devising consistent guidelines that can be applied globally (or, at minimum, more easily harmonized) to adequately regulate the technology's functionalities while at the same time allowing the technology to grow organically. The overriding approach adopted by US policymakers who seek this balance through supporting legislation that explores the beneficial applications of blockchain while simultaneously emphasizing consumer protections (e.g., see descriptions of H.R. 8128, H.R. 8153 and H.R. 6938 in Appendix Table B1) is that it is a useful starting point.

Regulations currently in place do not significantly challenge use cases of blockchain beyond that of cryptocurrencies. It is likely, however, that as the applications of blockchain technology expand, more concrete case studies of the implications of this technology's adoption will be conducted and regulations will need to adapt accordingly. In the case of food systems, it will take time to understand how these kinds of projects and blockchain applications can contribute to the sector and whether they are able to tackle the inefficiencies they propose to correct. Should these applications prove viable and productive, over time regulation will need to find continued balance in enabling blockchain applications without sacrificing necessary user protections.

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ENDNOTES

[1] When capitalized, Bitcoin refers to the peer-to-peer network and open-source software upon which bitcoin (lowercase), the virtual currency, is built (Buterin, 2014). Ether is the cryptocurrency built as part of the Ethereum blockchain (Buterin, 2014). XRP is a decentralized digital asset enabled by the XRP Ledger blockchain (Schwartz, 2019).

[2] The Internet of Things (IoT) refers to the ability of everyday devices to connect to the Internet and to send and receive data.

[3] The GDPR ensures the "right to be forgotten," or the erasure right, which in essence gives individuals greater control over their personal data and threatens steep penalties for company noncompliance (Peel, 2019).

[4] Distributed ledger technology is often used interchangeably with blockchain and/or digital ledger technology. However, it is important to note that these terms are not necessarily synonymous, nor interchangeable. Blockchain is a type of digital ledger technology and a type of distributed ledger technology (Rutland, n.d.).

[5] It is important to differentiate between the consensus mechanisms of public blockchains and those of private blockchains. Public blockchains require network-wide consensus, which is provided through mechanisms like proof-of-work or proof-of-stake that provide economic incentives to the network participants providing computing power. Private blockchains reach consensus through processes like selective endorsement. Essentially, nodes are likely to be well connected in a private blockchain. It is trusted that participants of the network have permissions within the network, and participants of a transaction can verify the transaction as legitimate (Buterin, 2015; Gargolinski Jaeger, 2018).

[6] This is comparable to the internet where there are public and private variations (internet and intranet, respectively).

[7] A more detailed description of the technical aspects of blockchain is provided in Appendix A.

[8] Discussion in this subsection is adopted from Schweizer et al. (2019).

[9] Stated in reference to the AgriLedger platform. Statement, however, would also be true of other blockchain-based platforms.

[10] AgriLedger offers a good example of this. AgriLedger uses distributed ledger technology to provide integrated services for agricultural producers and cooperatives; their service is hosted on a mobile application which can be accessed using smartphone technology and can be used to record every transaction along the supply chain. In addition to input purchases and product sales, through this platform farmers can access and record their information regarding seed provenance, crop location, and fertilizer use; this information can be used to improve their internal record keeping and can serve as a proof of their income (Agriledger.io, 2020). AgriLedger has developed pilot programs in Kenya, Myanmar, and Papua New Guinea (Lea, 2016) and, through a World Bank backed blockchain pilot project, is working on a pilot project to bring Haiti's fresh produce supply chains onto the blockchain.

[11] LegiScan is a legislative tracking and data service which covers all 50 states Legislatures and Congress across public and professional sectors.

[12] All legislation and regulations listed as of December 28, 2020. Important to note, the most recent engrossed version of H.R. 6395 struck the provision related to distributed ledger technology.

[13] Distinct is conceptualized as bills that were not aimed at achieving the same purpose; those that were not reintroduced and/or amended overtime to appease both the House and the Senate; and not those that had the same aim but were introduced different fiscal years (e.g., Congress' National Defense Act of FY 2018, of FY 2020).

[14] Smart contracts, introduced by Nick Szabo in 1994, are one part of a decentralized blockchain application which can promote counterparties of a contractual agreement to abide by their commitments, as transparency

of the ledger increases visibility of the contracts' contents (Mougayar, 2016; Tapscott & Tapscott, 2016). In basic terms, a smart contract is a computerized transaction protocol between two or more parties, with conditions defined in advance that are stored on blockchain; these conditions can be automatically executed or enforced without the need of a third-party intermediary (Carron & Botteron, 2019). Smart contracts also offer the management and organization of contracts, resources, and capabilities to be continually updated and recorded by a blockchain (Tapscott & Tapscott, 2016).

[15] H.R.3100, S.722, H.R. 3321, H.R. 3202, H.R. 3364, S. 3486, H.R. 7245, S. 1025, S.483, and H.R. 1865. H.R. 3364, the "Countering America's Adversaries Through Sanctions Act," became Public Law No. 115–44 in August 2017, and H.R. 1865, the "Further Consolidated Appropriations Act," became Public Law No. 116–94 in December 2019. The former requires a trend analysis of emerging illicit financial threats including transfers using cryptocurrencies. The latter requires the Secretary of State and Secretary of the Treasury, along with the Chairman of the SEC and Chairman of the CFTC, to develop a methodology to assess how cryptocurrencies issued for the Maduro regime in Venezuela may undermine US sanctions.

[16] H.R. 3100; H.R. 2810; H.R. 2825; S.1790. S.1790, the "National Defense Authorization Act for Fiscal Year 2020," became Public Law No.116–92 in December 2019. The bill requires collaborative effort between multiple national security entities to develop a report on the possible exploitation of cryptocurrencies by terrorist actors. H.R. 2810, "National Defense Act for FY 2018," became Public Law No.115–91 in December 2017. Similar to S.1790, included in the bill was a requirement for governmental coordination to provide a briefing on the potential threats of blockchain technology.

[17] H.R. 8128, H.R. 8153, H.R. 6938, H.R. 7225, H.R. 41, H.R. 923, H.R. 2858/S. 1567, H.R. 2500, H.R. 2613, H.R. 2513, H.R. 2514, and H.R. 3407.

[18] H.R. 6562, H.R. 6913, H.R. 1361, and S. 553.

[19] H.R. 8524, H.R. 4813, H.R. 6154, H.R. 7002, H.R. 2154, H.R. 6974/H.R. 528, H.R. 5777, H.R. 5892, and H.R. 2144, respectively.

[20] Many state-level regulations concur with those at the federal level. This is particularly relevant in the regulation of cryptocurrencies through state registration requirements via securities laws, as well as state money transfer laws (U.S. Commodity Futures Trading Commission, 2018; Labonte, 2020). Federal preemption laws dictate that if a certain entity registered with the SEC and is exempt from state registration requirements, they must adhere to relevant federal regulations (Labonte, 2020).

[21] Alabama, California, Colorado, Connecticut, Florida, Georgia, Hawaii, Illinois, Kentucky, Maryland, Nevada, New Jersey, New York, North Dakota, South Carolina, Utah, Vermont, West Virginia, and Wyoming.

[22] Alabama SJR45 and SJR71; Georgia HR 1036; Illinois HJR25; Kentucky HR171; North Dakota HCR3002 and HCR3004; Pennsylvania HR 737, HR 224, and SR 95; and South Carolina SR1158. Utah, Virginia, and West Virginia introduced similar resolutions (Utah House Joint Resolution 19, Virginia House Resolution 105, Virginia House Joint Resolution 82, Virginia House joint Resolution 63, Virginia House Joint Resolution 23, Virginia House Joint Resolution 677, and West Virginia House Concurrent Resolution 29) which have died.

[23] Arizona HB2602, Illinois HB3575, and Nevada SB398, respectively. Nebraska LB9 was also introduced—although it failed to advance—to prohibit local political subdivisions from taxing or furthering regulating the use of distributed ledger technology.

[24] In addition, Wyoming has implemented other initiatives, like the Blockchain Coalition, to provide education on blockchain and spur business use of blockchain. According to Tempte (2019), several blockchain companies have chosen Wyoming for their domicile. It is worth noting also that Wyoming Representative Tyler Lindholm is a co-founder of blockchain start-up BeefChain.io (Barber, 2019; highlighted in Table 1).

[25] The Chamber of Digital Commerce is a trade association representing the blockchain industry.

[26] For example, Colorado's SB 23 underscores that the costs and complex nature of state securities registration may outweigh the potential benefits offered by the use of the technology. Wyoming's HB 70 exempts the developer or seller of an open blockchain token from specific state securities and money transmission laws.

[27] International standards for NFC have been set by ECMA International (ECMA-340) and ISO (ISO 18000-3) (NFC.org, n.d.).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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